UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Wideband PIFA antenna for higher LTE band applications

Carlos Arturo Suárez-Fajardo [a], Rafael Rodríguez-León [b] & Eva Antonino-Daviú [c]

[a] *Facultad de Ingeniería, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. csuarezf@udistrital.edu.co*
[b] *Developmet Team, Sequoia Space, Bogotá, Colombia. rafael.rodriguez@sequoiaspace.com*
[c] *Escuela técnica de Ingenieros de Telecomunicación, Universidad Politécnica de Valencia, Valencia, España. evanda@upvnet.upv.es*

Received: February 17th, 2014. Received in revised form: October 30th, 2014. Accepted: November 24th, 2014.

Abstract
This paper introduces a broadband planar inverted-F antenna (PIFA) with U–Shaped capacitive feed technique for higher LTE band applications. The proposed antenna is based on a simple PIFA, where the capacitive feed plate, radiating plate and ground plate is modified into a U–Shaped such that the antenna can have wideband characteristics. With the use of the proposed feeding configuration, the antenna shows a very wide pattern and impedance bandwidth of about 81.6% for VSWR ≤ 2.0 from 1.66 GHz to 3.95 GHz which can cover the higher band of LTE (1.71GHz-3.8GHz), DCS 1800, DCS 1900, UCDMA, UMTS, IMT 2000, DMB, Wi-Fi, 2.4GHz, WiMAX (2.3–2.5 GHz), WiMAX (3.4–3.5 GHz) and Bluetooth applications.

Keywords: PIFA antenna; wideband antenna; capacitive feed technique; LTE antenna design.

Antena PIFA de banda ancha para aplicaciones en la banda alta de LTE

Resumen
Este artículo presenta una antena plana F invertida (PIFA) de banda ancha con la técnica de excitación capacitiva en U para aplicaciones en la banda alta de LTE. La antena propuesta se basa en una simple PIFA, donde las placas de excitación capacitiva, de radiación y de tierra se modifican a una geometría en U de tal manera que la antena puede poseer características de ancho de banda amplio. Mediante el uso de la configuración de excitación propuesta, la antena muestra un ancho de banda amplio de diagrama e impedancia del 81.6% para un VSWR ≤ 2.0 desde 1.66GHz a 3.95GHz la cual puede cubrir aplicaciones en la banda alta de LTE (1.71GHz-3.8GHz), DCS 1800, DCS 1900, UCDMA, UMTS, IMT 2000, DMB, Wi-Fi, 2.4GHz, WiMAX (2.3–2.5 GHz), WiMAX (3.4–3.5 GHz) y Bluetooth.

Palabras clave: Antena plana F invertida (PIFA); antenas de banda ancha; técnica de excitación capacitiva; diseño de antenas para LTE.

1. Introduction

The design of internal antenna for small-size mobile device used in wireless communication systems as LTE, CDMA, GSM, WCDMA, GPS, Bluetooth, among other bands continues to evolve even today, consequently several reports in the literature propose different PIFA designs. However to meet the needs of wireless communications, the bandwidth of the PIFA using a traditional wire–fed or a broadband design of a probe feed is too narrow to cover multi- frequency bands [1]. Therefore, a PIFA that is capable of covering many operating bands is desirable. Various design approaches have been applied to broaden the bandwidth of a conventional PIFA and to reduce antenna size while maintaining good multiband performance [2-4]. Some proposed that a very broad band (up to 65% for VSWR ≤ 2.0) can be achieved for a PIFA by selecting the right values for the feed and shorting plates [5], others proposed that 45.2% impedance bandwidth for S11<10 dB can be achieved reforming the shorting strip of the PIFA into a meandering strip [6].

Instead of using a direct feed, the modified PIFAs using a capacitive feed have also been demonstrated. In [7], the proposed design exhibits an impedance bandwidth of 96.4% for VSWR ≤ 3:1 (tree resonances), in [8] the impedance bandwidth achieved is 61.92% for VSWR ≤ 2.0, in [9] the impedance bandwidth achieved is 52.44% plus 8% for VSWR ≤ 2.0 (Two resonances). In [10] PIFAs were combined with slot radiators to increase the coverage of the frequency spectrum; the impedance bandwidth achieved is 84.6% for VSWR ≤ 3:1 (tree resonances).

