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Planar inverted-f antenna for universal serial bus dongle applications

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Abstract: A simple planar inverted-f antenna for universal serial bus dongles covering the frequency from 1.6 GHz to more than 3.6 GHz in a single band is presented in this paper. The height of the planar inverted-f antenna is only 3 mm and the dimensions of the ground plane are set equal to the usual size of a universal serial bus dongle (20 mm $\times$ 55 mm). For further enhancement in impedance bandwidth, a rectangular strip is etched on the ground plane. The frequency bands covered by this antenna include LTE / AWS / UMTS (1700), DCS (1800), PCS / LTE (1900), IMT / UMTS (2000), AWS / LTE (2100), WLAN / Bluetooth (2450), WiMAX / LTE (2500–2700), and LTE (3500) and can be employed in universal serial bus dongle applications for 3rd generation and 4th generation wireless communication standards. A prototype of the proposed antenna is fabricated to compare the measured results with the simulated ones.

Key words: Planar antennas, planar inverted-f antennas, universal serial bus, long term evolution, 3rd generation wireless communication standard, 4th generation wireless communication standard

1. Introduction

Over the last two-decades, planar inverted-F antennas (PIFAs) have been very popular candidates in portable wireless systems due to their appealing characteristics such as low profile, ease of fabrication, robustness, high directivity, and conformal nature [1–3]. For universal serial bus (USB) dongles, the antennas frequently used are printed antennas, which are conformal in nature and have omnidirectional radiation patterns [4]. For portable applications, it is a desirable feature to have high directivity. PIFAs, in addition to other required characteristics, have high directivity as compared to printed antennas. However, as the required dimensions of the USB dongle are too small, three-dimensional (3D) PIFAs are not at all found in the literature for USB dongle applications. Instead, two-dimensional (2D) printed inverted-F antennas (IFAs) are used/proposed for USB applications as they are easily integrated with the PCB of the USB dongle [5–9]. However, either they have a very low bandwidth or the radiation pattern is omnidirectional, having low gain and being less directive. As IFAs are narrow band antennas, a multiband approach is used to cover different bands for USB applications. For example, the authors in [5] designed a 2D printed PIFA for the worldwide interoperability for microwave access (WiMAX) frequency band of 2.5–2.69 GHz. In [6], a dual-band 2D PIFA was presented for WLAN application bands (2.4 to 2.484 GHz, 5.15 to 5.35 GHz, and 5.725 to 5.85 GHz). A printed multiband IFA was presented in

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[7] for GSM 1.8 GHz, Bluetooth 2.4 GHz, WiMAX 3.5 GHz, and WLAN 5.2 GHz. The authors of [8] presented a compact internal printed IFA for USB dongle applications for Wibro (2.3–2.39 GHz), WLAN (2.4–2.483 GHz and 5.15–5.825 GHz), and WiMAX (2.5–2.7 GHz) bands. In [9], a printed IFA-based dual-band antenna was presented for Wi-Fi USB dongles covering frequency bands of 2.55–2.65 GHz and 5.5–6.0 GHz. However, all these antennas are 2D printed antennas and a multiband design approach is used for covering different narrow bands. Since these are printed antennas, they have an omnidirectional radiation pattern, which makes them low-gain and less directive.

The PIFA is an extension of IFAs, replacing the radiating wire with a plate for increasing the impedance bandwidth, which makes it a 3D antenna. However, the increased bandwidth was not enough to consider the PIFA a broadband antenna and a multiband design approach was used to cover different bands for portable applications such as cellular phones. Recent studies of the bandwidth enhancement techniques of PIFAs have put this antenna in the category of broadband antennas [10–12] and ultrawideband PIFAs have been developed having more than 100% fractional bandwidth [13–15].

In this paper, we are presenting, for the first time, a simple, low-cost wideband 3D PIFA for USB dongles with height h = 3 mm as shown in Figure 1. The ground plane dimensions are set equal to the usual USB dongle size. This PIFA covers frequency bands used mostly for 3rd generation wireless communication standard (3G) and 4th generation wireless communication standard (4G) long-term evolution (LTE) applications, in a single band, and can be employed for USB applications.

