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Broadband planar antenna with improved pattern bandwidth

Antena plana de banda ancha con mejoramiento en el ancho de banda de diagrama

Carlos Suárez[1], *Rafael Rodríguez*[1], *Miguel Ferrando Bataller*[2]

[1] LIMER Group. Universidad Distrital Francisco José de Caldas. Cr 8 N°. 40-62. Bogotá D.C., Colombia.

[2] Institute of Telecommunications and Multimedia Applications (iTEAM). Universidad Politécnica de Valencia. Edificio 8G, Camino de Vera s/n, 46022. Valencia., Spain.

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Abstract

This paper presents the design of a broadband planar inverted-F antenna whose geometry splits the top (radiating plate), short, ground, and capacitive feed plates into two parts. The proposed geometry together with the capacitive-feed technique make it possible to achieve both measured-pattern and impedance bandwidths of about 52.44% (1.66 GHz - 2.84 GHz) and 8% (3.36 GHz - 3.64 GHz) for VSWR ≤ 2.0. These values are larger than the bandwidth obtained using a traditional wire-fed PIFA or other capacitive feeding techniques. A constructed prototype is enough to simultaneously cover various frequency bands, namely DCS 1800, DCS 1900, UMTS, Wi-Fi, 2.4GHz, WiMAX (2.3–2.5 GHz; 3.4–3.5 GHz), and Bluetooth. Radiation patterns are reasonably omni-directional throughout the whole operating bandwidth.

--------- *Keywords:* PIFA antenna, wideband antenna, capacitive feed technique

Resumen

En este artículo se presenta el diseño de una antena plana F invertida que utiliza una geometría en la cual se dividen en dos partes las placas superior (radiante), de corto, de tierra y de excitación capacitiva. Mediante esta geometría y la técnica de excitación capacitiva se logra alcanzar anchos de

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* Autor de correspondencia: teléfono: 571 + 323 93 00 ext. 1502, fax: 571 + 323 93 00, correo electrónico: csuarezf@udistrital.edu.co (C. Suárez).

banda de diagrama y de impedancia cercanos al 52.44% (1.66 GHz a 2.84 GHz) y del 8% (3.36 GHz a 3.64 GHz) para un VSWR ≤ 2.0. Los resultados medidos para estos parámetros son superiores a los obtenidos mediante la técnica tradicional de excitación directa con terminal u otros métodos de excitación capacitiva utilizado en antenas planas F invertidas (PIFA). El prototipo construido permite la operación simultanea de la antena en las bandas de DCS 1800, DCS 1900, UMTS, WiFi, 2.4GHz, WiMAX (2.3GHz a 2.5GHz) y (3.4GHz a 3.5GHz) y en la banda asignada para el estándar (Bluetooth). Los diagramas de radiación obtenidos dentro de estos anchos de banda son razonablemente omnidireccionales.

--------- *Palabras clave:* Antena plana F invertida (PIFA), antenas de banda ancha, técnica de excitación capacitiva

Introduction

As a result of the rapid and continuous development of mobile technology and services during the last decade, multiband or wideband internal antennas are necessary in order to increase the portable wireless unit functionality.

Planar inverted-F antennas (PIFAs) have been widely used in portable wireless units as internal antennas [1-7] due to their compact size and the capacity of comply with the required radiation performance. In recent years, several designs for wideband or multiband PIFAs have been proposed, covering different frequency bands. In [2-4], wideband planar inverted-F antennas were proposed to cover up to five and six frequency bands, while in [5] and [6], different excitation techniques were proposed to obtain wide impedance bandwidth (up to 65% for VSWR ≤ 3.0). Finally, in [7] PIFAs were combined with slot radiators to increase the coverage of the frequency spectrum.

In this paper, a wideband PIFA structure is proposed for portable wireless units (including mobile telephone handsets), which further increases the impedance bandwidth, while exhibiting very stable radiating patterns and gain within the whole operating band. An antenna with wide impedance and pattern bandwidth is thus presented. As shown later, this behavior will be accomplished by using a novel U-shaped capacitive feed [8], to allow further control of the impedance and gain curves.

