IETE Journal of Research

ISSN: 0377-2063 (Print) 0974-780X (Online) Journal homepage: http://www.tandfonline.com/loi/tijr20

# Low SAR PIFA Antenna for Wideband Applications

**Mohammad Naser-Moghadasi, Zahra Mansouri, Sachin Sharma, Ferdows B. Zarrabi & Bal S. Virdee**

IETE JOURNAL OF RESEARCH, 2016
http://dx.doi.org/10.1080/03772063.2015.1135300

# Low SAR PIFA Antenna for Wideband Applications

Mohammad Naser-Moghadasi[a], Zahra Mansouri[a], Sachin Sharma[b], Ferdows B. Zarrabi[a] and Bal S. Virdee[c]

[a]Faculty of Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran; [b]Faculty of Electrical and Information Technology, Technical University of Chemnitz, Chemnitz, Germany; [c]Faculty of Life Sciences and Computing, Center for Communications Technology, London Metropolitan University, London, UK

**ABSTRACT**

In this article, a novel low specific absorption rate (SAR) printed planar invert-F antenna (PIFA) antenna for wideband application is presented. The prototype antenna was designed to cover the frequency range between 1200 and 3000 MHz. Its radiation pattern is approximately omnidirectional, VSWR $<$ 2, gain in the range 2–4.6 dBi, and efficiency greater than 78%. The prototype antenna exhibits a low SAR of around 1.04 for 1 g at 1800 MHz, which is less than 51% than a conventional PIFA antenna. The antenna's performance was evaluated using finite element method (FEM) and time domain method (TDM) in electromagnetic (EM) simulation tools like HFSS and CST Microwave Studio. These results are compared with measured data. The antenna's wide band covers various wireless standards like GPS/DCS/GSM1800/PCS/WLAN/Bluetooth/WiMAX/LTE. The parametric studies clarified the effect of the stub line and via's on voltage standing wave ratio (VSWR).

**KEYWORDS**
Cell phone; Head tissue; PIFA; SAR; Wide band



## 1. INTRODUCTION

Extensive research is presently being carried out to develop compact antennas for multiband wireless systems like smart phones [1]. Nowadays the wireless communications market has expanded to include smart phones, Wi-Fi, tablets, and Global Position System (GPS) receivers [2–4]. Originally mobile handsets employed monopole antennas that had omnidirectional radiation patterns with horizontal polarisation. Such linear polarisation antennas can cause severe limitations for practical applications. Hence, these antennas were replaced with the next generation of helical antennas that offered wide bandwidth and circular polarisation. As the efficiency of the antennas is an important factor, especially for cell phone applications, this necessitates the length of the helical antenna to be approximately one-quarter wavelength [1–4].

Nowadays, the planar inverted-F antenna has become one of the most common types of antenna in use in headsets. Different types of these antennas have been presented by Kin Lu Wong et al. for wireless and cell phone applications [5,6]. PIFA antennas are attractive because of their economical benefits as well as for the following features: multiband operation, high efficiency, low profile, lightweight, approximate omnidirectional radiation characteristics, circular polarisation or diversity of polarisation, and low specific absorption rate (SAR) [7,8]. Many techniques have been reported to design multiband PIFA antennas including shorted patch, stacked shorted patch, shorted patch antenna with L-probe feed, shorted U-slot patch, and folded shorted patch. To improve its impedance match, a shorting pin and wall are commonly added to such antennas [1–6]. PIFA can be directly printed on the top of a non-ground portion of the system circuit board to enable easy integration with the system. Printed antennas with length of $\lambda_g/4$ have been implemented using coupling techniques, microstrip loops, or spiral structures with via connections to achieve higher quality and multiband designs [9–12].

Electromagnetic fields radiated by cell phones at microwave frequencies penetrate the user's head. This results in the absorption of the EM-field by the user's head and body tissues. Therefore, it is important to consider the SAR parameter in the design of such products. SAR quantifies the absorption ratio of electromagnetic by human body tissue. Reducing SAR is an active area of research [13,14], and it can be calculated using

$$\mathrm{SAR} = \frac{\sigma.E_{\max}^2}{2.\rho} = \frac{J_{\max}^2}{2.\rho.\sigma} \quad (1)$$

where $E_{\max}$ is the maximum value of the electric field (V/m), $\sigma$ is the electric conductivity (S/m), and $\rho$ is the mass density (kg/m$^{-3}$) of the tissue. Experimental data shows that during exposure to radiation from a smart phone, a variety of biological effects occur that do not cause any local increase in temperature. Differences between electroencephalography (EEG), with and without the use of the device, have been observed [15]. The interesting property of PIFA is that it reduces the backward radiation towards the user's head, thus minimising the EM wave power absorption. The desired SAR value for handset applications is about 1.5 kg/m$^{-3}$ at 1800 MHz [16,17]. This paper presents a printed PIFA for wideband applications that exhibit a substantially lower SAR than a conventional PIFA design. Its radiation pattern is approximately omnidirectional, VSWR $< 2$, gain in the range 2−4.6 dBi, and efficiency greater than 78%. The antenna's wide band covers various wireless standards like GPS/DCS/GSM1800/PCS/WLAN/Bluetooth/WiMAX/LTE.

