Design of Folded Planar Inverted-F Antennas with Stair-Shaped Radiator for LTE700

Muhammad Feroze Akbar J. Khan, Ahmad Rashidy Razali, Aslina Abu Bakar, Mohamad Amir Imran b. Mohd Hasli and Mohd Aminnudin Murad

Abstract A miniaturized Planar Inverted Antenna F-Antenna for LTE700M service band is presented. The main radiator of PIFA antenna is been folded into three radiating arm which provide optimized dimensions. Then, stair-shaped geometry have been used in order enhance impedance bandwidth for both lower band and higher band. Finally, the size of the finite ground is gradually reduced to achieve optimum size reductions. In the experimental results, the antenna achieves lower band impedance bandwidth between 725 MHz and 1.18 GHz at 6 dB return loss. At upper band, the antenna covers bandwidth between 2.33 and 3.82 GHz at 10 dB return loss. The final antenna #2 achieved reduction in overall dimension by 46.6 % in length, 33.7 % in width, and 5.19 % in height as compared to its reference antenna. Hence, this miniaturized size of proposed PIFA antenna is a promising candidate for several wireless services such as LTE700, GSM850/900, WLAN2.45G and WiMAX3.5G.

Keywords LTE · PIFA antenna · Miniaturizations · Folded and stairs shape radiator

1 Introduction

The challenges for modern portable devices are getting higher as most of devices are going for compact and slimmer design. Most of cellular communication system are using microstrip and printed antenna that is flat in nature of appearance. Planar Inverted-F antenna (PIFA) is widely used due to its flat nature and PIFA capable to

M.F. Akbar J. Khan (✉) · A.R. Razali · A.A. Bakar · M.A.I.b.M. Hasli · M.A. Murad
Antenna and Microwave Research Group, Universiti Teknologi MARA, 13500 Permatang Pauh, Penang, Malaysia
e-mail: feroze.aman@gmail.com

M.F. Akbar J. Khan
Motorola Solution Malaysia Sdn Bhd, 11900 Bayan Lepas, Penang, Malaysia

H.A. Sulaiman et al. (eds.), *Advanced Computer and Communication Engineering Technology*, Lecture Notes in Electrical Engineering 362,
DOI 10.1007/978-3-319-24584-3_84

cover several wireless communications services such as WiMax, WLAN, Long Term Evolutions (LTE), Bluetooth and many more [1–5].

PIFA has been introduced in 1987 by Taga for GSM Band Applications [6, 7]. PIFA was known for its inverted F-shape antenna with a shorting arm to its ground plane [2, 3, 8]. PIFA is an improvement from monopole antenna where the top radiating arm is been folded to reduce its size which forms F-shape [8]. In late 2009, authors in [9] has proposed Coplanar Inverted-F Antenna (CIFA), where the radiator and the ground plane are on the same planar substrate [9, 10, 5]. Figure 1 shows fundamental antenna of PIFA design. In this antenna, the folded radiator creates capacitive loading with the ground edge. Thus, an inductive shorting pin to ground is introduced to compensate the imbalance reactance.

On the other hand, compared to monopole, rod and helix antenna, PIFA has an advantage of easy integration with most of handheld devices [2]. However, compact PIFA antenna that covers lower WWAN band such as LTE700M are difficult to design due to its large radiator and ground size. As the resonant frequency goes lower, the overall antenna dimension becomes larger [8], and it will be difficult to integrate it into portable devices such as smart phones.

The limitation in PIFA is due to its narrow bandwidth achievement at lower band [1–4, 6, 8] and its overall dimensions. In literatures, several techniques have been studied in order to enhance the impedance bandwidth; one of the technique that are used is ground slot near the main radiator in order to improve the operating bandwidth [1–4, 9–13]. Other bandwidth enhancement techniques such as addition of stairs near the main radiator have been explained in [14–16]. Addition of stair creates longer electrical current path, hence creates better impedance bandwidth. Furthermore, fractal and spiral radiator techniques have also been used to achieve compact and multiband features as reported in [9, 17].

In this paper, two antennas of new PIFA designs that mainly design for LTE700M with additional capabilities to support others wireless services such as GSM900, WLAN2.5G and WiMAX3.5G are proposed. The antenna introduces a stair-shaped PIFA radiator design to increase the bandwidth. The antenna provides dual band operations with nearly omnidirectional radiation characteristics and good impedance matching.