A wideband capacitive feed PIFA has been designed and optimized using commercial electromagnetic software [9, 10]. The properties of the antenna will be analyzed, and then validated by experimental measurements. By changing four parameters—the area of the feeding plate, the separation from the radiating top plate, the probe placement on the feeding plate, and the area of the ground plate —it will be shown how the antenna designer can gain entire control over the resonance properties of the antenna.

Design of the proposed antenna

Fig. 1 shows the three – dimensional, top and side views of the proposed antenna structure. As observed, the U-shaped capacitive feed is constructed by terminating the inner conductor of a coaxial into to a conducting plate, which electromagnetically couples to the radiating top plate. The excitation of the antenna is placed at the edge of the capacitive feeding plate. The radiating top plate and the shorting plate are split in two parts, adding a slot in the ground plate. The antenna was made from a 0.3-mm-thick copper sheet.

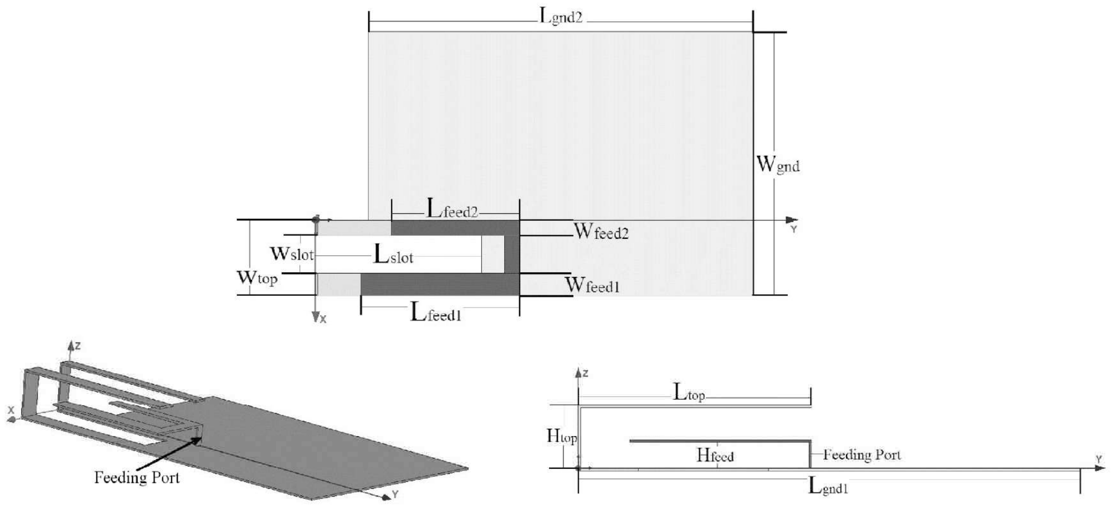

Figure 1 Three-dimensional, top and side views of the proposed PIFA antenna

Dimensions of the antenna have been optimized to achieve wideband performance, both from the impedance bandwidth, radiation pattern and gain point of view. The dimensions of the antenna are: $L_{top}=28mm$, $W_{top}=10mm$, $H_{top}=5mm$, $L_{Feed1}=23mm$, $W_{Feed1}=3mm$, $L_{Feed2}=12mm$, $W_{Feed2}=2mm$, $L_{gnd1}=60mm$, $L_{gnd2}=44mm$, $W_{gnd}=30mm$, $H_{feed}=1.9mm$, $L_{slot}=23mm$, $W_{slot}=5mm$. The total volume of the antenna is 60x30x5 mm^3.

Both the geometry and the capacitive U-feed technique proposed in this paper allow enhanced control in terms of frequency response, particularly regarding parameters such as gain and impedance. This enhancement is due to the PIFA antenna geometry, which separates the upper plate, and also the capacitive feed plaque, into two ends (branches). Through such separation, it is possible to create new shifting resonance points by adjusting the feed branches (L_{feed1} y L_{feed2}), the Slot length (L_{slot}), and the height of the feed plates (H_{feed}) that appear in figure 1; which permits determining antenna response completely. The whole proposal is detailed in the parametric analysis presented in the following section.

Parametric analysis

Figure 2 shows simulation results that represent the frequency response of the antenna-impedance coupling parameter (S11) when varying the Slot length of figure 1 (L_{slot}). It can be seen that this parameter has a direct impact on the high-frequency response of the antenna, as observed; this length has an important impact on the upper frequency band.

