

Small and Thin Inverted-F Antenna with Insensitive Ground Plane For Mobile Handsets

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Abstract— A small ultr-thin tri-band Planar Inverted-F Antenna (PIFA) is presented. The proposed antenna consists of slotted radiated parts supported by shorting walls and a ground plane. Intensive investigations are carried out in this paper to show that the ground plane and the antenna locations have insignificant effect on the performance of the antenna while the physical height of the radiated parts can be more significant. The radiated parts occupied a total size of $26 \times 25.6 \times 3.57 \text{ mm}^3$. It designed to operate at UMTS, m-WiMAX and 5 GHz WLAN bands. Simulated and measured results are in good agreements.

I. INTRODUCTION

Planar Inverted-F Antennas are widely used in a variety of communication systems especially in mobile phone handsets due to low profile, light weight, easy integration and easy to manufacture [1]. In recent years, there have been a number of PIFA designs describing different configurations to achieve single and multiple bands operation [2]-[5]. These are generally designed to operate to include one or more wireless communications bands which may include Global System for Mobile Communications (GSM900, 800, 1800 and 1900), Personal Communication System (PCS), Digital Communication Systems (DCS), Global Position System (GPS), Universal Mobile Telecommunications System (UMTS), Wireless Local Area Networks (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and many more. The ground plane of PIFA is an important factor and can play an important role to enhance the performance of the antenna as discussed in [6]. However, if the ground plane is acted as an antenna, the effect of the user hand is likely to degrade the antenna performance when the antenna is placed inside the mobile phone as well as causing several practical engineering problems [7]-[10]. In some designs, the location of the antenna on the substrate is also important to be considered as it can enhance the bandwidth of

the antenna to few more percentages as shown in a recent study [11].

In this paper, a relatively small and thin PIFA that can support three frequency bands at 2.09 GHz, 3.74 GHz and 5 GHz with achievable bandwidths of 10 %, 8.8 % and 11 % respectively is first presented. Then the effect of different ground plane dimensions, the location of the antenna on the substrate and the significance of the physical height of the antenna from the ground plane are studied. The simulated and measured result is in good agreements.

II. SIMULATED AND MEASURED RESULTS

Fig. 1 (a) demonstrates the structure of the proposed antenna while the detailed dimensions are given in Fig. 1(b) and Table I. The proposed antenna consists of the main radiated parts, a rectangular slot, shorting wall and a ground plane. The dielectric material selected for the design is FR-4 which has dielectric constant of 4.4, a loss tangent of 0.02 and height of dielectric substrate is 1.57 mm. The proposed antenna is very small in size and physically thin. The total dimensions of the radiated parts occupy $25.6 \times 26 \times 3.57 \text{ mm}^3$ while the overall size of the antenna including the ground plan is $40 \times 40 \times 3.57 \text{ mm}^3$. It can be seen that the radiated parts occupy 40% from the overall size of the antenna which can leave more space for other electronics. High Frequency Structure Simulator (HFSS) V.11.4 package is used for full wave analysis of the antenna structure. Material losses have been assumed in the simulations. In order to validate the simulated results, the proposed antenna was fabricated on FR-4 substrate 4.4 with thickness of 1.57 mm and loss tangent 0.02. The width of the copper used in the prototype is 0.15mm. The simulated and measured S_{11} of the proposed antenna is presented in Fig 2 (a) and the prototype antenna under test is shown in Fig. 2 (b). The S_{11} shows that three bands can be generated at 2.09 GHz, 3.74 GHz and 5 GHz. The simulated and measured results are