In [11], a compact PIFA with a tunable frequency response is presented. Tuning of the resonant frequency is realized by loading a varactor on an embedded slot of the proposed antenna structure. By changing the capacitance of the varactor from 0.1pF to 3pF, it will change the electrical length of current path flow as well as to shift the resonant frequency. The antenna shows a wide impedance bandwidth of about 49.4% for VSWR ≤ 2.0 from 1.57GHz to 2.6GHz, covering the GPS, PCS, DCS, UMTS, WLAN and LTE systems.

In [12], a miniaturized microstrip-fed planar monopole antenna with archimedean spiral slot to cover WiFi, Bluetooth and LTE standards, both for VSWR < 2:1 has been presented. The optimized antenna exhibits a bandwidth of 2.18GHz to 2.92GHz to cover WiFi/Bluetooth (2.45GHz) and LTE (2.6GHz) mobile applications. The simulated antenna gain varies from about 2.77dBi to 2.93dBi.

In [13], the design of reconfigurable antenna for LTE (band1, band23, band40) and WLAN applications has been presented. The proposed antenna consists of rectangular patch fed by a proximity feed. The presence of square slots on the diagonal corners is used for frequency reconfiguration. The antenna can operate at 2.07GHz, 2.1GHz, 2.4GHz and 2.45GHz by proper selection of diagonal slots. The directivity is greater than 5dB at all operating frequencies.

In [14], a novel hollow coupling element antenna for applications in the lower LTE (698-787MHz) and GSM (824-960MHz) bands, both for VSWR < 3:1(S11<-6dB) has been presented. Matching networks was used to tune the antenna-system to the desired frequency with a suitable reflection coefficient (-6dB), antenna gain results was not provided.

In this paper, a wideband PIFA structure is proposed for portable wireless units, 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 U-shaped capacitive feed [9] to allow further control of the impedance and gain curves.

A wideband capacitive feed PIFA has been designed and optimized using commercial electromagnetic software HFSS. The properties of the antenna will be analyzed and then validated by experimental measurements related with impedance and diagram bandwidth. By changing four parameters—the geometry of the feeding plate, the separation from the radiating top plate, the geometry of the radiating top plate and the geometry of the ground plate, it will be shown how the antenna designer can gain entire control over the resonance properties of the antenna.

The results presented in this paper show a very wide pattern and impedance bandwidth of about 81.6% for VSWR ≤ 2.0:1 from 1.66 GHz to 3.95 GHz, which can cover the higher LTE band of (1.71GHz-3.8GHz), the maximum gain of the antenna remains very stable over the entire operating bandwidth (from 2.3dBi to 2.8dBi).

2. PIFA Antenna Design

Fig. 1 shows the top and side views of the proposed antenna structure. As observed, the U-shaped capacitive

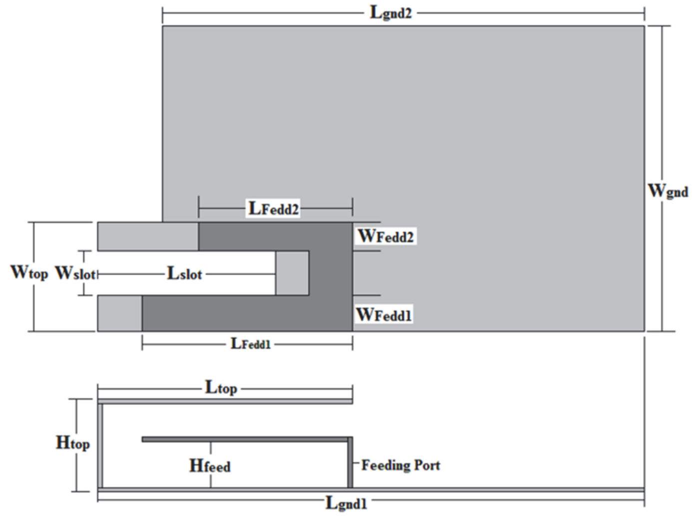


Figure 1. Top and side views of the proposed PIFA antenna.
Source: The Authors.