Figure 3 shows simulation results of the reflection coefficient (S11) for three different separation distances (separation between ground plane and feed plate – H_{feed} in Figure 1). It can be observed that, through the whole frequency range, the impedance bandwidth is extremely dependent on the selected length (H_{feed}) since failing to select an optimal length value clearly degrades the impedance coupling of the antenna.

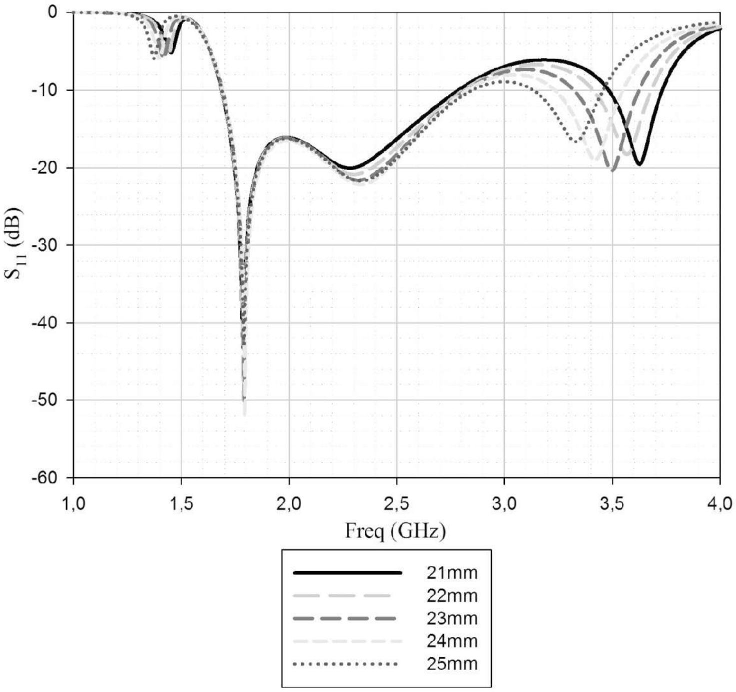

Figure 2 Simulated reflection coefficient for five different values of L_{slot}

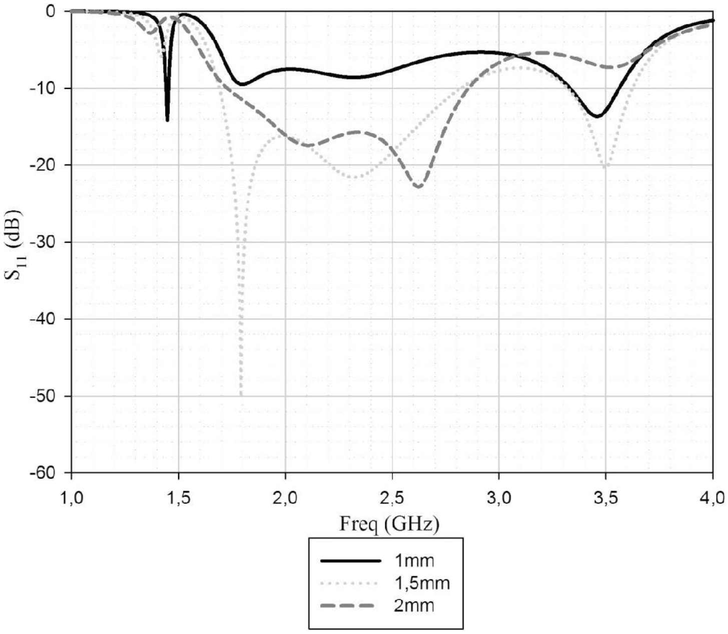

Figure 3 Simulated reflection coefficient for different values of H_{feed}

Figure 4 shows simulation results that are intended to determine the frequency-response effect of parameter S11 for five different branch lengths L_{feeed1} (as in Figure 1). Branch length is part of the capacitive feed system proposed herein. It can be observed that the reflection coefficient is largely sensitive to branch length, and so this also affects the whole antenna response. Likewise, Figure

5 shows simulation results regarding reflection coefficient S11 with five different branch lengths of the second branch that makes part of the feed system (L_{feed2} in fig. 1). This second branch largely affects antenna frequency response, particularly in the high-frequency band.