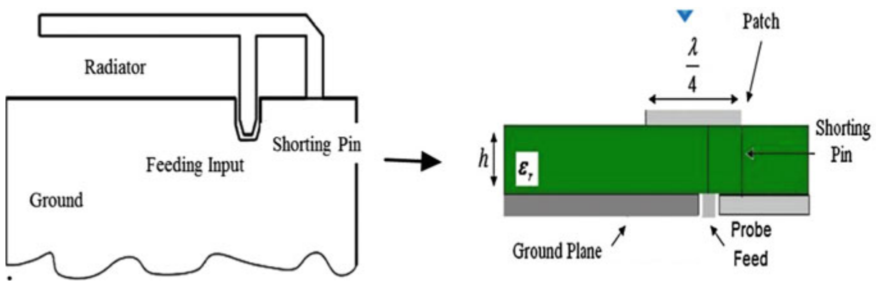

Fig. 1 PIFA configuration. Basic design (*left*) and antenna cross-section (*right*)

2 LTE700M PIFA Antenna Designs

PIFA is created at quarter wavelength of the lowest desired frequency, in this case, 690 MHz. The radiator is folded into three stages in order to reduce its size, which named as Arm1, Arm2 and Arm3. Figure 2 shows the initial design of PIFA. Folding main radiator into several arms creates capacitive loading which shift the resonant frequency. A shorting arm is introduced to compensate the capacitive loading that is created after folding the main radiator parallel to the ground at the bottom layer. The antenna is created on an FR4 with dielectric constant ε = 4.3 and thickness = 1.6 mm. The antenna design was modeled using CST Microwave Studio. Following subsection are the details of proposed PIFA designs.

2.1 *Antenna #1: LTE700M PIFA Antenna*

In this antenna, there are two approaches used that are the width arm increment and addition of stairs at radiator in order to enhance the bandwidth for LTE700M. Figure 3 shows the front and back view of PIFA antenna structure. This overall antenna dimension (*l x w x h)* is 125 × 60 × 1.634 mm, where the copper thickness is 0.017 mm and substrate thickness is 1.6 mm. At bottom layer, the finite ground size is 93 × 60 mm. Meanwhile, at the top layer, there are two stairs added at the radiator. The stair 1 dimension is 16 × 9 mm, and stair 2 dimension is 14 × 10 mm.

