

Development of Wideband Planar Inverted-F Antennas for Wireless Application

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Abstract: Problem statement: Due to the rapid development in wireless communication, the antennas capable of broad-band operations are very demanding in cellular communications systems. Among various possible antennas, planar inverted-F antennas (PIFAs) have the advantages of low profile and compact size and are very suitable for present-day wireless communication application. **Approach:** This study demonstrates a very effective method of bandwidth enhancement for planar inverted-F antenna. It was done by optimizing the width of feed plate and shorting plate, then by adding a parasitic element. **Results:** The obtained results of our developed wideband antenna was an impedance bandwidth of 72.8% for $S_{11} < -10$ dB from 1.74-3.54 GHz which could cover GPS, DCS, IMT-2000, 2.4GHz WLAN, 3.5 GHz WIMAX applications. **Conclusion:** As the antenna was successfully researched and well optimized, and desired results were achieved.

Key words: Planar inverted-F antenna (PIFA), Bandwidth, Antennas, bandwidth enhancement, wireless communication, shorting plate, impedance bandwidth, radiation pattern, parasitic element, parametric study, top patch

INTRODUCTION

Compact antennas have been the center of much research interest because of the rapid progress in wireless communications. The low profile, light weight and low fabrication cost make Printed Inverted-F Antennas (PIFAs) one of the most popular antennas in today's wireless communication handsets. However, the ever-increasing demand for size reduction of mobile handsets has led to embedded antennas, not only with reduced-size radiating elements, but also with limited-size ground planes. The effects of finite-sized ground planes may be critical to bandwidths, resonant frequencies and radiation patterns of such antennas (Huynh and Stutzman, 2003).

Various methods have been proposed for bandwidth enhancement of antennas, including utilization of additive stubs (Ammann and Doyle, 2001; Olmos *et al.*, 2002; Sekine *et al.*, 2004), patterning the ground plane (Wang *et al.*, 2004; Abedin and Ali, 2003), investigating the material properties (Ismail *et al.*, 2010), meandering the radiating element to achieve multiple resonance frequencies for bandwidth enhancement (Sim and Choi, 2006), slots to achieve wideband impedance matching (Park *et al.*, 2006), using the back side of the substrate (Chen, 2000; Dou

and Chia, 2000), changing the feed plate silhouette (Feick *et al.*, 2007), meandering the shorting strip (Chan *et al.*, 2008), adding a radiating element (Il-Young *et al.*, 2010), or by using antenna array (Islam *et al.*, 2007)

The aim of this study is to enhance the bandwidth of the planar inverted-F antenna, for this reason and to get a wideband antenna. Firstly we performed a parametric study of PIFA antenna where we have varied the shorting plate width, the feed plate width, the distance between the shorting plate and the feed plate, we studied afterwards the effects of these three parameters of the PIFA on its resonant frequency's impedance bandwidth and radiation pattern. Finally we added a parasitic element to improve the bandwidth of our developed PIFA antenna.

MATERIALS AND METHODS

Planar Inverted-F Antenna (PIFA): The inverted-F antenna is evolved from a quarter-wavelength monopole antenna. It is basically a modification of the inverted-F antenna IFA which is consisting of a short vertical monopole wire. To increase the bandwidth of the IFA, a modification is made by replacing the wires with a horizontal plate and a vertical short circuit plate to obtain a PIFA antenna (Balanis, 1997; Huang and Boyle, 2008).

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The conventional PIFA is constituted by a top patch, a shorting pin and a feeding pin. The top patch is mounted above the ground plane, which is connected also to the shorting pin and feeding pin at proper positions. They have the same length (distance between the top patch and the ground plane). The standard design formula for a PIFA is (Wang, 2003):

$$f_r = \frac{c}{4(W + L)} \quad (1)$$

where:

- f_r = Resonant frequency of the main mode
- c = Speed of light in the free space
- W, L = width and length of the radiation patch, respectively

Antenna configuration: The configuration of the studied PIFA antenna consists of a radiating top plate with the dimensions $W \times L$ and the ground plane dimensions are $W_g \times L_g$. The dielectric material used above the rectangular ground plane is FR-4 having a thickness t and a relative permittivity ϵ_r . The antenna height is h and the space between the top plate and the substrate is filled with air (free space). The shorting plate has dimensions of $W_s \times (h+t)$ and the feed plate has dimensions of $W_f \times h$. The distance between the shorting plate and the feeding plate is F_s .

The Fig. 1 shows the illustration of our developed PIFA antenna before adding the parasitic element.

RESULTS AND DISCUSSION

Parametric study: The procedure adopted for this study is to change only one parameter at a time and observe its effects on the characteristics of the PIFA while all other parameters are held constant. Different sets of parameters are simulated to cover a wide range of values. For convenience, a reference PIFA is chosen with the parameters shown in Table 1.

The effect of the feed plate width: The value of the width of the feed plate (W_f) is changed from 6-26 mm, while all other parameters are kept equal to the reference PIFA values (Table 1). The effect of changing W_f on the fractional bandwidth is shown in Fig. 2. It was found that the fractional bandwidth increases with an increasing width up to 50.13% at $W_f = 15$ mm. A further increase in the feed plate above width $W_f = 15$ mm decreases the fractional bandwidth. Therefore, the optimum value for the width of feed plate that should be selected in order to achieve the maximum bandwidth is $W_f = 15$ mm.

The Fig. 3 represents the effect of changing the

width of the feed plate on the return loss. From these results we note that the dimensions of the feed plate affect both the resonance frequency and the bandwidth of the antenna.

Table 1: Explanation and dimension of parameters

Parameter	Designation	Value
W	Width of the radiating plate	40 mm
L	Length of the radiating plate	21.5 mm
W_g	Width of the ground plane	40 mm
L_g	Length of the ground plane	55 mm
T	Thickness of the ground plane	1 mm
H	Antenna height	10.2 mm
W_f	Width of the feeding plate	18 mm
W_s	Width of the shorting plate	1 mm
F_s	Distance between the shorting plate and the feeding plate	15 mm
ϵ_r	Relative permittivity of the ground plane	4.4

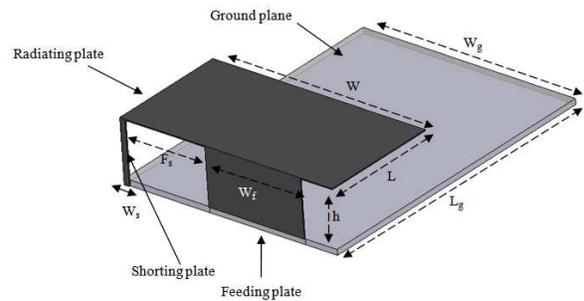


Fig. 1: Geometry of the PIFA antenna

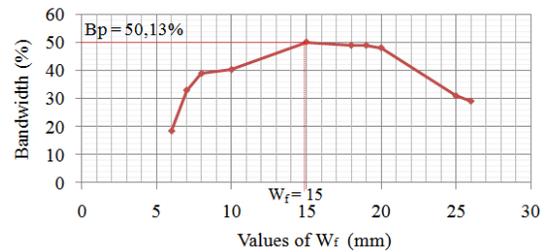


Fig. 2: Changes of the bandwidth (%) versus changes of W_f (mm)

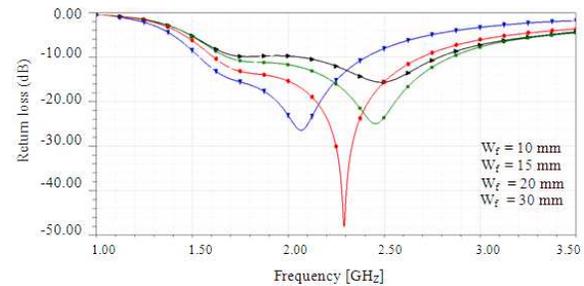


Fig. 3: Return loss in dB versus frequency in GHz for different values of W_f (mm)

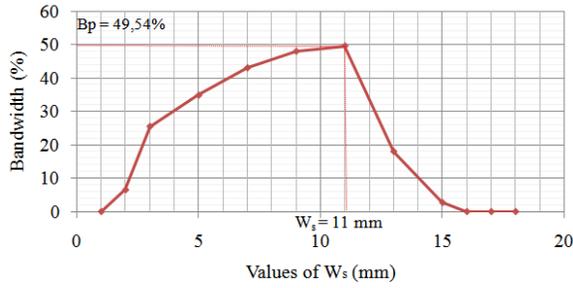


Fig. 4: Changes of the bandwidth (%) versus changes of W_s (mm)

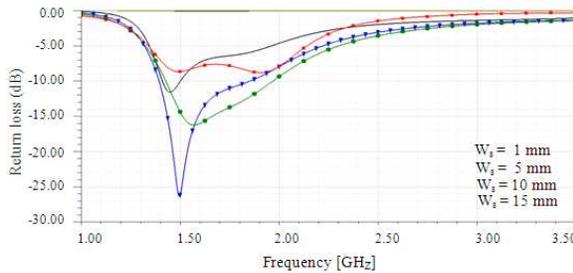


Fig. 5: Return loss in dB versus frequency in GHz for different values of W_s (mm)

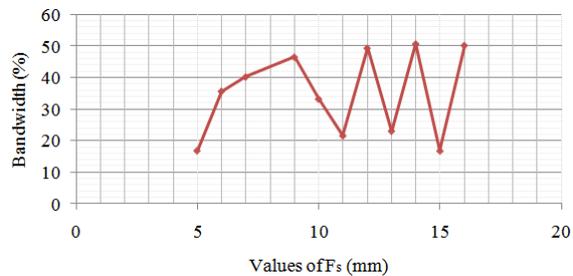


Fig. 6: Changes of the bandwidth (%) versus changes of F_s (mm)

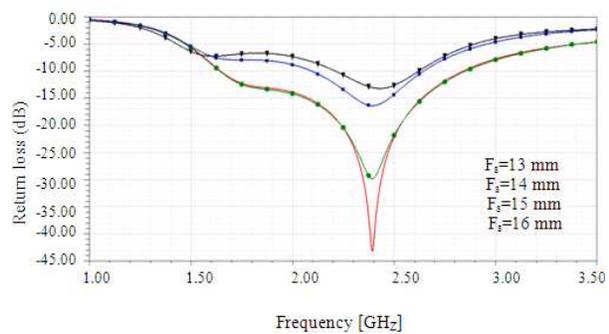


Fig. 7: Return loss in dB versus frequency in GHz for different values of F_s (mm)

The effect of the of shorting plate width: The width of shorting plate (W_s) is varied from 1-15 mm, while all other parameters are again the same as that of the reference PIFA. The Changes of the bandwidth versus changes of W_s are illustrated in Fig. 4. It observed that by increasing the width of the shorting plate, the fractional bandwidth increases up to a value of 49, 54% when the width of the feed plate is equal to 11 mm. Then further increase in the shorting plate width decreases the fractional bandwidth. Therefore, the optimum value for the width of the shorting plate giving the maximum bandwidth is $W_s=11$ mm.

Figure 5 shows the return loss versus frequency for different values of W_s . Similarly, it can be clearly seen that the variation of the shorting plate width affects the resonance frequency.

We also conclude that W_s affects both the bandwidth and the resonance frequency.

Changes in distance between feed plate and shorting plate: The distance separating the feed plate from the shorting plate F_s is varied from 1-16 mm. While all other parameters are equal to the reference PIFA parameters. It is observed in Fig. 6 that increasing the distance between the shorting plate and the feeding plate does not have a direct effect on the fractional bandwidth. Furthermore the Fig. 7 represents the return loss versus frequency for different values of F_s which proves that the variation of F_s does not affect the resonance frequency.

In this part, for F_s we could not get a conclusive Remark.

Performance evaluation of the developed PIFA: From all the last obtained results, we note that the parameters of the PIFA antenna are optimized in order to get the maximum impedance bandwidth for a resonance frequency around 2.4 GHz, the optimized values of all the parameters are:

$$W_f = 18 \text{ mm}, W_g = 40 \text{ mm}, L_g = 60 \text{ mm}, W = 40 \text{ mm}, L = 20 \text{ mm}, h = 10 \text{ mm}, W_s = 1 \text{ mm}$$

To evaluate the performance of the developed PIFA, we plotted the return loss versus frequency (Fig. 8). We have found that the maximum return loss is -49 dB at 2.4 GHz, the upper and lower band frequencies are 1.65 GHz and 2.84 GHz respectively. The obtained absolute bandwidth is 109 MHz and, the bandwidth obtained for the proposed PIFA is 47,39%. Moreover we drafted the radiation pattern (Fig. 9), from this figure we note that the simulated radiation pattern of our optimized antenna is similar to a conventional PIFA antenna.

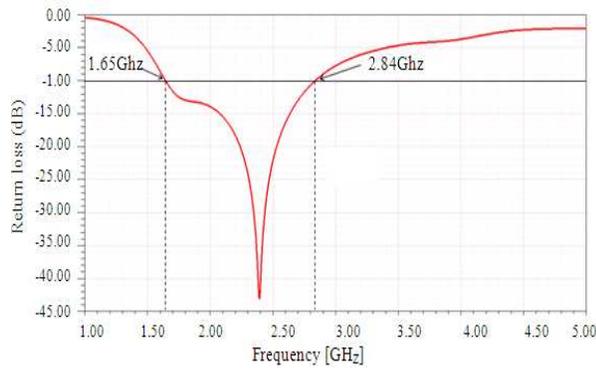


Fig. 8: The return loss in dB versus frequency in GHz for the optimized antenna

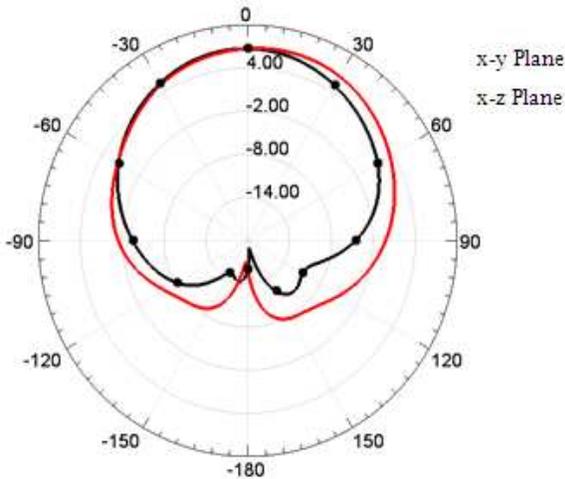


Fig. 9: 2D radiation pattern for the optimized PIFA antenna for $f_r = 2,4$ GHz

The effect of parasitic element: In this part, we are interested in studying the effect of adding a parasitic element on the bandwidth of the developed PIFA antenna (Fig. 10). The dimensions of the parasitic element are described in Table 2.

To study the effect of adding the parasitic element to our developed PIFA antenna, we have plotted in Fig. 11 the return loss versus frequency with and without a parasitic element. We observed that there is an additional resonance frequency achieved with little modification in the layout. Furthermore, the maximum return loss is -43 dB at 2.4 GHz, the upper and lower band frequencies are 1.74 GHz and 3.54 GHz respectively. On the other hand, Fig. 12 shows the radiation patterns of our PIFA antenna with a parasitic element. From these results we conclude that there is an agreement between the radiation pattern before and after adding a parasitic element (Fig. 9-12 respectively).

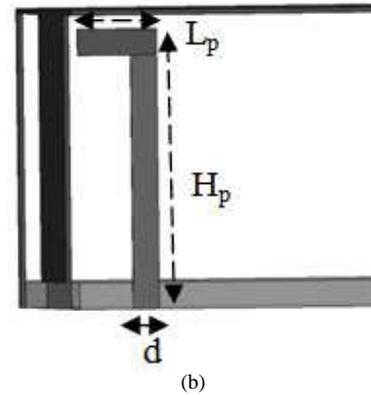
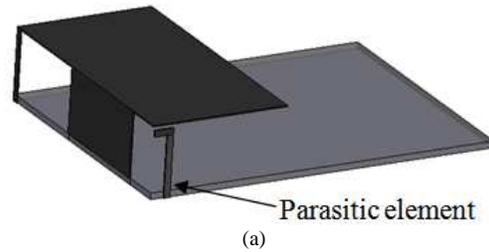


Fig. 10: The developed antenna with the parasitic element, (a) the proposed antenna, (b) dimensions of the parasitic element

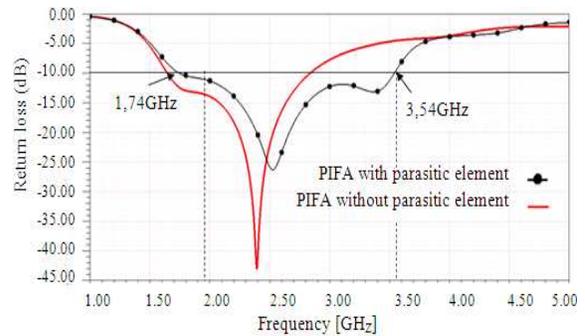


Fig. 11: The simulated return loss for the proposed PIFA antenna before and after adding parasitic element

Table 2: Explanation and dimension of parameters

Parameter	Designation	Value
H_p	Height of the parasitic element	9.5mm
L_p	Length of the parasitic element (part1)	2.5mm
d	Length of the parasitic element (part2)	0.5mm

So, the addition of the parasitic element increase the bandwidth of the antenna without affecting the radiation pattern of our developed antenna, which supports the standards of the GPS, DCS, IMT-2000, 2.4 GHz WLAN, 3.5 GHz WIMAX.

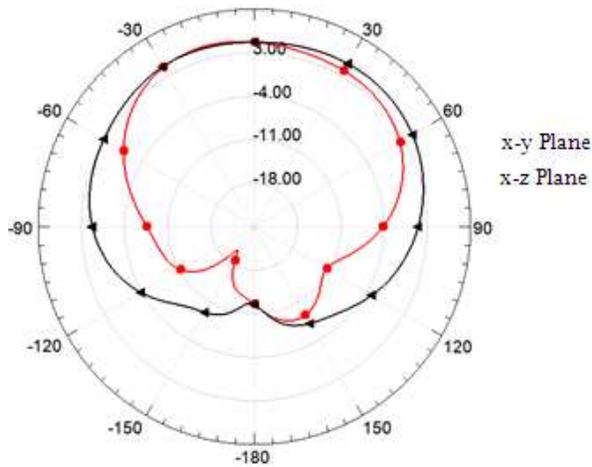


Fig.12. 2D radiation pattern for the optimized PIFA antenna with parasitic element for fr = 2,4 Ghz

CONCLUSION

This study has focused on the development of wideband planar inverted-F antennas. Two different studies were used to obtain the wideband operation. Firstly, we investigated how the variation of the feed plate and the shorting plate dimensions affects the performance of the PIFA antenna.

A series of simulations are used to choose the better parameters for the antenna that gives the maximum bandwidth. Secondly we added a parasitic element to the antenna to obtain a wider bandwidth. Furthermore, in terms of the addition of a parasitic element, a comparison is performed between the developed antenna with and without a parasitic element. The obtained results demonstrate the advantages of adding a parasitic element.

Consequently, the performance of the studied antenna provides satisfactory results and shows a good radiation pattern. These developed wideband antennas cover the GPS, DCS, IMT-2000, 2.4GHz WLAN and 3.5 GHz WIMAX bands applications.

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