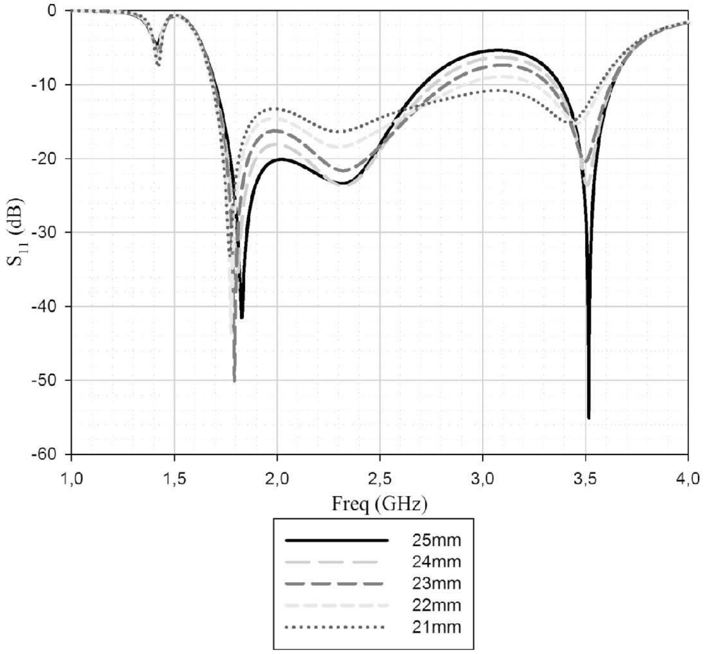

Figure 4 Simulated reflection coefficient for different values of L_{feed1}

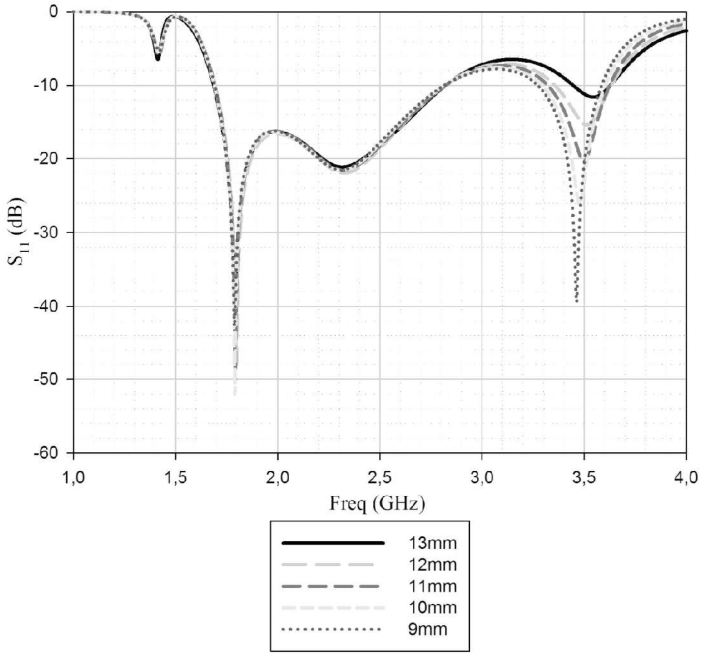

Figure 5 Simulated reflection coefficient for different values of L_{feed2}

Simulated and measured results

Once optimized the geometry of the antenna, a prototype has been fabricated and measured. Fig. 6 shows a picture of the top and bottom view for the fabricated prototype of the capacitive feed PIFA with SMA connector. The antenna was constructed over Rohacell material, to facilitate the fabrication process.

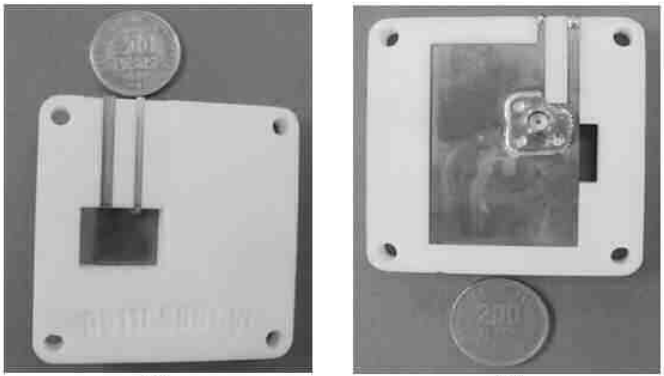
(a) (b)