## 2. ANTENNA DESIGN

The top and bottom layout of the proposed PIFA antenna is shown in Figure 1(a), where the elements on both sides of the common substrate are connected through two vias. The proposed technique effectively increases the antenna's length. As the surface current is distributed on the two sides of the substrate, the antenna radiates energy on both sides of the dielectric substrate. The important consideration that needs to be taken in the design of this type of implementation is to minimise the mutual coupling between the two radiators and hence increase its bandwidth. The antenna was fabricated on a low cost FR4 substrate with dielectric constant of $\varepsilon = 4.4$, loss tangent of $\tan\delta = 0.02$, and height is $h =$ 1.6 mm. The prototype was fed through a 50 Ω SMA. The antenna's dimensions are 100 mm × 60 mm. This size of antenna is suitable for application in smart phone handsets and tablets. The two radiating patches are connected to each other through two vias of 0.5 mm diameter. In addition to obtaining good omnidirectional pattern and a complete distribution current for SAR reduction, we have implemented two vias to make a loop structure. The $\lambda_g/2$ for 1200 MHz with FR-4 substrate is around 59 mm and in this antenna, the distance between feed points to first via is assumed around 55 mm and the distance between two stubs are 65 mm which is near to $\lambda_g$ at the central frequency. So without effect on matching, we are conducting the current to bottom layer and furthermore, with tuning the stubs and meandered line we are achieving wide bandwidth for our demand.

**Table 1:** The antenna parameters

| Parameter | mm |
|---|---|
| a | 100 |
| b | 60 |
| c | 70 |
| d | 22 |
| e | 6 |
| f | 38 |
| g | 26 |
| h | 21 |
| i | 8 |
| j | 48 |

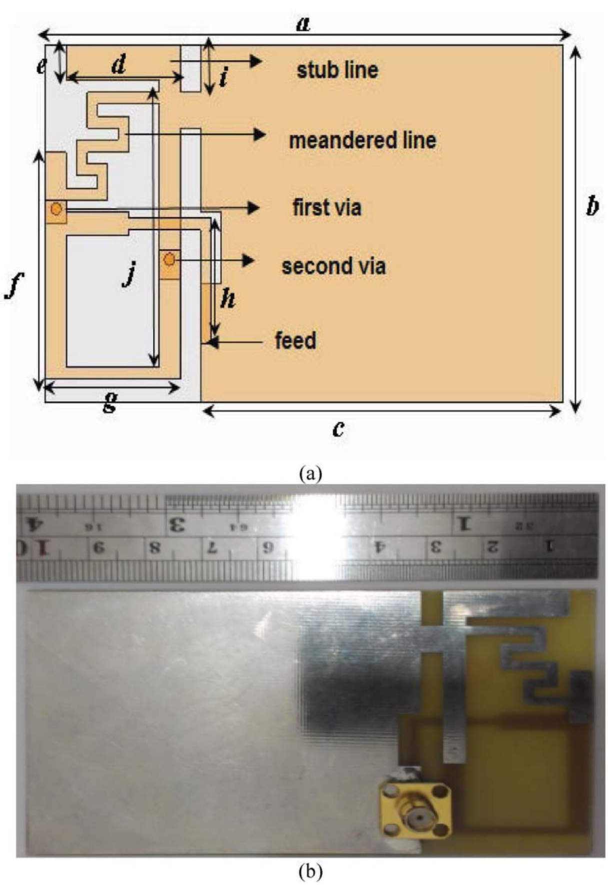


**Figure 1:** (a) Top and bottom layout of proposed antenna, (b) fabricated antenna.

The SMA connector is connected to the top radiating patch. The bottom patch is connected to the ground through a microstrip line. The fabricated PIFA antenna is shown in Figure 1(b). Table 1 shows the antenna's dimensions.

