Design, Realization, and Analysis of PIFA for an RFID Mini-Reader

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Abstract: - In this paper a planar inverted-F antenna (PIFA) designed to operate at 922–928 MHz is presented. Its dimensions are reduced by 30% when a meander structure is etched onto a conventional PIFA. The measured return loss of the designed PIFA at 925 MHz is −34 dB and the ground plane and patch slot sizes of the PIFA can be modified to obtain the required resonance frequencies in a variety of applications.

Keywords: - RFID Reader, Patch antenna, PIFA

1 Introduction
Current applications require that antennas be mounted on small ground planes, such as those in handheld communication devices. The planar inverted-F antenna (PIFA) has several advantages, such as ease of fabrication, low cost, and a simple structure. PIFAs are commonly used in small communications terminals, such as handheld radios, because they have a low profile and can cover popular wireless communications bands [2]. However, some important limitations prevent the use of PIFAs in a wide range of applications; namely, their large volumes at low frequencies and narrow bandwidths.

Patch antennas are often used in RFID applications. They are composed of a layered structure with two parallel conductors separated by a thin dielectric substrate, where the lower conductor acts as a ground plane. If the ground plane is not large compared to a wavelength, then the electrical performance will usually differ from that of a finite ground plane. The most common method of reducing their size is the use of various slots, which is equivalent to increasing the electrical length of the patch [3].

2 RFID Reader Antenna Design and Analysis

2.1 Theoretical Background
PIFAs have been studied extensively because of their low profile structure that can be easily accommodated into wireless handsets [4]. Their basic structure evolved from the L antenna. The inverted-L antenna is a variation of the monopole antenna, where the monopole antenna is bent into an L shape [5].

The layout of a typical PIFA is shown in Fig. 1. The antenna consists of a ground plane, a rectangular patch element aligned parallel to the ground plane, and a short-circuit plate.

Fig. 1. The layout of a typical PIFA.

Its resonant frequency can be estimated using the formula [6]:

\[ f_0 = \frac{c_0}{4(L_1 + L_2)} \]  \hspace{1cm} (2-1)

where \( c_0 \) is the speed of light, \( L_1 \) and \( L_2 \) are the length and width of the radiation element, respectively, and \( f_0 \) is the resonant frequency. Another way is to create a table describing the trend of variations in the resonant frequency [6], as shown in Table 1.

Table 1. Trend of resonant frequency variation in a typical PIFA.

<table>
<thead>
<tr>
<th></th>
<th>( L_1 )</th>
<th>( L_2 )</th>
<th>( W )</th>
<th>( H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \uparrow )</td>
<td>( \downarrow )</td>
<td>( \downarrow )</td>
<td>( \uparrow )</td>
<td>( \downarrow )</td>
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PIFAs are usually very thin. As a result, the ground plane must be longer and larger. The cost can be reduced by building the antenna with an air substrate, which can be fabricated by standard PCB manufacturing processes.
2.2 Design of the PIFA

Prior to designing the RFID reader antenna, it is necessary to first determine the matching at 50 Ω. In this work, a PIFA was utilized to design the RFID reader antenna shown in Fig. 2.

The radiation resistance of a PIFA is twice that of the half-wave patch antenna. The resonant frequency given by the model is accurate when \( W_s/W = 1 \). As shown in Fig. 3, when \( W - W_s < L \), the current on the underside of the planar element mainly flows to the open-circuit edge on the long side of the planar element. However, when \( W - W_s > L \), the current flows to the open-circuit edge on the short side of the planar element. By analyzing the surface current, it is possible to derive the effective length of the current flow on the short-circuit plate and the planar element. When \( W_s/W = 1 \), the resonance is expressed by:

\[
L + H = \frac{\lambda}{4},
\]

while for \( W_s = 0 \), it is expressed by:

\[
L + W + H = \frac{\lambda}{4}.
\]

When \( 0 < W_s/W < 1 \), the resonant frequency \( f_r \) can be expressed as:

\[
f_r = r \cdot f_1 + (1 - r) \cdot f_1 \quad \text{for} \quad \frac{W}{L} \leq 1
\]

and:

\[
f_r = r^k \cdot f_1 + (1 - r^k) \cdot f_1 \quad \text{for} \quad \frac{W}{L} \geq 1
\]

where \( r = W_s/W \), \( k = W/L \), and the resonance for the frequency \( f_1 \) is given by Equation (2-2), while the resonance for the frequency \( f_2 \) is given by Equation (2-3) [7].