Figure 6 Picture of the fabricated prototype of the capacitive feed PIFA: (a) Top view; (b) Bottom view

Fig. 7 shows the reflection coefficient of the antenna, both simulated and measured. As shown, the measurement correlates quite well with the simulated response. As it can be observed, the proposed capacitive feed PIFA exhibits a very wide impedance bandwidth with two resonances, covering approximately from 1.66 GHz to 2.84 GHz and 3.36 GHz to 3.64 GHz. This represents a relative impedance bandwidth of more than 52.44% and 8% respectively for S_{11}<- 10dB.

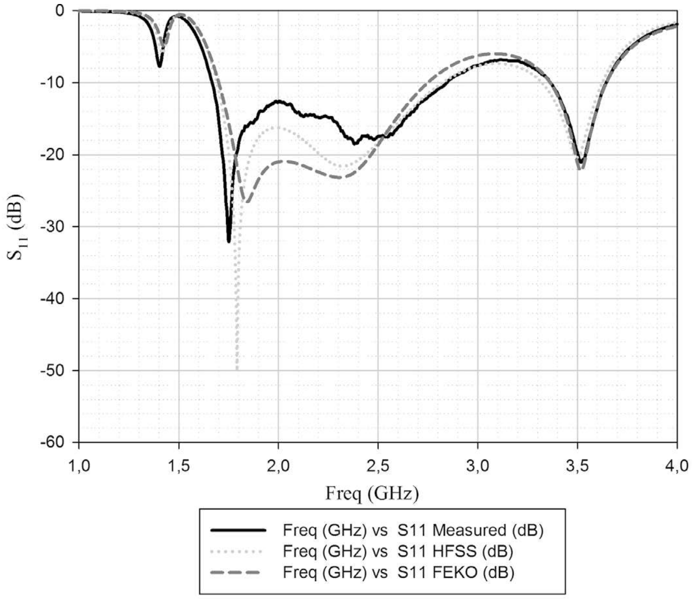

Figure 7 Measured and simulated (HFSS and FEKO) reflection coefficient for the proposed antenna

In addition, fig. 7 shows the reflection coefficient of the antenna, both simulated (HFSS and FEKO) and measured. As shown, the measurement correlates quite well with the simulated response using FEKO and HFSS software.

Thus the antenna satisfies a 10 dB return loss requirement to cover the Digital Communication System, 1710–1880 MHz (DCS1800), 1850–1990 MHz (DCS1900), PCS (1850–1990 MHz), UMTS (1920–2170 MHz), Wireless Local Area Network, 2400–2483 MHz (WLAN), Digital Mobile Broadcasting, 2605–2655 MHz (DMB), IEEE 802.11b/g, Wi-Fi, WiMAX (2.3–2.5 GHz) and (3.4–3.5 GHz) and Bluetooth standards at the same time.

Figure 8 shows the simulated current distribution at 1.8, 2.5 and 3.5 GHz. As observed, the current distribution on the surface of the U-shaped radiating top plate (two arms) of the antenna remains uniform, which can be considered the most outstanding effect of this novel feeding technique. As a result of the uniformity and intensity of the current distribution observed in Fig. 8, the measures radiation patterns and gain remain almost reasonably constant in the whole useful bandwidth of the antenna.

Figure 9 and figure 10 illustrate two cuts (XZ-plane and YZ-plane) of the radiation patterns measured at different frequencies within the operating bandwidth. As observed, quite stable omnidirectional radiation behavior is obtained at all operating frequencies, as it is desirable in handset antennas.

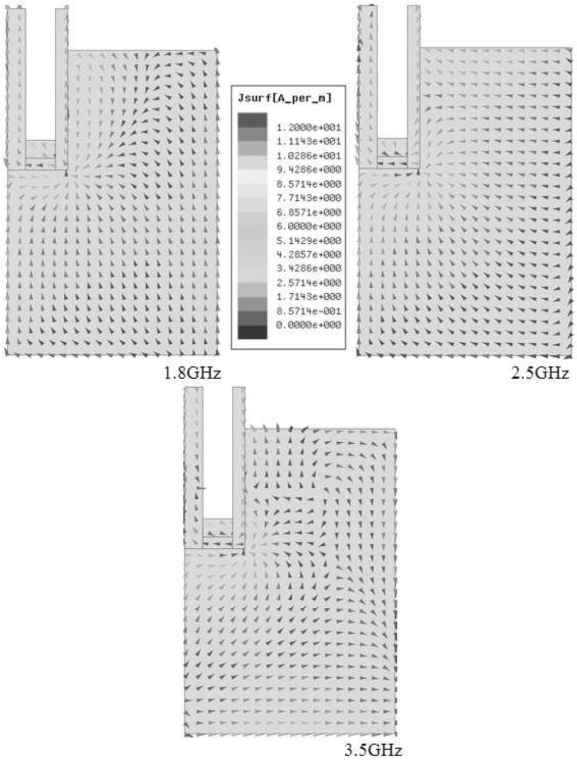

Figure 8 Simulated current distribution at 1.8, 2.5 and 3.5 GHz

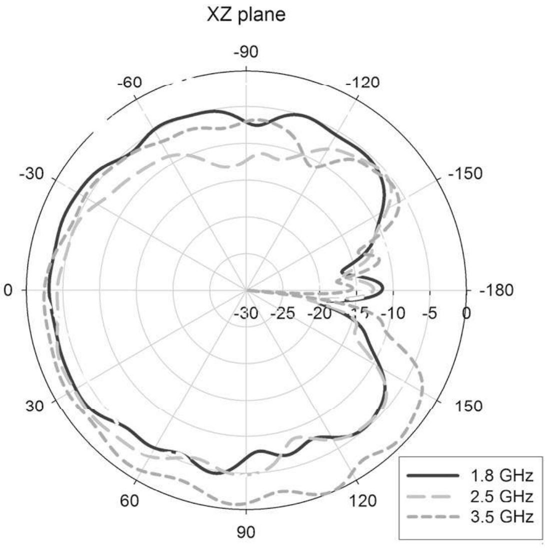

Figure 9 Measured radiation patterns in XZ-plane at 1.8, 2.5 and 3.5 GHz

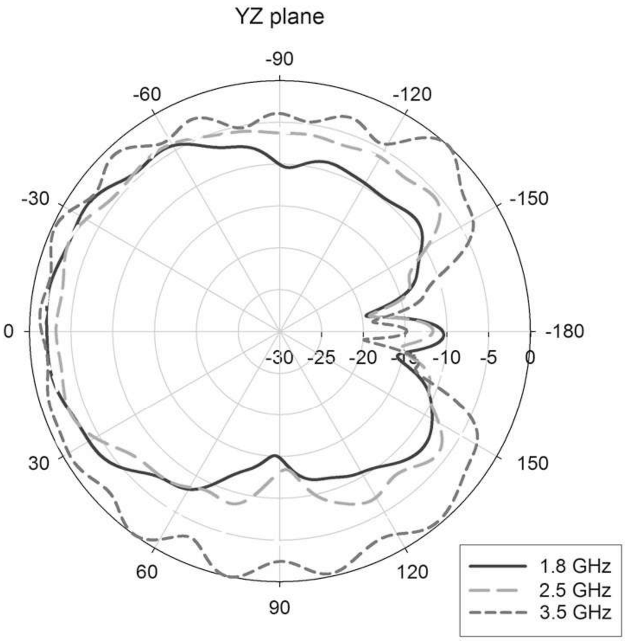

Figure 10 Measured radiation patterns in YZ-plane at 1.8, 2.5 and 3.5 GHz

Figure 11 shows the simulated gain within the overall bandwidth of the antenna. As observed, the maximum gain of the antenna remains very stable over the entire operating bandwidth, which can be considered the most outstanding effect of this novel feeding technique.