feed is constructed by terminating the inner conductor of a coaxial into 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. Dimensions of the antenna have been optimized to achieve wideband performance, both from the impedance bandwidth, radiation pattern and gain point of view. In relation to the Fig. 1, the dimensions of the antenna are: L_{top} = 27mm (0.25λ), W_{top} = 10mm (0.09λ), H_{top} = 7mm (0.06λ), L_{Feed1} = 21mm (0.2λ), W_{Feed1}=3mm (0.03λ), L_{Feed2} = 17mm (0.16λ), W_{Feed2} = 2mm (0.019λ), L_{gnd1} = 58mm (0.54λ), L_{gnd2} = 51mm (0.48λ), W_{gnd} = 35mm (0.33λ), H_{feed} = 3mm (0.03λ), L_{slot} = 22mm (0.2λ), W_{slot} = 5mm (0.05λ). The total volume of the antenna is 58x35x7 mm^3. The antenna was made from a 0.3mm – thick cooper sheet and this parameter was included in the simulation process using HFSS Electromagnetic software.

3. Parametric Study

As previously commented, the radiating behavior of the antenna can be controlled by changing four physical parameters: The geometry of the feeding plate, the separation from the radiating top plate, the geometry of the radiating top plate, and the geometry of the ground plate. In this section, the reflection coefficient of the antenna depending on the variation of these parameters will be analyzed.

Fig. 2 shows the simulated S_{11} behavior of the proposed antenna for different values of the ground plane length (parameter L_{gnd2} in Fig. 1). As observed, the length of ground plane has an important impact on the upper frequency band of the impedance bandwidth, decreasing the impedance bandwidth as the length increases.

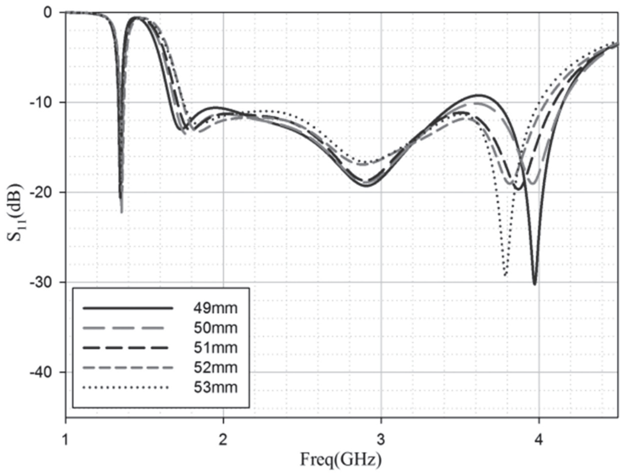


Figure 2. Simulated reflection coefficient for different values of Lgnd2.
Source: The Authors

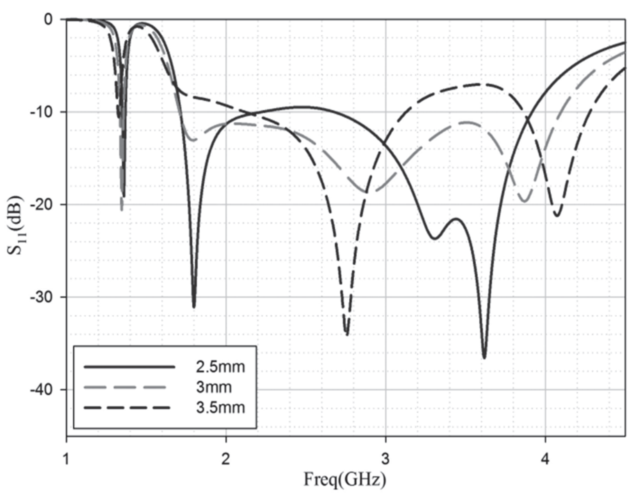


Figure 3. Simulated reflection coefficient for different values of Hfeed.
Source: The Authors.