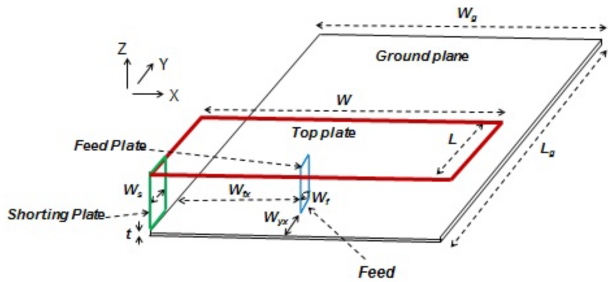

Figure 1. Three-dimensional view of the proposed PIFA.

2. Antenna configuration

The design work for developing a wideband PIFA for USB applications is started by considering the factors mentioned in [3,11], such that the position and widths of feeding and shorting plates are very critical in getting the required resonance and enhanced bandwidth. The initial design decisions taken are the size of the ground plane, the selection of the substrate, and the height of the antenna. The ground plane size $W_g \times L_g$ is made equal to the usual dimensions of a USB dongle where the width of the ground plane W_g is 20 mm and the length L_g is 55 mm. The height of the antenna is equal to h = 3 mm to make it low-profile and make it feasible for USB applications. The substrate selected is Taconic TLC-30 having a relative permittivity of $\varepsilon_r = 3.0$ and a thickness of t = 0.5 mm to further reduce the overall height of the PIFA. To use all the space available, the width of the radiating top plate is made equal to the ground plane width, i.e. $W = W_g = 20$ mm. There is nothing but air between the Taconic substrate and the radiating plate. For keeping the antenna design simple, low-cost, and easily manufactural, no etching technique is used on the top-plate. There are still many antenna variables left, which are critical and can significantly affect the antenna parameters, such as resonant frequency and impedance bandwidth [3]. These variables include the length of the top-plate and positions and widths of feeding and shorting plates. Therefore, a computer-aided parametric study is carried out to optimize these parameters to cover 3G and 4G LTE bands in a single band and to get maximum impedance bandwidth. Figure 1 shows the proposed antenna with the length of the radiating top-plate L = 27 mm. The dimensions of the shorting plate are $W_s \times (h + t)$ and that of the feeding plate are $W_f \times h$, where $W_f = 2$ mm and $W_s = 5$ mm are widths of feeding and shoring plates, respectively. The placement of the shorting plate is along the length of the ground plane at the top upper corner under the radiating plate. $W_{fx} = 8$ mm is the separation between feeding and shorting plates. The feeding plate is placed at $W_{fy} = 9.5$ mm from the upper end of the ground plane and the feeding plate is also placed along the length of the ground plane. For further enhancing the impedance bandwidth of the antenna, a slot is etched out on the ground plane as the technique of modifying the ground plane is found in the literature for increasing the impedance bandwidth [15–17]. The bottom view of the modified ground plane is shown in Figure 2. The slot inserted in the ground plane has dimensions $S_x \times S_y$ where $S_x = 17$ mm and $S_y = 2$ mm. The placement of the slot is at a separation $D_y = 22$ mm from the upper end of the ground plane. For simulation purposes, the High Frequency Structure Simulator (HFSS) v. 15 by Ansoft is used to design this antenna.