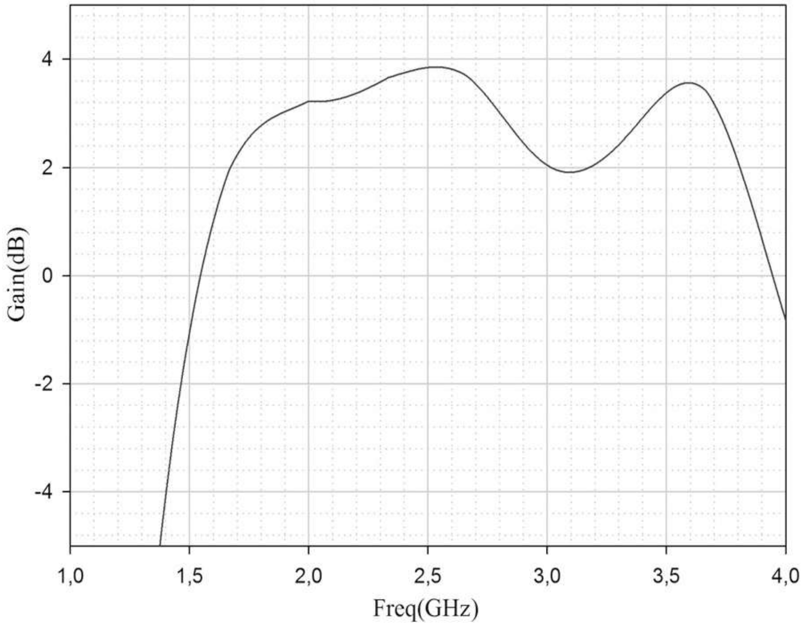

Figure 11 Simulated gain vs. frequency

Finally, figures 12, 13 and 14 show the measured 3D radiation pattern at 1.8, 2.5, and 3.5 GHz. As observed, quite stable omnidirectional 3D radiation behavior is obtained at all operating frequencies, as it is desirable in handset antennas.