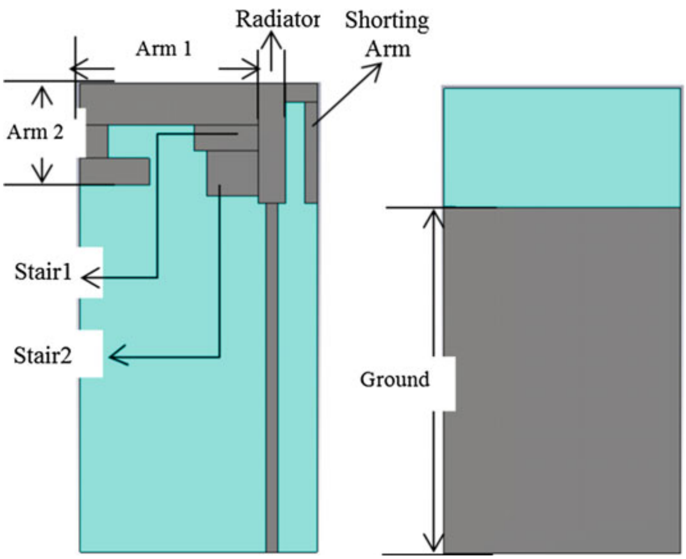

Fig. 2 Proposed LTE antenna design descriptions

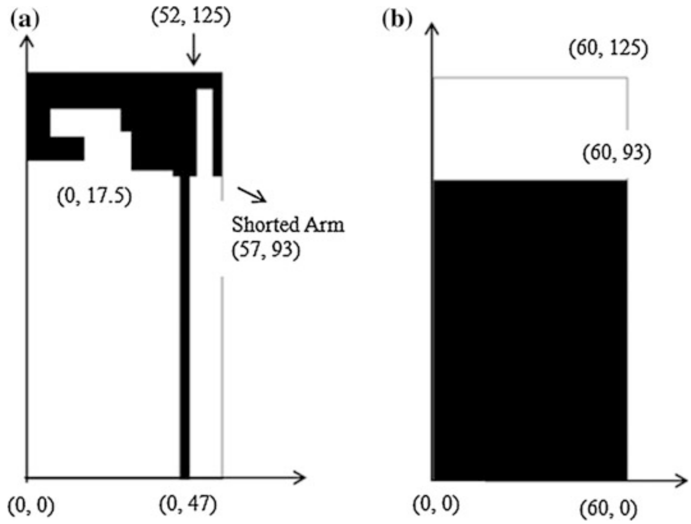

Fig. 3 Antenna #1 design geometry. **a** Front view. **b** Back view

The PIFA is fed by 50 Ω microstrip feedline that is positioned at (0, 47) and width of 3 mm. The shorting arm was located at (57, 93) and width of 3 mm.

2.2 Antenna #2: Miniaturized of LTE700M PIFA Antenna

Based from antennas #1, the size of the antenna finite ground plane is miniaturized in order to have compact design. In the miniaturization, the length of the ground is reduced from 125 to 115 mm, a 10 mm length reduction. Due to this reduction, the antenna stair-shaped geometry is re-optimized to achieve the original LTE700M band resonance. After miniaturization, the overall antenna (l × w × h) is 115 × 60 × 1.634 mm and stair 1 and stair 2 dimension is 22 × 6 mm and 15 × 13 mm respectively (Fig. 4).

3 Simulation and Fabrication Results

3.1 Results of Antenna #1

With the introduction of stair-shaped geometry at the radiator, there is a significant frequency shifting and bandwidth enhancement that can be observed in Fig. 5a

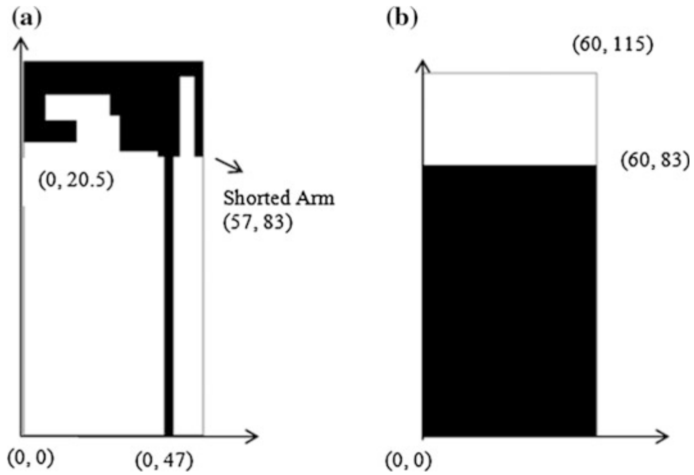

Fig. 4 Antenna #2 design geometry. **a** Front view. **b** Back view

compared to the antenna without the stair-shaped geometry. As simulated data shows the bandwidth achieves at −6 dB is from 0.68 to 0.96 GHz, which met the LTE700M requirements.

Figure 5b shows both the simulated and measured results for the input reflection coefficient of antenna #1. Good correlation has been observed between measured and simulated results.

The measured results show that minor shift in the lower band LTE700M which may probably due to fabrication error. The measured results of antenna #1 at −6 dB return loss is covers from 725 up to 980 MHz, and at −10 dB return loss it cover from 2.6 up to 4.2 GHz.

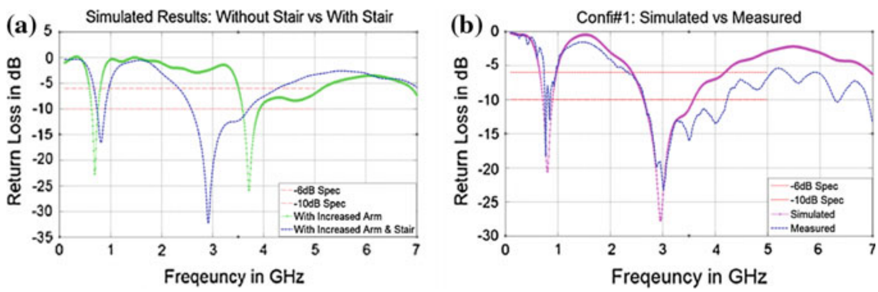

Fig. 5 Antenna #1 results. **a** Simulated results with and without stairs. **b** Simulated versus measured data