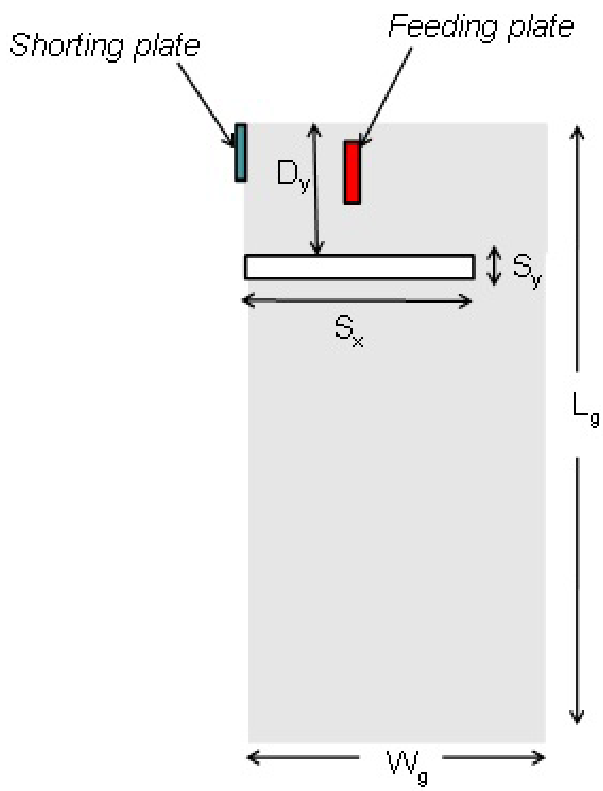

Figure 2. Bottom view of the proposed PIFA.

3. Results and discussion

Figure 3 shows the prototype of the proposed PIFA antenna fabricated for measurement purposes. Simulated and measured results for reflection coefficient S_{11} in dB are shown in Figure 4. The results show that the impedance bandwidth achieved for $S_{11} < -10$ dB is around 2 GHz from 1.6 GHz to more than 3.6 GHz, thus covering most of the frequency band used for 3G and 4G LTE wireless communication systems, including

LTE / AWS / UMTS (1700), DCS (1800), PCS / LTE (1900), IMT / UMTS (2000), LTE / AWS (2100), / Bluetooth / WLAN (2450), LTE / WiMAX (2500–2700), and LTE (3500) in one single band. Measured and simulated results are generally in good agreement where small variation is due to the facts that simulations did not consider the discrepancies due to fabrication and soldering errors in the design manufactured locally in the laboratory and the cable losses. Three-dimensional and two-dimensional radiation patterns of this antenna at 2.5 GHz in dB are shown in Figure 5 where the two-dimensional radiation pattern is for the XZ ($\Phi = 0°$) plane. Radiation patterns achieved have high directivity as compared to the omnidirectional radiation pattern. Figure 6 shows the peak gain of this PIFA for frequencies from 1.6 to 3.6 GHz and maximum peak gain obtained in the covered bands is above 4.5 dB with an average peak gain of around 3 dB. The average measured radiation efficiency of this antenna is above 90% in the frequency range from 1.6 GHz to 3.6 GHz. The Table provides a comparison of the proposed PIFA with the 2D IFA/PIFA designs found in the literature. It is found that all previously found IFA/PIFA-based antennas have 2D printed structures with a narrow multiband having an omnidirectional radiation pattern, whereas our proposed antenna has a 3D structure with one single ultrawide band covering most of the frequencies used for 3G and 4G LTE wireless USB applications. As shown in Figure 5, it has a directional radiation pattern, whereas all the previously designed antennas for USB applications have omnidirectional radiation patterns.

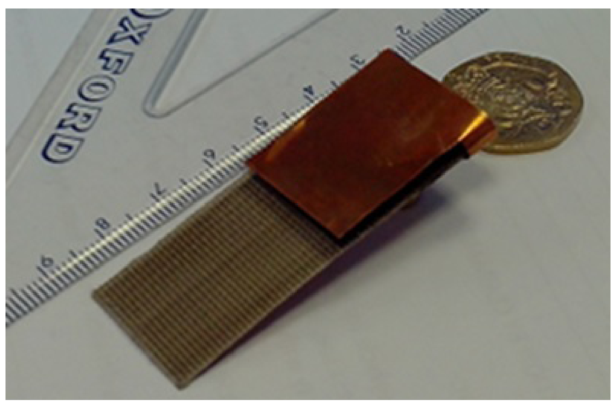

Figure 3. The fabricated prototype of the proposed PIFA.

Table. Comparison of the proposed antenna with the antennas found in literature for USB applications.