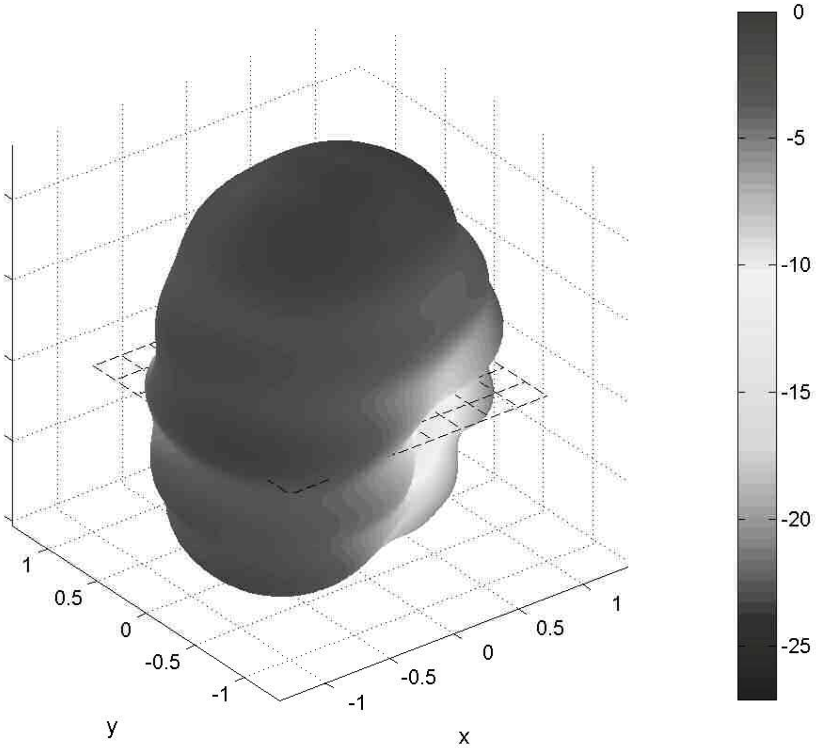

Figure 12 Measured 3D radiation patterns at 1.8GHz

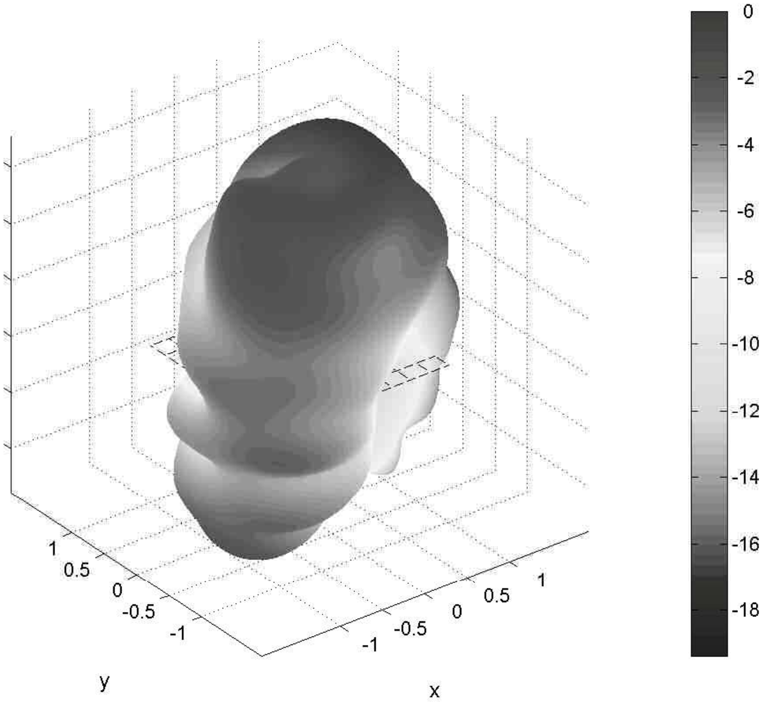

Figure 13 Measured 3D radiation patterns at 2.5GHz

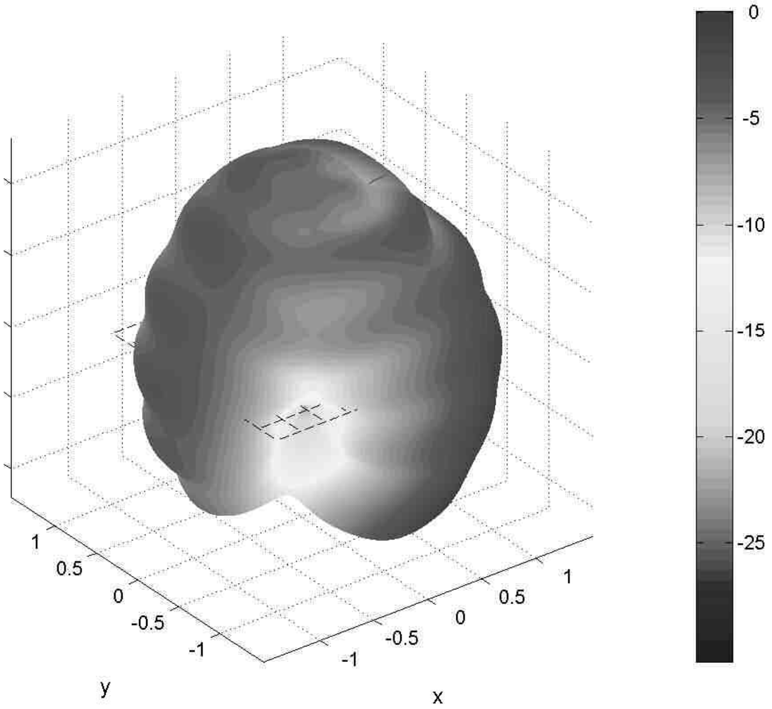

Figure 14 Measured 3D radiation patterns at 3.5GHz

Results and discussion

Based on radiation-pattern measurements at different frequencies, return-loss measurements and gain simulations, it can be observed that the geometry and the capacitive U-feed technique proposed in this paper allow suitable control of frequency response parameters such as gain, radiation pattern and impedance. Unlike other feed techniques and geometries commonly used for PIFA antennas [1]-[7] (where radiation patterns and gain vary considerably as operating frequency changes), the proposed technique achieves a stable behaviour of these parameters within the antenna's intended operating bandwidth. On the other hand, impedance bandwidth is expected to further increase (compared to the values presented herein) through the use of the proposed geometry-and-feed technique.

Conclusions

In this paper a U-shaped capacitive feed PIFA having very wideband pattern and impedance bandwidth characteristics has been designed. U-shaped capacitive feed PIFA offers satisfactory performance of the radiation patterns (omnidirectional), as well as improved impedance matching at the input port over a large bandwidth. The simulated results of the proposed antenna agree quite well with the measured reflection coefficient. Measurements also indicate that the pattern and impedance bandwidths of the proposed U-shaped capacitive feed PIFA are larger than other published papers using other capacitive feeding techniques or a traditional wire-feed technique.

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