3 Simulation and Measurements

An RFID reader antenna needs to function at \( f_0 = 925 \) MHz. Therefore, the speed of light, \( c_0 = 3 \times 10^8 \) (m/s), is used to find the wavelength in free space, \( \lambda \). The total length \( L \) of a microstrip patch antenna is:

\[
f_0 = \frac{c_0}{4(L_t + L_s)}
\]

\[
\Rightarrow L_t + L_s = \frac{c_0}{4 f_0} = \frac{3 \times 10^8}{4 \times 925} \approx 0.08 \text{m}
\]

A slot is selected to reduce the size of the patch for the PIFA shown in Fig. 4.

Next, simulate an RFID reader antenna is simulated with 50 Ω. The proposed design has a ground plane size of 50x50 mm, a height of \( h = 10 \) mm, a trace width of \( w = 5 \) mm, and a thickness of \( t = 0.2 \) mm, as shown in Fig. 5. Some manufactured examples of the RFID reader antenna that we designed are shown in Figs. 9(a) and (b).
The simulated input return loss, Smith Chart, and the radiation pattern are shown in Figs. 6, 7, and 8, respectively. The return loss of the RFID reader antenna at 925 MHz is $-14$ dB when matched to 50 $\Omega$. The RFID tag antenna matches $Z_a = 55 - j19.8$, which is the simulation result from the Smith Chart. In the 3D volume, the radiation pattern is omni-directional and the maximum gain is 1.4 dBi.

The measured bandwidth was 12 MHz, over a range from 918 MHz to 930 GHz with a $-10$ dB return loss, as shown in Fig. 10. For $f_c = 925$ MHz, the measured return loss of $-34$ dB and the Smith Chart with $43.7 - j1.45$ are shown in Figs. 10 and 11.
If the PIFA's ground plane size needs to be modified for use in a different project, the patch slot size can be adjusted to obtain the resonant frequency shown in Fig. 9(b).

The measured radiation patterns for the $x$–$y$ plane are shown in Figs. 12 and 13. In the $x$–$y$ plane, the radiation pattern is omni-directional. The maximum gain and average gain are 2.32 dBi and 1.90 dBi for 925 MHz and 930 MHz, respectively.

The measured radiation patterns in the $y$–$z$ plane are shown in Figs. 14 and 15. In the $y$–$z$ plane, the radiation pattern is omni-directional. The maximum gain and average gain were 2.66 dBi and 1.70 dBi for 925 MHz and 930 MHz, respectively.

4 Conclusions

The planar inverted-F antenna (PIFA) is a common choice for use in portable wireless devices, for its small size and profile, simple design, easy fabrication and low cost. However, PIFAs are limited from widespread application due to their narrow bandwidths and large volumes at low frequencies.

The radiation resistance of a PIFA is twice that of a half-wave patch antenna. The resonant frequency determined by the model is accurate when $\frac{W_1}{W} = 1$.

For $f_c = 925$ MHz, the measured return loss was $-34$ dB and the Smith Chart had $43.7 - j1.45$. In the $x$–$y$ plane, the radiation pattern was omni-directional. The maximum gain and average gain were 0.77 dBi and 2.32 dBi for 915 MHz and 925 MHz, respectively. In the $y$–$z$ plane, the radiation pattern was also omni-directional. The maximum gain and average gain were 2.66 dBi and 1.70 dBi for 925 MHz and 930 MHz, respectively.
References: