Design Considerations of Planar Inverted-F Antenna (PIFA) on a Finite Ground Plane

Jian-Wei He and Kah-Seng Chung
Communications Technology Research Group
Department of Electrical and Computer Engineering
Curtin University of Technology, GPO Box U 1987, Perth, Western Australia
E-mail: hej@ece.curtin.edu.au; k.chung@ece.curtin.edu.au

Abstract—In this paper, the operation of a PIFA mounted on a finite ground plane is investigated. This includes the influence on the input and radiation characteristics caused by the placements of the short-circuit plate and the feed wire as well as where the antenna is mounted on a finite ground plane. It has been found that the location where the antenna is mounted on the finite ground plane has a significant impact on the resonant frequency, bandwidth and radiation characteristics. Moreover, the positions of both the short-circuit plate and the feed wire have little impact on the radiation characteristics of the PIFA. The numerical simulations have been validated by measurements.

Index Term – PIFA, Feed wire, Short-circuit plate, Finite Ground Plate, Input and radiation characteristics.

I. INTRODUCTION

Planar inverted-F antennas (PIFAs) are attractive for use in small communication terminals, such as handheld radios, because of their low profile structure and appreciable electrical characteristics. The operation of a PIFA needs a ground plane which may take the form of the conducting body of the device itself or the printed circuit board inside the portable terminal. The performance of a PIFA mounted on a conducting box was reported in [1]. The study reported in [2] focused on examining the effects of the different component parts of a PIFA on its input and radiation characteristics. The variations of input impedance caused by moving a PIFA along one direction on a finite ground plane were studied in [3]. The influence of the finite ground size on the performance of PIFAs was examined in [4] and [5].

This paper investigates the influence on the input and radiation characteristics of a PIFA described in section II due to different placements of the short-circuit plate and the feeding point as well as where the antenna is mounted on a finite ground plane. Section III presents the modeling of the PIFA and the computer simulated results. Section IV provides a comparison between the measured and computer simulated results. Finally, the findings obtained in this study are summarized in section V.

II. ANTENNA STRUCTURE

The PIFA structure under investigation is shown in Fig. 1. This antenna is designed to operate at 900 MHz, a widely used frequency band for mobile communications. The finite ground plane has a length along the x-axis of 110 mm and a width along the y-axis of 50 mm. The dimensions of the top plate are \((L_2, L_1) = (56.5\, \text{mm}, 30\, \text{mm})\) at a height \(H = 13.33\, \text{mm}\) from the ground plane. The width of the short-circuit plate, \(W\), is 10 mm. The corner edge of this plate is located at the coordinates \((D, g_s, 0) = (6\, \text{mm}, 10\, \text{mm}, 0)\). The feed wire is located at \((D+d_f, g_f, 0) = (18\, \text{mm}, 10\, \text{mm}, 0)\).

![Fig. 1 The structure of a PIFA with a finite ground plane.](image)

III. MOM MODELING AND SIMULATIONS

The operation of the PIFA of Fig. 1 has been studied using the electromagnetic simulator IE3D from Zeland [6]. Fig. 2 shows the MOM model for this PIFA. In the simulations, the highest meshing frequency has been set at 1.2 GHz., with 20 cells per wavelength discretisation. Good accuracy in computing the current distribution is achieved using finer edge-meshing. The model includes 259 patches involving 435 unknown currents.
The variations of the resonant frequency and bandwidth of the PIFA caused by moving the position of the short-circuit plate along the y-axis have been simulated and plotted as dotted curves in Fig. 3 and Fig. 4. For this part of the study, \( d_f \) and \( g_f \) remain constant at 12 mm and 10 mm, respectively. Also, the top plate remains unchanged from its initial setting as shown in Fig. 1. The distance, \( g \), as shown in Fig. 3 and Fig. 4, represents the change in location of the short-circuit plate along the y-axis from its initial position, \( g_s \).

From Fig. 3, it is noted that both the resonant frequency and the bandwidth of the antenna tend to increase when the position of the short-circuit plate is moved along the y-axis away from the feed wire. When this short-circuit plate moves from its initial position to the other end of the top plate, the resonant frequency and corresponding bandwidth will increase by more than 9.5 % and 92 %, respectively.

Furthermore, it is observed from Fig. 3 and Fig. 4 that the “placement” of the feed wire has a greater influence on the resonant frequency than the short-circuit plate. On the contrary, the placement of the short-circuit plate has a greater impact on the bandwidth than the feed wire.

The input resistance and reactance, which together constitute the input impedance of the antenna, as a function of the separation between the feed wire and the short-circuit plate are shown in Fig. 5a and Fig. 5b, respectively. As expected, both the resistance and reactance tend to increase as the feed wire is moved closer to the open-end of the top plate along the x-axis. This feature of the antenna provides a convenient way for impedance matching.

This section investigates how the resonant frequency and bandwidth could be affected by assembling the PIFA at different locations on the finite ground plane. For this study, both the short-circuit plate and the feed wire are located at the edge of the top plate with \( d_f = 12 \text{mm} \). The corner point,
shown as point $R$ in Fig. 1, formed by the intersection of the top plate and the short circuit plate is used as the reference location. The resultant resonant frequencies and bandwidths as a function of the locations of the top-plate assembly on the finite ground plane are shown in Fig. 6 and Fig. 7, respectively. Also, the ratio of the bandwidth to resonant frequency as a function of the location of the top plate assembly on the finite ground plane is shown in Fig. 8. It is to be noted that no resonance is observed when point $R$ of the PIFA assembly moves beyond the $x$ and $y$ coordinates as indicated in these figures, i.e., with $x > 25\, \text{mm}$ and $y > 20\, \text{mm}$.

![Graph](image1)

Fig. 5 Input impedance of the PIFA associated with different positions of the feed wire ($d_f$ from 5 mm to 25 mm) along x axis. (a) Resistance. (b) Reactance.

From Fig. 6, it is noted that the lowest resonant frequency of the antenna is achieved when point $R$ is located at the edge of the ground plane, i.e., $(x, y = 0, 0)$. This observation suggests that for a given resonant frequency, the size of a PIFA can be made smaller if it is located at the edge of the ground plane. On the other hand, it is observed from Fig. 7 that a larger bandwidth could be obtained when the point $R$ is located within the area of the ground plane bounded by $2.5\, \text{mm} \leq x \leq 12.5\, \text{mm}$ and $10\, \text{mm} \leq y \leq 20\, \text{mm}$. This means that if it is desired to have a large ratio of the bandwidth to resonant frequency, then the PIFA has to be located in the middle of the ground plane or having the point $R$ located within the area bounded by $0 \leq x \leq 10\, \text{mm}$ and $10\, \text{mm} \leq y \leq 20\, \text{mm}$, as shown in Fig. 8. These two seemingly contradicting requirements for small size and wide bandwidth call for some form of compromise in the actual PIFA implementation. An example of a compromised design with good input characteristics for the test PIFA is to have the coordinates $(x, y)$ of the point $R$ of the top patch assembly, the short-circuit plate and the feed point set to (6 mm, 10 mm), (6 mm, 10 mm), and (18 mm, 10 mm), respectively.

![Graph](image2)

Fig. 6 Resonant frequency as a function of the position of the antenna on the ground plane.

![Graph](image3)

Fig. 7 Bandwidth as a function of the position of the antenna on the ground plane.
Fig. 8 The ratio of bandwidth to resonant frequency as a function of the position of the antenna on the ground plane.

(d) Radiation characteristics

The influence on the radiation characteristics, in terms of the efficiency and radiation patterns, due to the actual placements of the short-circuit plate and the feed wire as well where the antenna is mounted on the finite ground plane has also been examined. Four different configurations, as tabulated in Table 1, have been used for this study. The resultant radiation patterns are shown in Figs. 9(a-d). The respective gains and efficiencies obtained with these four PIFA assemblies are tabulated in Table 2.

Table 1 The four PIFA configurations.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The short-circuit plate is located at $D = 10$ mm and $g_s = 30$ mm with the point $R$ at $x, y = 6, 10$ mm.</td>
</tr>
<tr>
<td>2</td>
<td>Feed wire is located at $D + d_f = 18$ mm and $g_f = 30$ mm with the point $R$ at $x, y = 6, 10$ mm.</td>
</tr>
<tr>
<td>3</td>
<td>Point $R$ of the test PIFA is located at $(x, y = 0, 0)$.</td>
</tr>
<tr>
<td>4</td>
<td>Point $R$ of the test PIFA is located at $(x, y = 15, 14$ mm).</td>
</tr>
</tbody>
</table>

Table 2 The gain and efficiency of a PIFA configuration

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Gain (dB)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.3</td>
<td>98.8</td>
</tr>
<tr>
<td>2</td>
<td>3.2</td>
<td>98.9</td>
</tr>
<tr>
<td>3</td>
<td>2.7</td>
<td>98.3</td>
</tr>
<tr>
<td>4</td>
<td>2.7</td>
<td>96.8</td>
</tr>
</tbody>
</table>

Fig. 9a and Fig 9b show that the antennas 1 and 2 have almost identical radiation pattern. Also, Table 2 reveals that they also have similar gain and efficiency. However, the radiation pattern for the antenna located at the edge of the ground plan, as shown in Fig. 9c, is quite different from its counterpart located in the middle of the ground plane, as shown in Fig. 9d. Both of these two antennas suffer from a 0.5 dB decrease in gain as compared with antennas 1 and 2. Furthermore, antenna 4 has the lowest efficiency of 96.8%.
The test PIFA, as described in Section II and shown in Fig. 1, has been fabricated and its input impedance measured using a network analyser (HP8753C) over a frequency range spanning from 600 MHz to 1200 MHz. Fig. 10 is a photo of the test PIFA.

Fig. 11 shows good agreement between the measured and simulated values of the input impedance of the PIFA. This comparison provides us with confidence in using the MOM-based computer simulations for studying the different PIFA configurations.

Fig. 10 The test PIFA.

Fig. 11 Measured and simulated input impedance of the test PIFA. Red dot line – simulated, green solid line – measured, and “x” and “o” indicate the start and stop frequency, respectively.

V. CONCLUSIONS

The effects on the input characteristics and radiation patterns of a PIFA due to different placements of its short-circuit plate and feed wire as well as where the PIFA is mounted on a finite ground plane have been investigated in this paper. The main observations are summarized as follows:

- A PIFA of a given size will produce the lowest resonant frequency when it is mounted at the lower corner of the ground plane, i.e., $x, y = 0, 0$. However, to achieve a wider bandwidth, a PIFA needs to be moved along the $y$-axis to around the middle of the ground plane with the short-circuit plate close to the edge of the ground plane.

- The positions of both the short-circuit plate and the feed wire seem to have minimal impact on the radiation characteristics of the PIFA. However, the radiation pattern is significantly affected by where the PIFA is mounted on the finite ground.

These findings enable design engineers to make informed trade-offs for choosing the physical parameters of a PIFA to achieve the required electrical performance.

References