Fig. 3 shows the simulated reflection coefficient results of the proposed antenna for three different values of separation between the capacitive feeding plate and the ground plane (parameter H_{feed} in Fig. 1). As observed, the reflection coefficient is very sensitive to the height of the feeding plate within the entire frequency band, degrading the impedance coupling when this value is not optimum.

Fig. 4 shows the simulated reflection coefficient results of the proposed antenna for five different values of one of the capacitive feed arms (parameter L_{Feed1} in Fig. 1). As observed, the reflection coefficient is again very sensitive to the length of the capacitive feed plate within the entire frequency band.

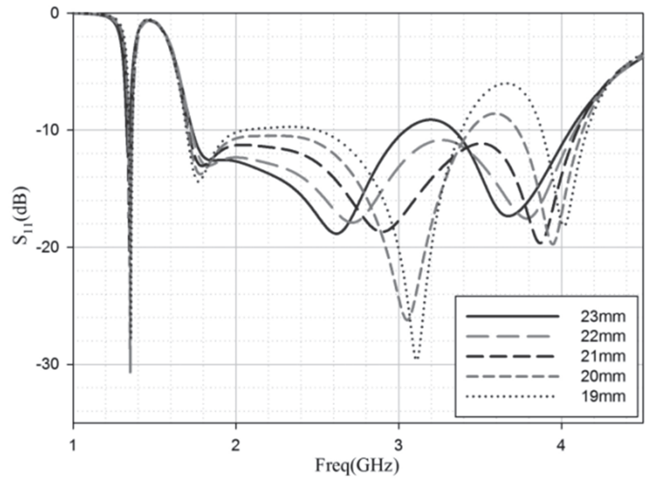


Figure 4. Simulated reflection coefficient for different values of Lfeed1.
Source: The Authors.

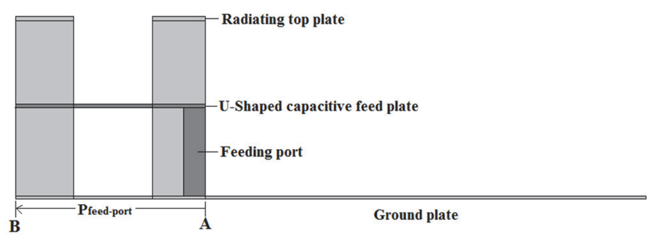


Figure 5. Feeding port position between the capacitive feeding plate and the ground plane.
Source: The Authors.

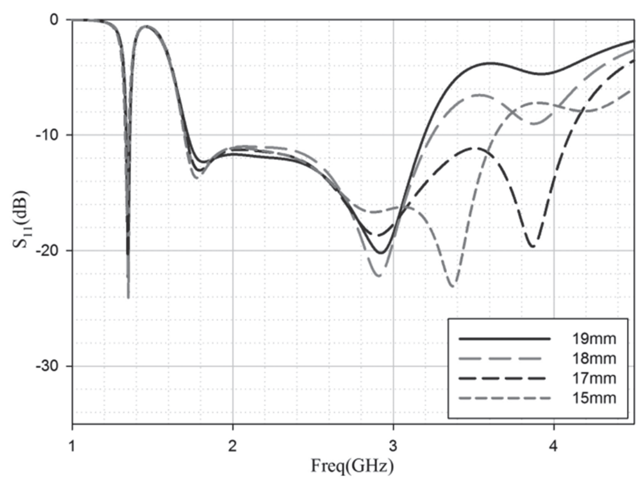


Figure 6. Simulated reflection coefficient for different values of Lfeed2.
Source: The Authors.

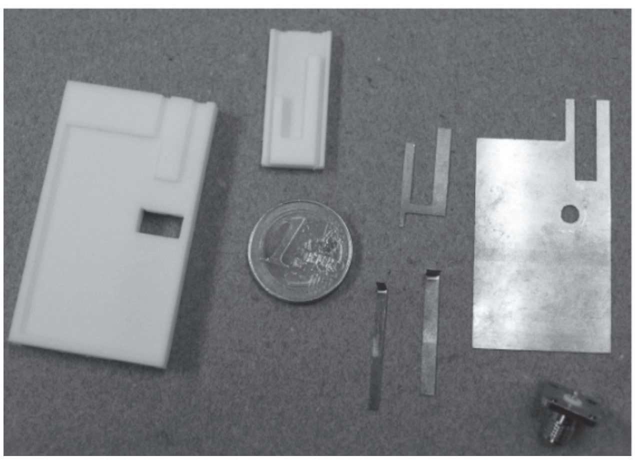
Fig. 5 shows the feeding port position, between the ground plate and the capacitive feeding plate, which is displaced for analysis from point A to B.

Fig. 6 shows the simulated reflection coefficient results of the proposed antenna for four different values of the other capacitive feed arm (parameter L_{Feed2} in Fig. 1). As observed, this length has also an important impact on the upper frequency band.

As a result of the parametric study previously commented, the radiating behavior of the antenna can be controlled by changing the geometry of the capacitive feed plate (L_{Feed2}, L_{Feed1}, W_{Feed2}, W_{Feed1}), the separation from the radiating top plate (H_{top}, H_{feed}), the geometry of the ground plate (L_{gnd1}, L_{gnd2}, W_{gnd}, W_{top}, L_{slot}, W_{slot}), and the geometry of the radiating top plate (L_{top}, W_{top}, W_{slot}, W_{Feed2}, W_{Feed1}).

4. Experimented Results and Discussion

Once optimized the geometry of the antenna, a prototype has been fabricated and measured. Fig 7-a shows the antenna parts including: Rohacell material (antenna structure), capacitive feed plate, radiating top plate, ground plate, coupling plates (join the radiating top plate and ground plate together) and SMA connector. Fig. 7-b shows a picture of the top 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 7. Picture of the fabricated prototype of the capacitive feed PIFA: (a) Antenna parts; (b) assembled antenna top view.
Source: The Authors.

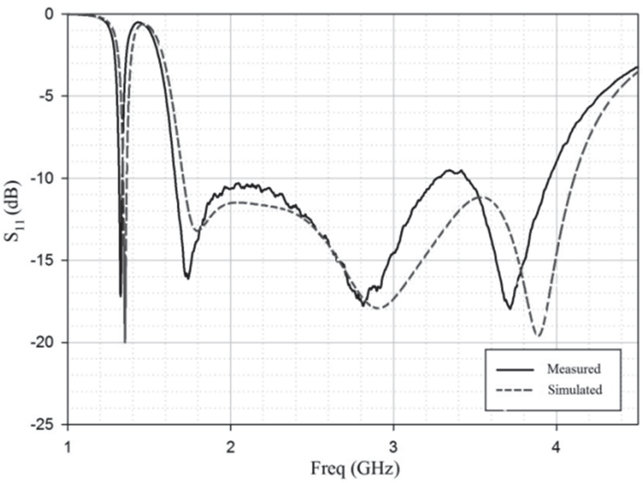


Figure 8. Measured and simulated reflection coefficient for the proposed antenna.
Source: The Authors.

4.1. Return loss

Fig. 8 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, covering approximately from 1.66 GHz to 3.95GHz for S11<-10dB. This represents a relative impedance bandwidth of more than 81.6%. A very narrow band is also present at lower frequencies (around 1.4 GHz), as observed. Thus the antenna satisfies a 10 dB return loss requirement to cover the upper band of LTE (1.71GHz-3.8GHz), Digital Communication System,