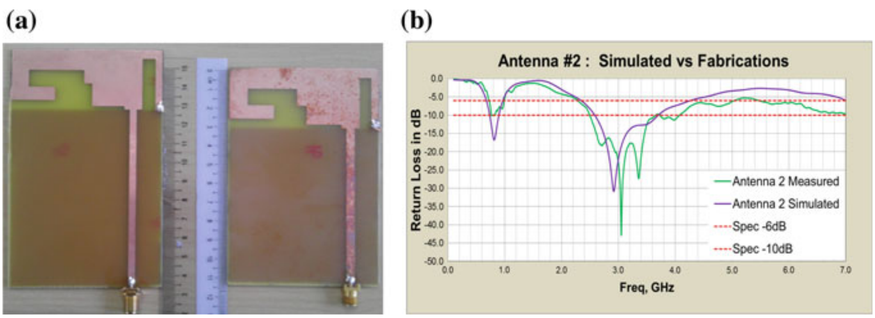

Fig. 6 Antenna #2 results and antenna design. **a** Antenna #1 and #2 design geometry. **b** Simulated versus measured data

3.2 Results of Antenna #2

This antenna is the improvement of antenna #1, whereby the total length was reduced by 10 mm. Figure 6a shows the geometry difference observed between antenna #1 and antenna #2.

Figure 6b shows both the simulated and measured results for the input reflection coefficient of antenna #2. The measured results show that minor shift in the lower band LTE700M. The measured results of antenna #2 at −6 dB return loss is covers from 720 up to 980 MHz, and at −10 dB return loss it cover from 2.38 up to 4.1 GHz.

4 Analysis and Discussion

The folded mechanism is basically for the purpose of miniaturization process where it help to reduce antenna overall dimension. The shorting pin plays an important role to achieve zero reactance at the desired resonance frequency. Figure 7a shows

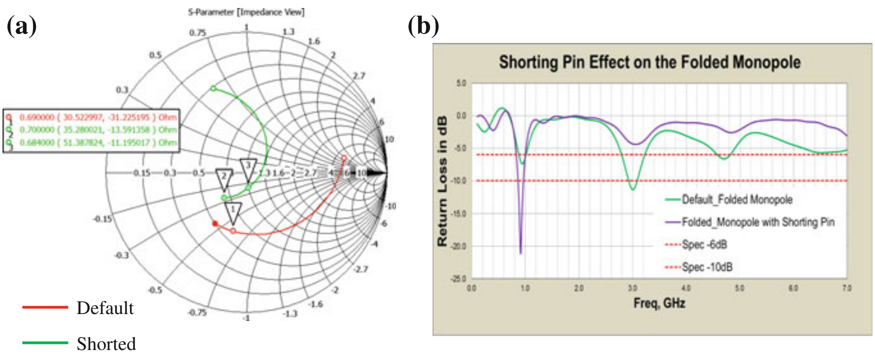

Fig. 7 Shorting pin effect analysis. **a** Smith chart characteristic. **b** Shorting pin effect in term of S11 response

the Smith Chart characteristic where default impedance point is located at −ve reactance (capacitive). As mentioned by author in [9, 10], by adding shorting pin to the ground, it help to improve reactive excitation thus the overall impedance point near zero. Figure 7b shows the S11 parameter response of shorting pin effect.

By having the shorting pin, PIFA achieve better impedance matching. The introduction of stairs act as series capacitance which helps broaden the bandwidth from 690 to more than 960 MHz. Figure 8 shows the effect of addition of stairs in term of Smith Charts.

The simulated surface current distribution also been studied for PIFA antenna #2 for three frequency band which are f_1 = 700 MHz, f_2 = 800 MHz and f_3 = 2400 MHz. As shown in Fig. 9a–c, the excited surface currents flowing near the stairs have maximum strength and begin to decreases slowly before turn to max peak again at Arm3. The longer path taken by this surface current creates better impedance matching at particular frequencies.

Figure 10 shows the simulated VSWR characteristic of both antennas. Typical antenna design required VSWR characteristic of less than 3:1, whereby lower VSWR indicates better reflection coefficient, hence better impedance matching.