## 3. SIMULATION AND MEASURED RESULTS

HFSS and CST Microwave Studio were chosen for the accuracy of their three-dimensional (3D) simulations. In the simulation, an analogue of a human head and its thermal distribution model was used, where the head $\varepsilon = 48$ at 835 MHz and $\varepsilon = 41$ at 1900 MHz [18]. A comparison of the antenna's VSWR using HFSS and CST Microwave Studio is shown in Figure 2. The correlation between the two simulation tools is remarkable for

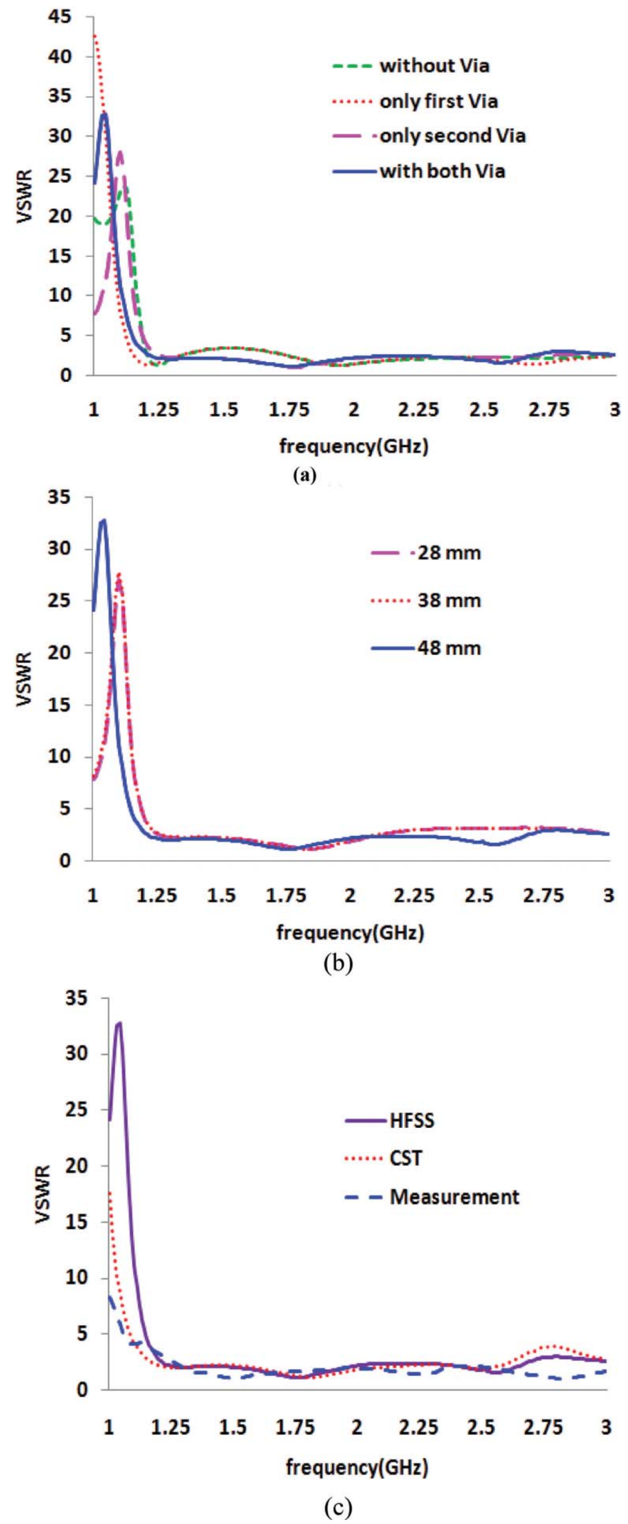


**Figure 2:** VSWR of the proposed PIFA antenna, (a) the via effect study, (b) the stub line effect, (c) simulated and experimental antenna.

frequencies greater than 1.25 GHz. The results show the antenna's operation extends from 1200 to 3000 MHz for VSWR less than 2. HP8722ES was used to measure the prototype antenna's VSWR, shown in Figure 2(c). These results confirm the antenna operates across 1200−3000 MHz for VSWR less than 2. The antenna's bandwidth covers the following wireless communication standards: GPS, DCS, GSM 1800, PCS, WLAN 2.4, Bluetooth, and WiMAX. The effect of via on VSWR is presented in Figure 2(a) and as shown in here, the vias are helpful for control of the VSWR and matching. The first via is used for antenna matching at lower frequency, but some mismatching is visible at 1.25−1.75 GHz and it is corrected by a second via in this structure. The effect of the Stub line on VSWR is presented in Figure 2(b) and shows here the stub size reduction is effected on antenna matching at a lower frequency and at 2.25−2.75 GHz.