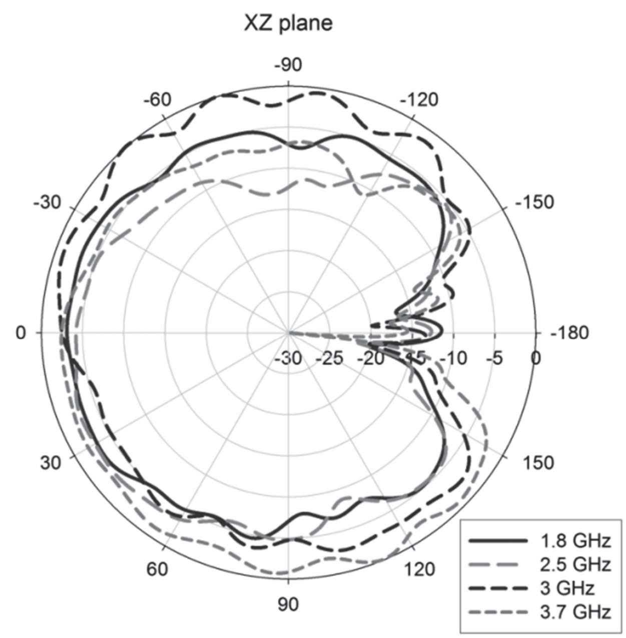


Figure 9. Measured radiation patterns in XZ-plane at 1.8, 2.5, 3.0, and 3.7 GHz.
Source: The Authors.

1710–1880 MHz (DCS1800), 1850–1990 MHz (DCS1900), PCS (1850–1990 MHz), UMTS (1920–2170 MHz), International Mobile Telecommunication, 1885–2200 MHz (IMT2000), 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.

4.2. Radiation pattern and gain

Fig. 9 and Figure 10 illustrate two cuts (XZ-plane and YZ-plane) of the radiation patterns measured at different frequencies within the operating bandwidth (1.8, 2.5, 3.0 and 3.7 GHz).

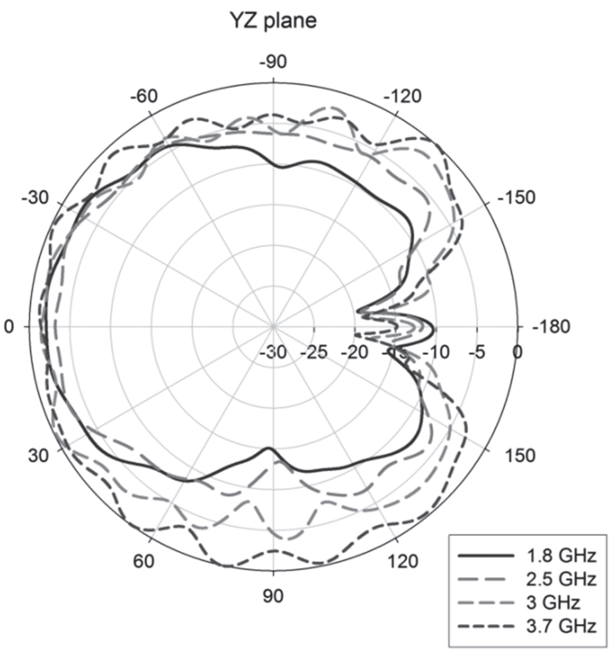


Figure 10. Measured radiation patterns in YZ-plane at 1.8, 2.5, 3.0, and 3.7 GHz.
Source: The Authors.

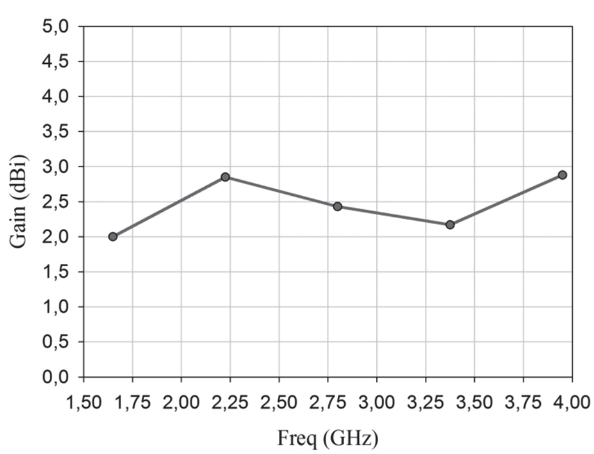


Figure 11. Measured gain vs. frequency.
Source: The Authors.