In term of excitation position, antenna #1 center resonant frequency occurs at 764 MHz and 3.01 GHz, while antenna #2 center resonant frequencies occurs at 834 MHz and 3.03 GHz. Table 1 shows the design summary of both PIFA antennas.

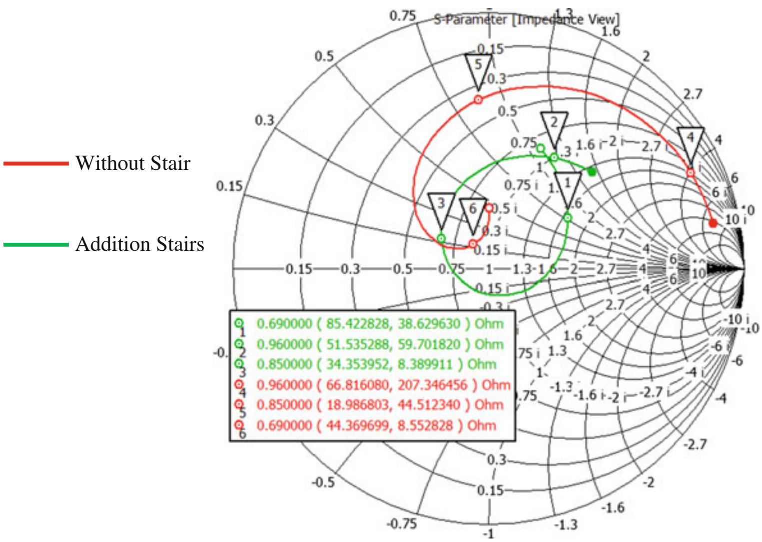

Fig. 8 Addition of stair effect based on Smith chart

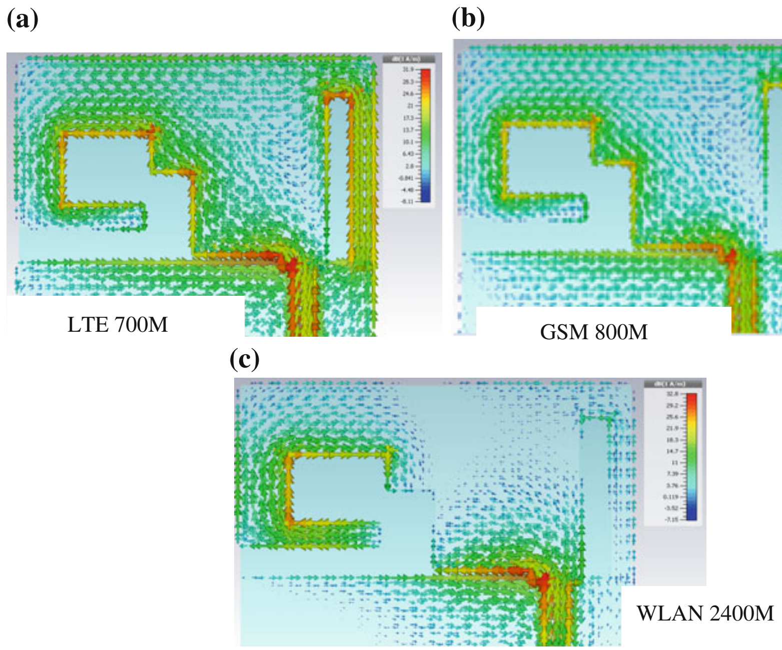

Fig. 9 Simulated surface current distribution on PIFA Antenna #2. **a** f = 700 MHz. **b** f = 800 MHz. **c** f = 2400 MHz

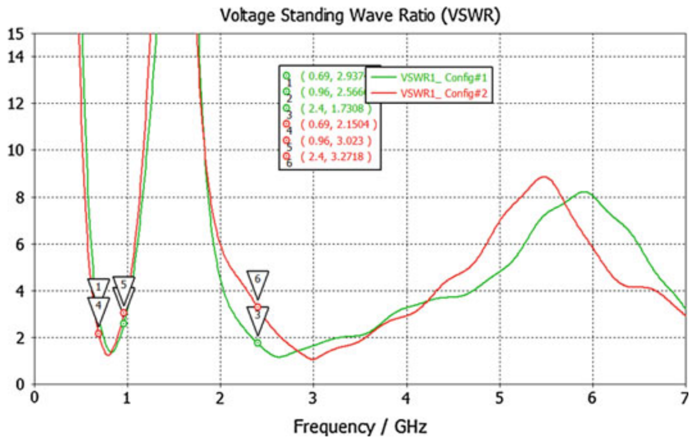

Fig. 10 Simulated VSWR characteristics for proposed antennas

Table 1 Summary of fabricated results

Type of antenna	Antenna #1		Antenna #2		Units
	Simulated	Measured	Simulated	Measured	
Bandwidth for LTE700M	0.65–0.96	0.715–0.97	0.689–0.96	0.725–1.18	GHz
Bandwidth for higher resonance	2.66–3.54	2.672–4.23	2.34–3.30	2.33–3.82	GHz
Dimension (*w x l x h*)	60 × 125 × 1.634		60 × 115 × 1.634		mm
Applications	LTE700, GSM8/900 and WLAN		LTE700, GSM8/900, LTE2600M, Bluetooth, WLAN, WiMAX		

4.1 Radiation Pattern: Antenna #1

The simulated radiation pattern of the antenna is shown in Figs. 11 and 12. The patterns are nearly omnidirectional which is suitable for wireless portable devices.

4.2 Radiation Pattern: Antenna #2

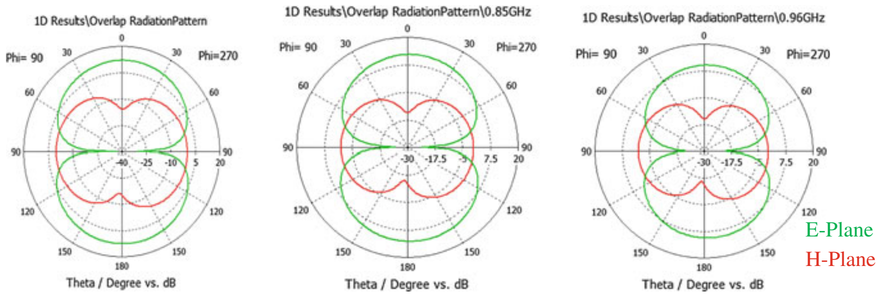

Fig. 11 Simulated 2D radiation pattern for 700, 850 and 960 MHz in antenna #1

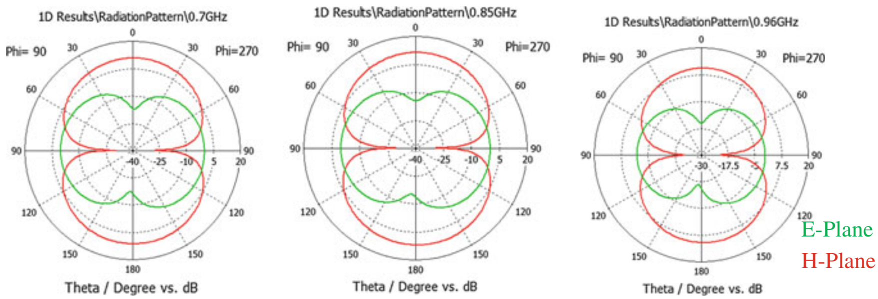

Fig. 12 Simulated 2D radiation pattern for 700, 850 and 960 MHz in antenna #2

5 Conclusions

In this paper, two new PIFA that operates at LTE700M have been presented. PIFA Antenna #1 operates at 0.715 up to 0.96 GHz at 6 dB return loss reference and at 2.672 up to 4.23 GHz at 10 dB return loss. Meanwhile, PIFA Antenna #2 operates at 0.72–1.18 GHz at 6 dB return loss and also operates 2.32–3.82 GHz at −10 dB return loss reference. The overall Antenna #2 size has achieved reduction in volume by 46.6 % in length, 33.7 % in width, and 5.45 % in height when compared to its reference antenna [18]. Therefore, with its compact size and easy integration with modern handheld devices, the antenna is a promising candidate for several wireless services such as LTE700, GSM850/900, WLAN2.45G and WiMAX3.5G.

Acknowledgement The authors would like to acknowledge the Ministry of Science and Technology (MOSTI), Malaysia through EScience Research Grant Project No. 04-01-01-SF0620 that supports this work.