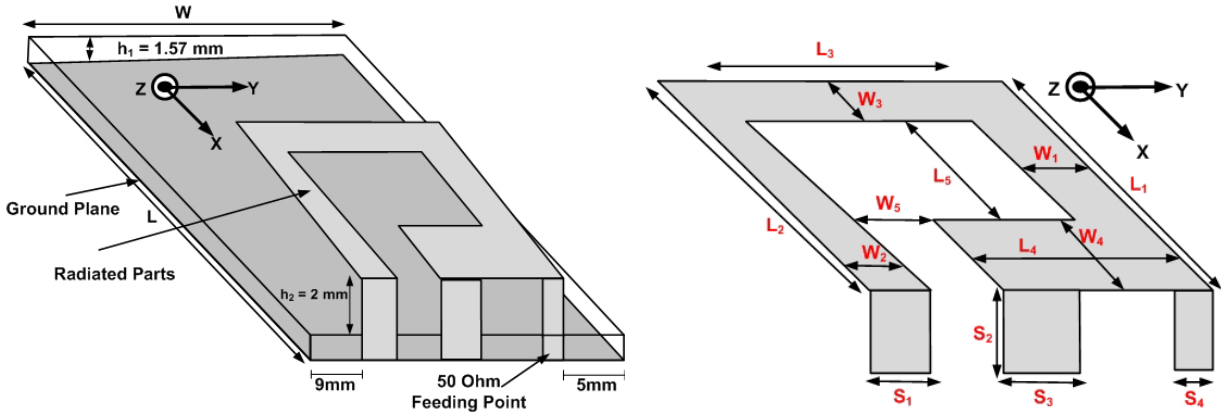
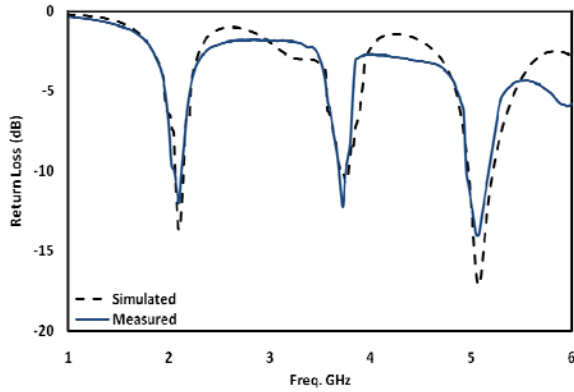


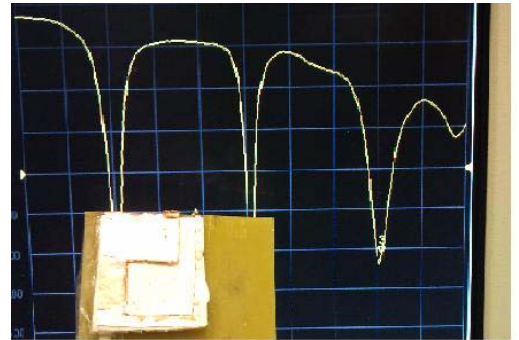
Fig.1 The layout of the proposed antenna (a) 3D View (b) Detailed dimensions

TABLE I: DETAILED DIMENSIONS OF THE PROPOSED ANTENNA (IN MM)

| Parameter | W | W ₁ | W ₂ | W ₃ | W ₄ | W ₅ |
|-----------|----------------|----------------|----------------|----------------|----------------|----------------|
| Dimension | 40 | 6 | 2 | 2 | 11.6 | 4 |
| Parameter | L | L ₁ | L ₂ | L ₃ | L ₄ | L ₅ |
| Dimension | 40 | 25.6 | 25.6 | 20 | 20 | 12 |
| Parameter | S ₁ | S ₂ | S ₃ | S ₄ | Ground Plane | |
| Dimension | 2 | 3.57 | 4 | 3 | 40 x 40 | |



(a)



(b)

Fig. 2 (a) The simulated and measured S_{11} (b) The fabricated prototype of the proposed antenna connected to the network analyser.

in good agreements. The corresponding bandwidth defined by -6 dB for the three bands is 11 % (1978 MHz – 2200 MHz) for the 2.09 GHz band, 8.84 % (3571 MHz – 3900 MHz) for the 3.74 GHz band and 10 % (4887 MHz – 5391 MHz) for the 5 GHz band. Thus, the bandwidth can satisfy the requirements for most of the wireless applications.

III. THE SIGNIFICANCE OF SOME PARAMETERS ON THE ANTENNA PERFORMANCE

In the proposed antenna, the effect of the ground plane, the antenna location and the physical height of the PIFA were examined:

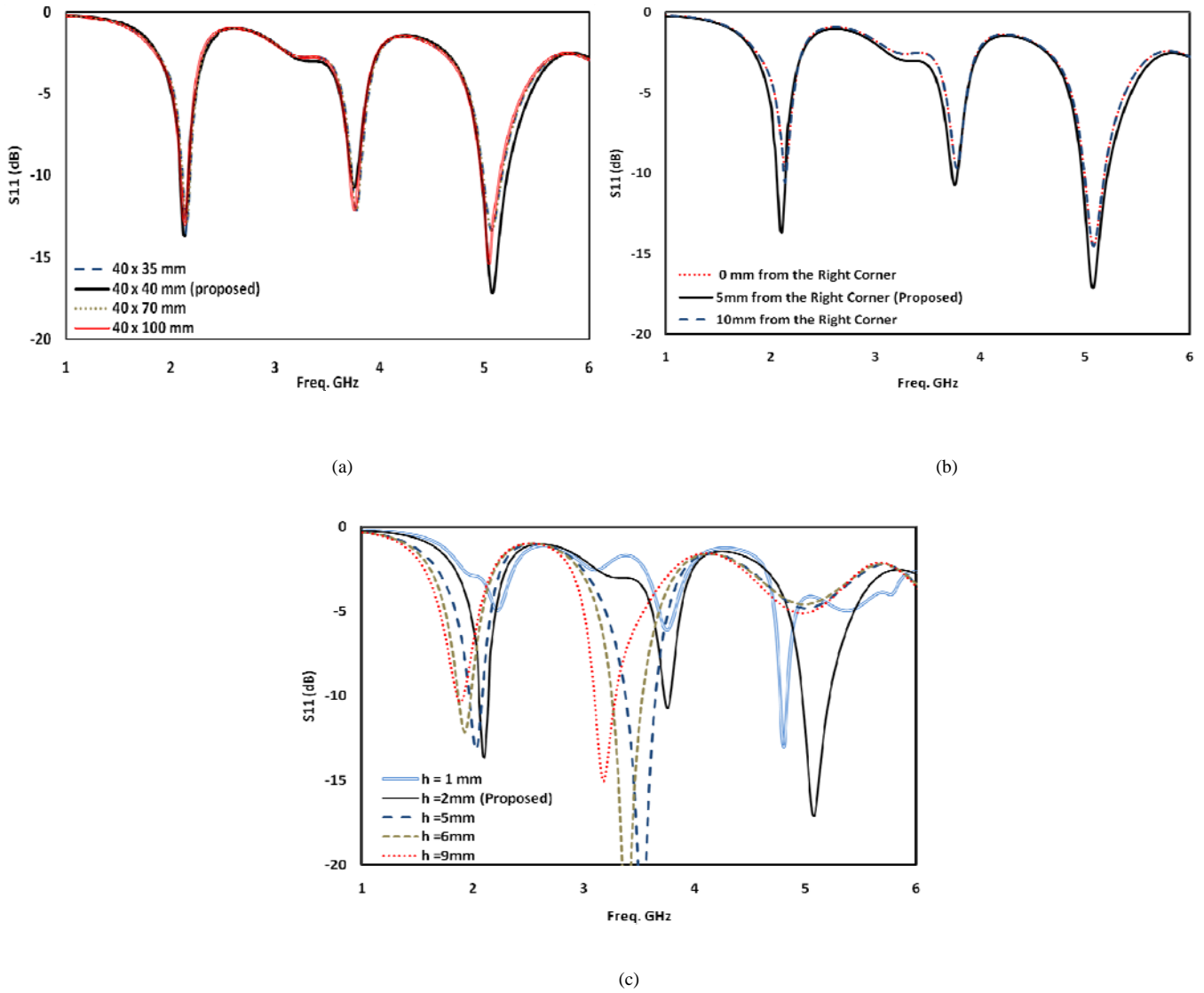


Fig. 3 The effect of some parameters on the S_{11} performance (a) The ground plane size (b) The antenna location (c) The physical height of the PIFA.

A. The Ground Plane Size

It is a well known that the ground plane size and the geometrical modification of PIFA can affect the performance of the antenna. For example in [12] the addition of the slots in the ground plane has significantly contributed in obtaining the wideband performance. Not only is the geometrical structure affecting the performance of the antenna but also the size of the ground plane. Some antennas tend to couple strongly to the ground plane making the whole device the antenna. Therefore, the ground plane might lead to an apparent advantage when bandwidth alone is considered but has many drawbacks for system performance when the user holds the phone in different positions and drawbacks when multiple antenna integration is required. For this reason, the performance of the antenna should be obtained mainly from

the structure alone not the surrounding elements [7, 10]. If the ground plane becomes part of the radiator, a significant frequency shift will be observed due to the different loading of the ground plane as a function of the hand position [9, 13]. Another advantage of making the ground plane of the antenna independent from the radiators is that, when multiple antennas are integrated, isolation values between antennas are reduced. This is due to the low level currents on the ground plane which allow further optimization of the relative position of each antenna. In the proposed antenna, the effects of varying the length of the ground plane from 40 x 40 to 40 x 70 and to 40 x 100 mm did not affect the matching nor the bandwidth of the antenna as shown in Fig. 3 (a). Similar observation was reported in a recent investigation [11]. However, in [12, 14] this was not so since the investigators had designed the ground

plane as part of the antenna which made the over size of the antenna large. Insensitive ground plane is expected to lead to reduced user's hand effects on the matching of the bands and also the effect on the radiation efficiency of the antenna. With this attractive feature, the antenna can be applied to the mobile phone with various possible ground plane lengths. In addition it reduces the isolation distance required between the antenna and the nearby conducting elements or electronic components in the mobile phone. The shapes of the radiation pattern remain principally unchanged when varying the size of the ground plane.

B. The Antenna Location

The location of feed points also can enhance the performance of the antenna in some designs [11]. However, changing the location of the proposed antenna along the substrate did not disturb the matching of the bands and no enhancement in the bandwidth was observed either as shown in Fig. 3 (b).

C. The Height of the Antenna

In some designs, the physical height of the PIFA from the ground plane can enhance the bandwidth by few percentages. In the proposed antenna, by decreasing the height of the radiated parts, the antenna's first, second and third mode is greatly affected and can no longer be excited. This behaviour is largely because, for small height values of h , radiated parts will be too close to the substrate base to be of any effect. This can prevent the currents from travelling longer distances which result in mismatching of the three bands. Furthermore, by increasing the height to a maximum of 9 mm, the currents coming from the shorting walls (S_1 , S_2 and S_3) will travel longer resulting in size reduction of the antenna as the bands shifted to the lower frequencies as shown in Fig. 3 (c). Since the objective of this research is to provide a small antenna with a thin structure, the selected height of the PIFA is 2 mm from the substrate and 3.57 mm from the ground plane. With these dimensions, the proposed antenna can operate at the UMTS, m-WiMAX and 5 GHz WLAN bands with a wide enough bandwidth to cater for these applications.

IV. CONCLUSIONS

This paper has focused on the development of a compact multiband Printed Inverted-F Antenna (PIFA). The ground plane of the antenna has shown no effect on the antenna performance which helped to keep the total volume of the antenna to be small. The antenna has a planar configuration

and cost effective. A prototype antenna has been fabricated where the simulated and measured results were in good agreements. The proposed antenna is small and thin which make it better suited for modern mobile phone handsets. Measurements for radiation patterns, gain and efficiency will be presented in a different paper.

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