Reference \ An. param.	Structure type	Multiband/ single band	Bands covered [GHz]	Bandwidth	Radiation pattern
Ref. [5]	2D printed	Single band	2.5–2.69	Narrowband	Omnidirectional
Ref. [6]	2D printed	Multiband	2.4–2.484, 5.15–5.35, 5.725–5.85	Narrowband	Omnidirectional
Ref. [7]	2D printed	Multiband	1.8, 2.4, 3.5, 5.2	Narrowband	Omnidirectional
Ref. [8]	2D printed	Multiband	2.3–2.7, 5.15–5.825	Narrowband	Omnidirectional
Ref. [9]	2D printed	Multiband	2.55–2.65, 5.5–6.0	Narrowband	Omnidirectional
Proposed design	3D	Single band	1.6–3.6	Wideband (ultrawideband)	Directional

The rectangular slot etched on the ground plane is inserted to increase the bandwidth of the antenna. The dimensions and position of the rectangular slot are very important in getting the enhanced bandwidth. To understand the effects of the slot, its dimensions are varied, whereas the distance of the slot from the upper edge

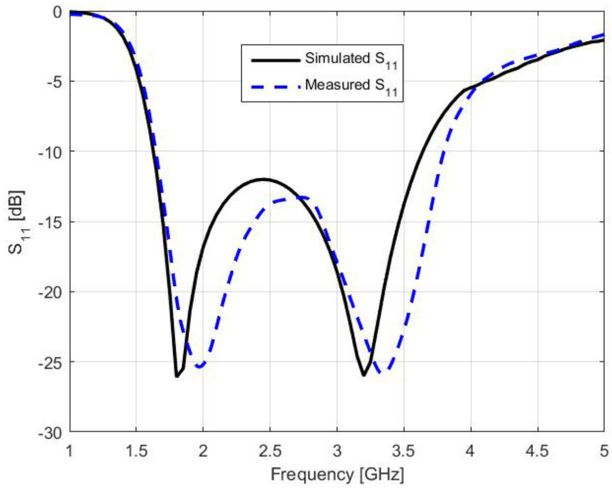

Figure 4. Simulated and measured reflection coefficient S_{11} [dB] versus frequency [GHz].

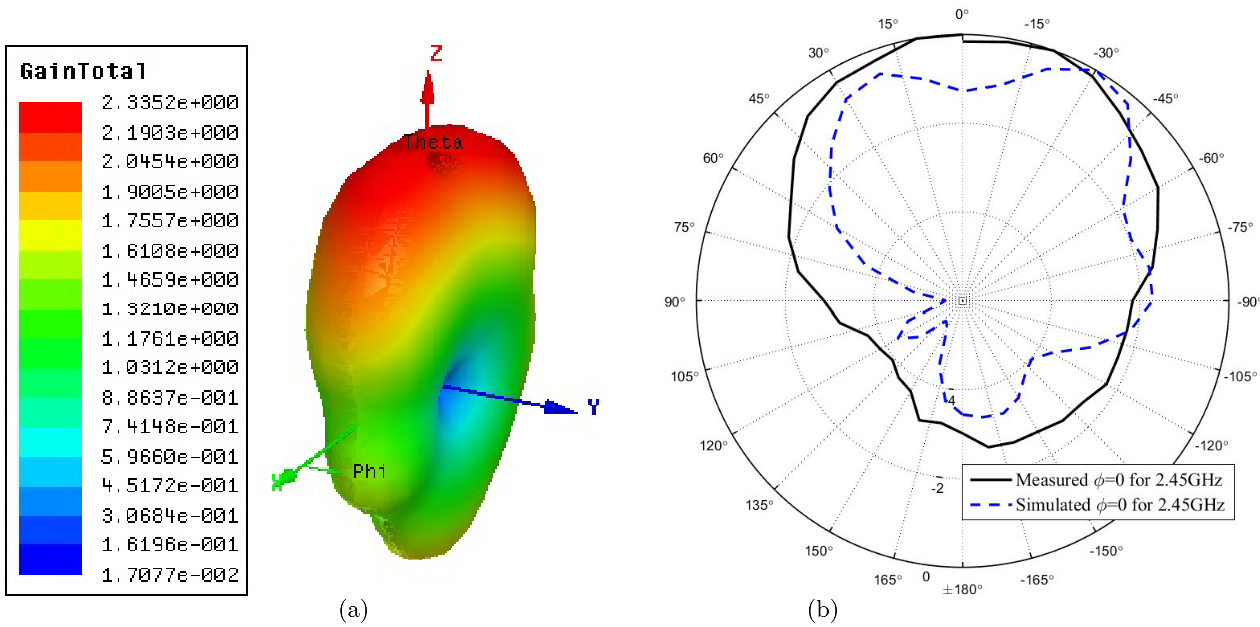

Figure 5. Radiation patterns of the proposed PIFA at 2.5 GHz: a) three-dimensional radiation pattern in dB; b) two-dimensional radiation pattern in dB for ($\Phi = 0°$) XZ plane.

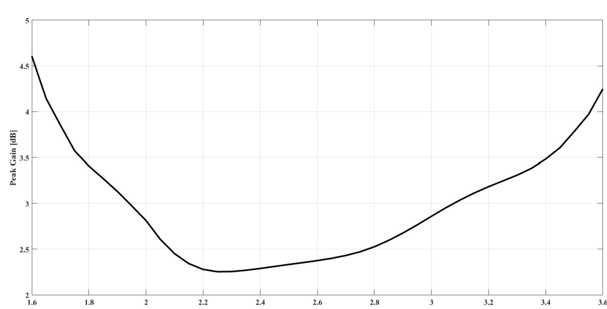

Figure 6. Peak gain [dB] of the proposed PIFA versus frequency in GHz.

of ground plane D_y is fixed at 22 mm. The slot length S_x is varied from 15 mm to 17 mm with an increment of 2 mm and the width of slot S_y is varied from 0.5 mm to 2.5 mm with an increment of 1 mm. The impacts of these variations on reflection coefficient S_{11} are shown in Figure 7. It is shown that when there is no slot then the impedance bandwidth achieved is too low and it only covers a band from 1.7 GHz to around 2.4 GHz, whereas the insertion of the slot introduces the second resonance in such a way to make one single wideband increasing the overall bandwidth of the antenna and its placement and dimensions have very significant effects on the impedance bandwidth of the antenna, which implies that its parameters need to be carefully optimized for obtaining the maximum impedance bandwidth.

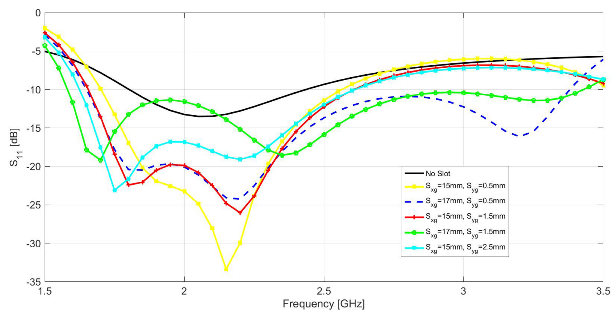

Figure 7. Reflection coefficient S_{11} [dB] versus frequency [GHz] for different values of S_x and S_y.

4. Conclusions

A new simple single-wideband 3D PIFA with height h = 3 mm is proposed for the first time. It covers the frequency band from around 1.6 GHz to 3.6 GHz in one single band, thus covering most of the frequency band used for 3G and 4G LTE wireless communication systems, including LTE / AWS / UMTS (1700), DCS (1800), PCS / LTE (1900), IMT / UMTS (2000), LTE / AWS (2100), / Bluetooth / WLAN (2450), LTE / WiMAX (2500–2700), and LTE (3500) in one single band. It is concluded that besides the dimensions and positions of the shorting and feeding plates, the slot inserted in the ground plane plays a significant role in enhancing the overall bandwidth of the antenna.

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