The simulated 3D radiation pattern of the antenna at 1800 MHz, shown in Figure 3(a), verifies it radiates approximately omnidirectionally with sufficient gain performance. The gain is 4.45 dBi at 1800 MHz. The measured E-plane and H-plane patterns at 1800 MHz, shown in Figure 3(b) and 3(c), confirm the antenna's co-polarisation and cross-polarisation radiation characteristics.

CST Microwave Studio was used to calculate the antenna's SAR. The proposed antenna's SAR was compared with a conventional PIFA antenna at the same position as shown in Figure 4. For the conventional PIFA antenna the current is limited to radiator, therefore the conventional PIFA has more current density and SAR is concentrated at limited area around the user's head at 1800 MHz is shown in Figure 4(a). The SAR rate is about 2.17 W/kg at 1800 MHz for 1 g. Figure 4(b) shows proposed PIFA antenna and its SAR distribution around the users head at 1800 MHz and the SAR is reduced to about 1.04 W/kg at 1800 MHz for 1 g, which constitutes a decrease of SAR by more than 51% compared to the conventional PIFA antenna. For 10 g, the SAR is reduced to 0.63 W/kg at top position.

The current distribution over the prototype antenna at three different frequencies is shown in Figure 5. The current distribution indicates elements of the antenna structure that enhance its bandwidth and reduce its SAR compared to a conventional PIFA. These results show that the current distribution at 1.5 GHz is concentrated over the feed-line in the meandered line, and the line top and bottom lines on the connected by the both vias and most part of current on bottom layer is directed by first via. At 2 GHz, the current distribution intensity is mainly over the feed-line, the edges of the stub line, and at the top and bottom lines connected with the second via, and edges of the line connecting the ground-plane. The current intensity at 2.5 GHz is over a portion of the feed-line, over the meandered line next to the stub line, at the top and bottom lines near the first via, and edges of the

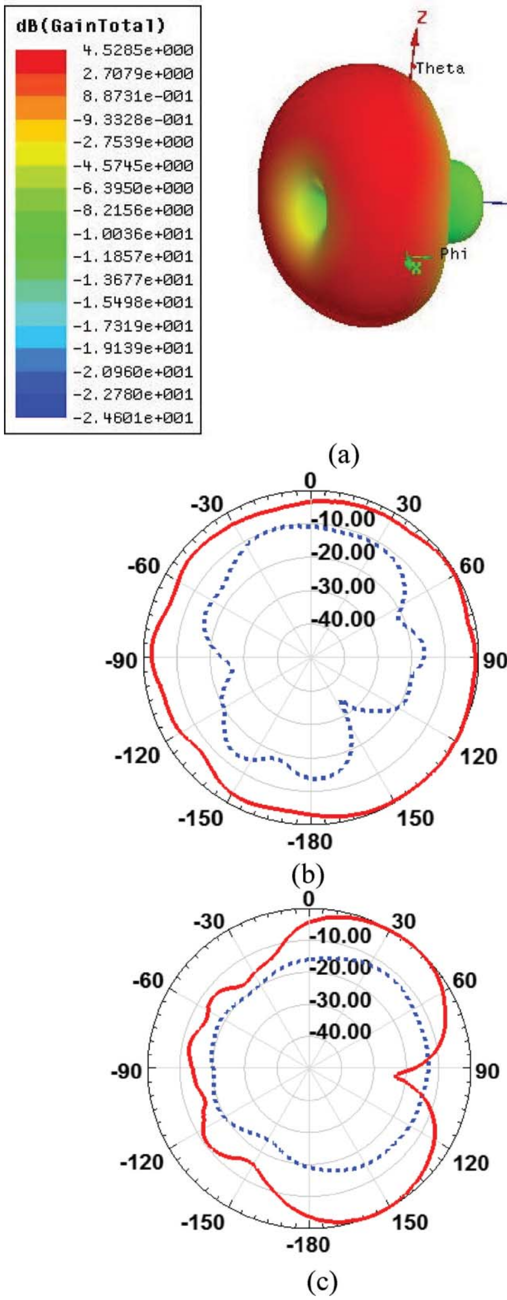


Figure 3: Antenna pattern, (a) the simulated 3D radiation pattern of an antenna at 1800 MHz, (b) E-plane co-polarisation and cross-polarisation, (c) H-plane co-polarisation and cross- polarisation.