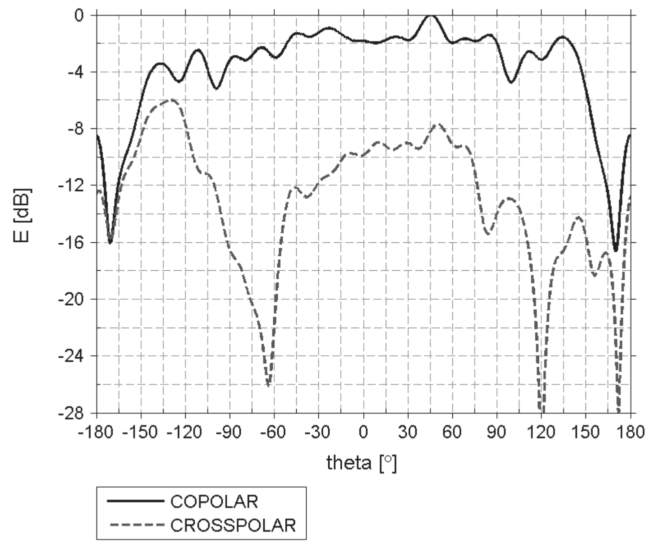


Figure 12. Measured crosspolar and copolar components for the radiated electric Field (E) in the XZ plane at 2.0GHz.
Source: The Authors.

As observed, quite stable omnidirectional radiation behavior is obtained at all operating frequencies, as it is desirable in handset antennas.

Fig. 11 shows the measured gain within the overall bandwidth of the antenna. As observed, the maximum gain of the antenna remains very stable over the entire operating bandwidth (from 2.3dBi to 2.8dBi).

Fig. 12 shows the measured crosspolar and copolar components for the radiated electric Field (E) in the XZ plane at 2.0GHz.

The differences between the simulated results versus measured results for the reflection coefficient (S11) are due to manufacturing errors, especially to the distance between the capacitive feed plate and the ground plate.

5. 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. The measured radiation patterns are in good agreement with conventional PIFA (omnidirectional), as well as improved impedance matching at the input port over a large bandwidth, 2.29GHz (up to 81% for VSWR $\leq$ 2.0, only one resonance).

The proposed U-Shaped capacitive feed PIFA antenna has been simulated, prototyped and tested. It is shown that the numerically simulated results are in close agreement with the experimental prototype results and proved that the antenna operates as proposed.

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. Moreover, gain has a very stable behavior versus frequency.

It finds an impedance bandwidth of 81.6% for VSWR ≤ 2.0 which can cover the Upper band of LTE (1.71GHz-3.8GHz), and: DCS 1800, DCS 1900, UCDMA, UMTS, IMT 2000, DMB, Wi-Fi, 2.4GHz, WiMAX (2.3–2.5 GHz), WiMAX (3.4–3.5 GHz) and Bluetooth applications.

Acknowledgements

The authors gratefully acknowledge professor M. Ferrando from Electromagnetic Radiation Group (ERG) of the Universidad Politécnica de Valencia (Spain) for the sharing of their manufacturing, anechoic chamber, measuring equipment and Electromagnetic software facilities.