References

1. Wang, H., Zheng, M.: A multi-band internal antenna. In: Loughborough Antennas and Propagation Conference, UK, (2011)
2. Kwak, W.I., Park, S.O., Kim, J.S.: A folded planar inverted-F antenna for GSM/DCS/Bluetooth triple-band application. IEEE Antennas Wirel. Propag. Lett. **5**(1), 18–21 (2006)
3. Lee, C.T., Wong, K.L.: Uniplanar printed coupled-fed PIFA with a band-notching slit for WLAN/WiMAX operation in the laptop computer. IEEE Trans. Antennas Propag. **57**(4), 1252–1258 (2009)
4. Gomez-Villanueva, R., Jardon-Aguilar, H., Linares-y-Miranda, R.: Broadband PIFA antenna for mobile communications terminals. In: IEEE, Campeche, pp. 1–6, 29 Sept 2014–3 Oct 2014
5. Bialkowski, M.E., Razali, A.R., Boldaji, A.: A folded quarter-elliptical wideband antenna for portable devices. In: IEEE, Toronto, ON, pp. 1–4, 11–17 July 2010
6. Taga, T., Tsunekawa, K.: Performance analysis of a built-in planar inverted F antenna. IEEE J. Selected Areas Commun. **5**(5), 921–929 (1987)
7. Taga, T., Tsunekawa, K.: A built-in diversity antenna for 800 MHz band portable radio units. In: Antennas and Propagation Society International Symposium, 1986, vol. 24, pp. 705–708, Philadelphia, PA (1986)
8. Ray, J.A., Chaudhuri, S.R.B.: A review of PIFA technology. In: Indian Conference on IEEE Antenna Week (IAW) 2011, Kolkata, pp. 1–4, Dec 2011
9. Razali, A.R., Bialkowski, M.E.: Coplanar inverted-F antenna with open-end ground slots for multiband operation. IEEE Antennas Wirel. Prop. Lett., **9**, 1029–1032 (2009)
10. Razali, A.R., Bialkowski, M.E.: Design of a dual-band Microstrip-Fed Meandered-tail PIFA for WLAN Applications. In: Antennas and Propagation Society International Symposium, 2009. APSURSI'09. IEEE, Charleston, pp. 1–4, 1–5 Jun 2009
11. Alja'afreh, S.S., Huang, Y., Xing, L.: A compact, wideband and low profile planar inverted-L antenna. In: 8th European Conference on Antennas and Propagation (EuCAP), 2014, The Hague, pp. 3283–3286, 6–11 Apr 2014
12. Chen, Z., Ban, Y.-L., Chen, J.-H., Li, J.L.-W., Wu, Y.-J.: Bandwidth enhancement of LTE/WWAN printed mobile phone antenna using slotted ground structure. Prog. Electromagnet. Res. **129**, 469–483 (2012)

13. Razali, A.R., Bialkowski, M.E., Boldaji, A., Tsai, F.-C.E.: Invention on a mulitband microstrip-fed inverted-F antenna with ground slot. Microw. Opt. Technol. Lett. **58**(8), 1713–1719 (2010)
14. Sobli, N.H.M., Abd-El-Raouf, H.E.: Design of a compact band-notched antenna for ultrawideband communication. In: Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE, San Diego, pp. 1–4, 5–11 July 2008
15. Islam, M.R., Alam, A.Z., Khan, M.F.A.J., Alkaraki, S..: Design of microstrip patch antenna using slotted partial ground and addition of stairs and stubs for UWB application. Cyber J. Multidisciplinary J. Sci. Technol., JSAT (2012)
16. Raj, R.K., Gurhar, S., Sharma, M.: Design of stair and slotted UWB antenna using stepped-feed with modified slotted ground plane. Int. J. Comput. Appl.® (IJCA) (0975–8887), 22–25 (2014)
17. Nie, Y., Song, L.: A compact triband fractal PIFA antenna for mobile handset applications. In: 6th International Congress on Image and Signal Processing (CISP) 2013, vol. 03, pp. 1468–1472, Hangzhou, 16–18 Dec 2013
18. Loutridis, A., John, M., Ammann, M.: Dual band LTE planar inverted-F antenna for M2M applications. Microw. Opt. Technol. Lett. **55**(12), 2925–2929 (2013)