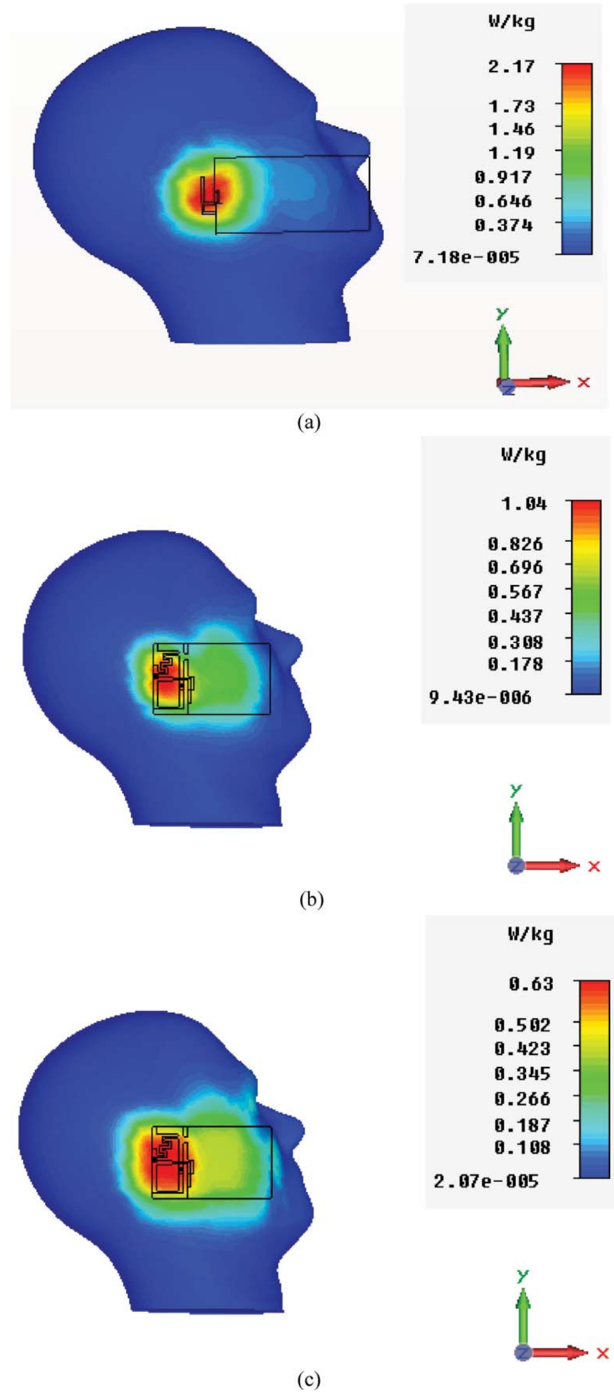


Figure 4: Specific absorption rate (SAR) at 1800 MHz around the human head. (a) Conventional PIFA antenna top position, (b) prototype antenna SAR for 1 g, (c) prototype antenna SAR for 10 g.

line connecting the ground-plane. The most part of current by the first via is directed to the bottom side and the ground plane as shown Figure 5(c).

In the prototype antenna the current is dispensed in both sides of the antenna, but in the conventional PIFA antenna the current concentrates on one side of the radiator, therefore the conventional PIFA has more current density and SAR is concentrated at limited area as shown in Figure 4(a). On the other hand, in prototype antenna the current is distributed in larger surface and as shown in Figure 4(b) and 4(c) the SAR dispense in larger surface too and low SAR is available.

The simulated efficiency of the prototype PIFA's is greater than 78% over its operating range of 1.2 to 3 GHz as shown in Figure 6. In addition, the antenna's gain in Figure 6 shows the proposed PIFA has the gain performance, greater than 2 dBi over 1.2 to 3 GHz. The