References

[1] Feick, R., Carrasco, H., Olmos, M. and Hristov, H., PIFA input bandwidth enhancement by changing feed plate silhouette, Electronic Letters, 40 (15), pp. 921-922, 2004. http://dx.doi.org/10.1049/el:20045276
[2] Wong, K.L., Planar antennas for wireless communications. New York: Wiley Series in Microwave and Optical Engineering, 2003.
[3] Chiu, C.W. and Chi, Y.J., Planar Hexa-Band Inverted-F antenna for portable device applications. IEEE Antennas and Wireless Propagation Letters, 8, pp. 1099-1102, 2009. http://dx.doi.org/10.1109/LAWP.2009.2033623
[4] Du, Y., Zhao, A., Salo, A. and Saunamaki, J., Bandwidth potential analysis of GSM antennas based on oval-shaped mobile terminals, Proceedings of 2010 International Conference on Microwave and Millimeter Wave Technology (ICMMT), pp. 4-7, 2010. http://dx.doi.org/10.1109/ICMMT.2010.5525305
[5] Chattha, H., Huang, T. and Yang, L., PIFA bandwidth enhancement by changing the widths of feed and shorting plates, IEEE Antennas and Wireless Propagation Letters, 8, pp. 637-640, 2009. http://dx.doi.org/10.1109/LAWP.2009.2023251
[6] Chan, P.W., Wong, H. and Yung, E.K.N., Wideband planar inverted-F antenna with meandering shorting strip. Electronics Letters, 44 (6), pp. 395-396, 2008. http://dx.doi.org/10.1049/el: 20083688
[7] Wu, C.H. and Wong, K.L., Ultrawideband PIFA with a capacitive feed for penta-band folder-type mobile phone antenna. IEEE Transactions on Antennas and Propagation, 57 (8), pp. 2461-2464, 2009. http://dx.doi.org/10.1109/TAP.2009.2024571
[8] Suárez, C., Gómez, J., and Ferrando, M., Broadband PIFA with capacitive feed, Proceedings of IEEE International Symposium on Antennas and Propagation Society, APSURSI '09, pp. 1-4, 2009. http://dx.doi.org/10.1109/APS.2009.5171974
[9] Suárez, C., Rodríguez, R. and Ferrando, M., Broadband planar antenna with improved pattern bandwidth. Revista Facultad de Ingeniería Universidad de Antioquia, 65, pp. 74-84, 2012.
[10] Anguera, J., Sanz, I., Mumbru, J. and Puente, C., Multiband handset antenna with a parallel excitation of PIFA and slot radiators. IEEE Trans. on Antennas and Propagation, 58 (2), pp.348-356, 2010. http://dx.doi.org/10.1109/TAP.2009.2038183
[11] Elfergani, I., Hussaini A.S., Rodríguez, J., See, C.H. and Alhameed, R., Wideband tunable PIFA antenna with loaded slot structure for mobile handset and LTE applications. Radioengineering, 23 (1), pp 345-355, 2014.
[12] Zhou W. and Arslan T., Planar monopole antenna with archimedean spiral slot for Wifi/Bluetooth and LTE applications, Proceedings of 2013 Loughborough Antennas & Propagation Conference, pp 186-189, 2013. http://dx.doi.org/10.1109/LAPC.2013.6711879
[13] Bezawada V.N., Shambavi K. and Alex Z.C., Design of reconfigurable antenna for LTE and WLAN applications. Proceedings of 2013 International Conference on Communications and Signal Processing (ICCSP), pp 51-54, 2013. http://dx.doi.org/10.1109/iccsp.2013.6577013
[14] Cihangir A., Sonnerat F., Ferrero F., Luxey, C., Pilard R., Gianesello F. and Jacquemod G., Design of traditional and a novel space-efficient antenna-coupling elements for lower LTE/GSM mobile phones. Proceedings of 2012 Loughborough Antennas & Propagation Conference, pp 1-4, 2012. http://dx.doi.org/10.1109/LAPC.2012.6402954

C.A. Suárez-Fajardo, received the MSc. and PhD. in Electrical Engineering from the Universitat Politècnica de València, Valencia, Spain, in 2003 and 2006, respectively. In 2006, he joined the LIMER Group, Universidad Distrital Francisco José de Caldas, Bogotá and in 2007 he became as an associate professor at the Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. His research interests include wideband and multi-band planar antenna design and optimization, microwave engineering, applied electromagnetic and small satellite communication systems.

R. Rodríguez-León, was born in 1985. Since 2010, he has been with SEQUOIA SPACE as a development engineer. He is currently a MSc. student in Space Engineering at Kyushu Institute of Technology, Japan. His research interests include satellite subsystems, Spacecraft Environment Interaction Engineering and digital applications.

E. Antonino-Daviú, was born in Valencia, Spain, on July 10, 1978. She received the MSc. and PhD. degrees in Electrical Engineering from the Universitat Politècnica de València, Valencia, Spain, in 2002 and 2008, respectively. In 2002, she joined the Electromagnetic Radiation Group, Universitat Politècnica de València, and in 2005 she became a Lecturer at the Escuela Politécnica Superior de Gandia, Gandia, Spain. During 2005 she stayed for several months as a guest researcher at the Department of Antennas & EM Modelling of IMST GmbH, in Kamp-Lintfort, Germany. Her current research interests include wideband and multi-band planar antenna design and optimization and computational methods for printed structures. Dr. Antonino-Daviu was awarded the "Premio Extraordinario de Tesis Doctoral" (Best PhD. thesis) from the Universitat Politècnica de València in 2008.