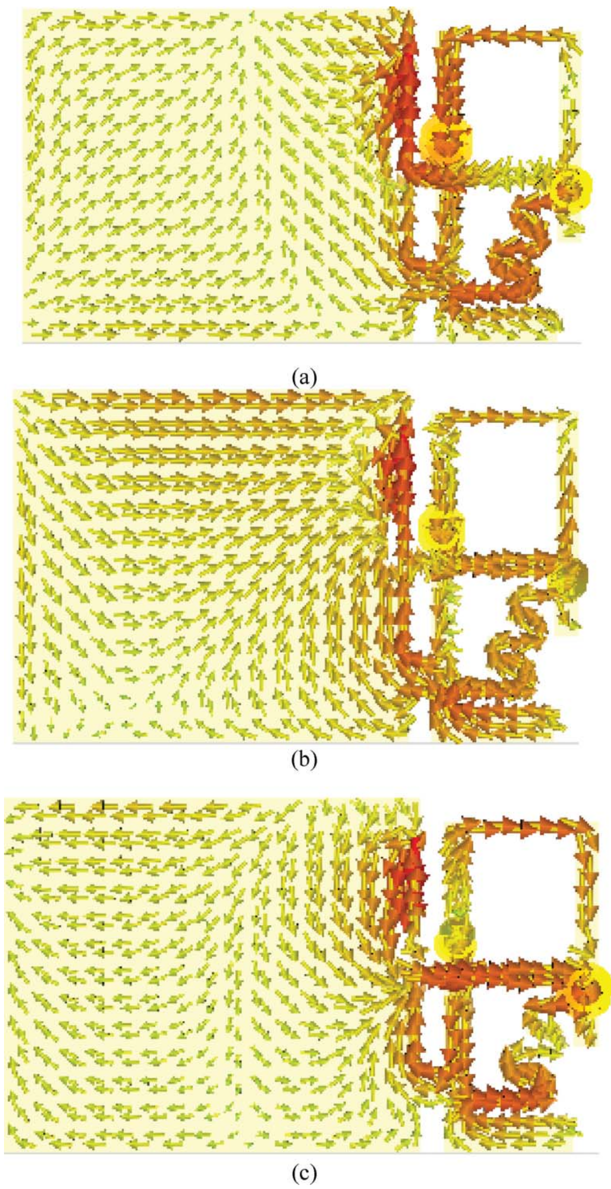

Figure 5: Surface current distribution on the PIFA prototype antenna at (a) 1.5 GHz, (b) 2 GHz, and (c) 2.5 GHz.

measured and simulated is showing good similarity. The prototype antenna is compared with four previous models and this comparison is presented in Table 2 at 1800 MHz when SAR calculated for an antenna at top position.

Typically, the handset SAR for 1800 MHz is around 2−3 W/kg at 1 (g) and 1−2 W/kg (10 g) for top antenna position and 0.5−0.9 W/kg at 1 (g) and 0.3−0.5 W/kg (10 g) for top antenna position [2−18]. However, the prototype antenna shows more efficiency and gains with a lower SAR in comparison to other PIFA antenna.

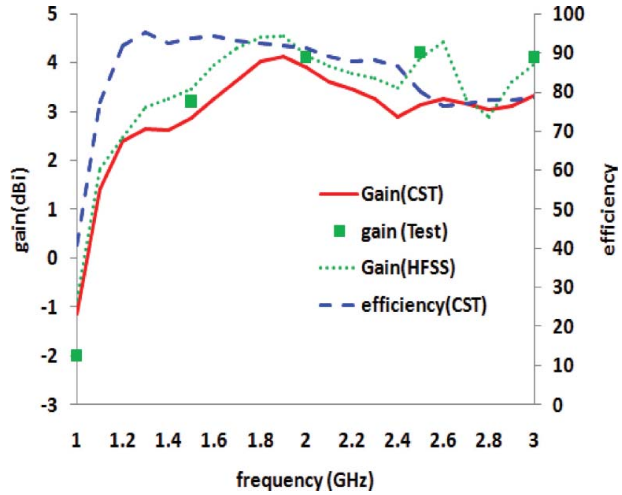


Figure 6: Antenna efficiency and gain: (a) PIFA efficiency and (b) PIFA gain comparison.

## 4. CONCLUSION

A printed PIFA antenna was presented that exhibits a low SAR for ultra wideband (UWB) applications. The proposed antenna operates across the frequency range of 1200−3000 MHz for VSWR of less than 2. This antenna has an approximate omnidirectional radiation pattern, and its SAR is 1.04 for 1 g and 0.63 for (10 g) at 1800 MHz, which represents a reduction of more than 51% compared to a conventional PIFA antenna. In addition, the antenna's efficiency is 78% and gain between 2 and 4.6 dBi over 1200−3000 MHz .The prototype antenna shows more efficiency and gain with a lower SAR in comparison to other PIFA antenna. For commercial application, 1.6W/kg is defined for mobile SAR in 1 (g); therefore, the prototype antenna has sufficient qualification. In conclusion, current distribution controlling is the best method for improving bandwidth and SAR parameter. Therefore, in this article, we dispense current in top and bottom layer by the implementation of two vias. Current distribution is controlled by antenna effective length and it is useful to achieved more bandwidth.

**Table 2: The antenna parameters comparison (*SAR for bottom position)**

| | Our design | Ref [3] | Ref [4] | Ref [12]* | Ref [18]* |
|---|---|---|---|---|---|
| Size (mm) | 100 × 60 × 1.6 | 100 ×40×1.6 | 100 × 40 × 6 | 100 × 40 × 1.6 | 100 × 60 × 1.6 |
| Gain (dBi) | 2−4.6 | 1−3.8 | – | 2−3.8 | 0—5 |
| SAR 1 g | 1.04 W/kg | 2.91 W/kg | 2.91 W/kg | 0.53 W/kg | 0.96 W/kg |
| SAR 10 g | 0.63 W/kg | 1.37 W/kg | 1.03 W/kg | – | – |
| B.W | 1.2−3 GHz | 1.7−2.2 GHz | 1.7−2.4 GHz | 1.5−2.7 GHz | 1.7−2.2 GHz |
| Efficiency | 78%−90% | 55%−80% | 50%−65% | 60%−92% | 45%−80% |

On the other hand, when current is distributed at larger area the SAR factor improved and reduced dramatically as shown in this article.

## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

## REFERENCES


1. Z. Li, and Y. Rahmat-Samii, “Optimization of PIFA-IFA combination in handset antenna designs,” *IEEE Trans. Antennas Propag.*, Vol. 53, no. 5, pp. 1770−8, May 2005.
2. J. Thaysen, and K. B. Jakobsen, “Mutual coupling between identical planar inverted-F antennas,” *AEU-Int. J. Electron. Commun.*, Vol. 61, no. 8, 540−5, Sep. 2007.
3. C. H. Chang, and K. L. Wong, “Printed PIFA for penta-band WWAN operation in the mobile phone,” *IEEE Trans. Antennas Propag.*, Vol. 57, no. 5, pp. 1373−81, May 2009.
4. A. Cabedo, J. Anguera, C. Picher, M. Ribö, and C. Puente, “Multiband handset antenna combining PIFA, slots, and ground plane modes,” *IEEE Trans. Antennas Propag.*, Vol. 57, no. 9, pp. 2526−33, Sep. 2009.
5. C. H. Wu, and K. L. Wong, “Ultrawideband PIFA with a capacitive feed for penta-band folder-type mobile phone antenna,” *IEEE Trans. Antennas Propag.*, Vol. 57, no. 8, pp. 2461−4, Aug. 2009.
6. Y. L. Kuo, T. W. Chiou, and K. L. Wong, “A novel dual-band printed inverted-F antenna,” *Microw. Optic. Technol. Lett.*, Vol. 31, no. 5, pp. 353−5, Dec. 2001.
7. K. S. Sultan, H. H. Abdullah, E. A. Abdallah, and E. A. Hashish, “Low-SAR, Miniaturized Printed Antenna for Mobile, ISM, and WLAN Services,” *IEEE Antennas Wireless Propagat. Lett.*. Vol. 12, pp. 1106−9, Sep. 2013.
8. K. Zhao, S. Zhang, Z. N. Ying, T. Bolin, and S.He, “SAR study of different MIMO antenna designs for LTE application in smart mobile handsets,” *IEEE Trans. Antennas Propagat.*, Vol. 61, no. 6, pp. 3270−9, Jun. 2013.
9. W. Y. Li, C. Y. Wu, K. L. Wong, and M. F. Tu, “Internal Small-Size PIFA for LTE/GSM/UMTS operation in the mobile phone,” *2010 IEEE Antennas and Propagation Society International Symposium*, Toronto, ON, Jul. 2010, pp. 1—4.
10. S. Y. Jeon, and H. D. Kim, “Mobile terminal antenna using a planar inverted-E feed structure for enhanced impedance bandwidth,” *Microw. Optic. Technol. Lett.*, Vol. 54, no. 9, pp. 2133−9, Sep. 2012.
11. K. L. Wong, Y. W. Chang, and S. C. Chen, “Bandwidth enhancement of small-size planar tablet computer antenna using a parallel-resonant spiral slit,” *IEEE Trans. Antennas Propagat.*, Vol. 60, no. 4, pp. 1705−11, Apr. 2012.
12. T. W. Kang, and K. L. Wong, “Simple small-size coupled-fed uniplanar PIFA for multiband clamshell mobile phone application,” *Microw. Optic. Technol. Lett.* Vol. 51, no. 12, pp. 2805−10, Dec. 2009.
13. A. Andujar, J. Anguera, C. Picher, and C. Puente, “Ground plane booster antenna technology: Human head interaction: Functional and biological analysis,” *6th European Conference on Antennas and Propagation (EUCAP)*, Prague, Mar. 2012, pp. 2745−9.
14. N. A. Saidatul, A. A. A.-H. Azremi, R. B. Ahmad, P. J. Soh, and F. Malek, “Multiband fractal planar inverted F-antenna (F-pifa) for mobile phone application,” *Progr. Electromagnet. Res. B*, Vol. 14, pp. 127−48, Apr. 2009.
15. J. Dlouhy, and J. Rozman, “The thermal distribution and the SAR calculation of RF signal inside the human head,” *Proceedings of the 14th Conference Student (EEICT)*, Brno, CZ, Aug. 2008, pp. 17−21. ISBN: 978-80-214-3616- 9.
16. A. A. H. Azremi, J. Ilvonen, C.-H. Li, J. Holopainen, and P. Vainikainen, “Influence of the user’s hand on mutual coupling of dual-antenna structures on mobile terminal,” *6th European Conference on Antennas and Propagation (EUCAP)*, Prague, Mar. 2012, pp. 1222−6.
17. M. R. I. Faruque, N. Misran, M. T. Islam, B. Yatim, and B. Bias. “New low specific absorption rate (SAR) antenna design for mobile handset,” *Int. J. Phys. Sci.*, Vol. 6, no. 24, pp. 5706−15, Oct. 2011.
18. K. L. Wong, Y. W. Chang, C. Y. Wu, and W. Y. Li, “A small-size penta-band WWAN antenna integrated with USB connector for mobile phone applications,” *International Conference on Applications of Electromagnetism and Student Innovation Competition Awards (AEM2C)*, Taipei, Aug. 2010, pp. 147−51.




## Authors

Mohammad Naser-Moghadasi was born in Saveh, Iran, in 1959. He received the BSc degree in Communication Engineering in 1985 from the Leeds Metropolitan University (formerly Leeds polytechnic), UK. Between 1985 and 1987, he worked as an RF design engineer for the Giga tech Company in Newcastle Upon Tyne, UK. From 1987 to 1989, he was awarded a full scholarship by the Leeds educational authority to pursue an MPhil in studying in CAD of microwave circuits. He received his PhD in 1993 from the University of Bradford, UK. He was offered then a two-year postdoc to pursue research on Microwave Cooking of Materials at the University of Nottingham, UK. From 1995, he joined Islamic Azad University, Science and Research Branch, Iran, where he currently is the head of postgraduate studies and also member of Central Commission for Scientific Literacy & Art Societies. His main areas of interest in research are Microstrip Antenna, Microwave Passive and Active Circuits, radio frequency micro electro mechanical systems (RF MEMS). He is a member of the Institution of Engineering and Technology, MIET and the Institute of Electronics, Information and Communication Engineers (IEICE). He has so far published over 130 papers in different journals and conferences.

E-mail: mn.moghaddasi@srbiau.ac.ir

**Zahra Mansouri** was born in Zanjan, Iran. She received her BSc degree in Electrical Engineering (Telecommunication) from Zanjan University, Zanjan, Iran, in 2008 and MSc degree in Electrical Engineering (Telecommunication) from Islamic Azad University, Science and Research Branch, Tehran, Iran, in 2012 and now, she is a PhD student at Islamic Azad University, Science and Research Branch. Her primary research interests are in microwave components such as couplers and power dividers, and metamaterials and UWB antenna.

E-mail: zm.mansouri@gmail.com

**Sachin Sharma** was born in India. He received his Bachelor degree in Electronics & Communication from C.C.S University and presently he is pursuing MS from Technical University of Chemnitz, Germany. His major research interest is designing of antenna for wireless and UWB application for radar, microwave Devices, and metamaterials.

E-mail: sachinmrt11@gmail.com

**Ferdows B. Zarrabi** was born in Iran, Babol. He studied Electrical Engineering at University of Tabriz in major of Communication Engineering in 2008 and now he is pursuing his MS at Tarbiat Modares University. His major research interest is designing of antenna for wireless and UWB application for breast cancer detection radar, Microwave Devices, Absorber, Metamaterial, Plasmonic, Nano-antenna, and THz antenna. He is the author and co-author of more than 32 papers. He is currently work-focused on Fluid Plasmonic for Bio-sensing, Cloak, Photocell development base on Nano-antenna. He is also the reviewer of the Journal of ACES and few other journals.

E-mail: ferdows.zarrabi@yahoo.com

**Bal S. Virdee** received the BSc (Hons) degree and MPhil degree in Communications Engineering from the University of Leeds, UK, and PhD degree in Electronic Engineering from the University of London, UK. He has worked in various companies including Philips (UK) as an R&D engineer at Filtronic Components Ltd. as a future products developer in the area of RF/microwave communications. Previously he was a lecturer at several institutions. He is a professor of Microwave Communications in the Faculty of Life Sciences and Computing at London Metropolitan University, where he heads the Center for Communications Technology and is the Director of London Metropolitan Microwaves. His research, in collaboration with industry and academia, is in the area of microwave wireless communications encompassing mobile phones to satellite technology. He has chaired technical sessions at IEEE international conferences and published numerous research papers. He is a fellow of IET.

E-mail: b.virdee@londonmet.ac.uk