A Hepta-Band Frequency Reconfigurable Antenna for Mobile Handsets with Impedance Matching Technique

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Abstract. A compact hepta-band frequency reconfigurable antenna (45 x 13.5 x 4 mm^3) for mobile phone applications is proposed in this paper. The proposed antenna is constructed of folded strips. It is working in loop antenna and planar inverted-F antenna (PIFA) modes depends on the switching action of PIN diode. The proposed antenna operates over seven frequency bands (lower band (GSM 850, GSM 900), middle band (GSM 1800, GSM 1900, UMTS), upper band (LTE 2300, LTE 2500) with respect to ī 6 dB reflection coefficient. The proposed antenna is having three resonances in which lower and upper resonances are obtained with an impedance bandwidth of 23.28% and 18.9% when the antenna is working in PIFA mode, and middle resonance is occurred with an impedance bandwidth of 26.35% when the antenna is operating in Loop antenna mode. The antenna characteristics like reflection coefficient, radiation patterns, current distribution, and realized gain are presented in this paper.

Keywords: Reconfigurable antenna, multiband, LTE, planar inverted F-Antenna, loop antenna

1. Introduction

The demand for multi-band and multi-functional antennas for the mobile phones has been increased tremendously with the growing development of wireless communication technology. The demand to integrate more wireless services to the small volume of the mobile handsets is significant. Compact multi-band antenna structures with wide impedance bandwidth such as monopole antennas [1], PIFA [2], and some other designs [3-5] are important requirements for the mobile devices. It is observed from recent literature that the Loop antennas are capable of providing a promising solution for mobile phone applications [3]. Arranging loop antenna in a compact volume with good impedance matching is a challenging task as discussed in the literature. In general, the PIFA and loop antenna operate at a resonance length of ə/4 and ə/2, respectively. However, the conventional PIFA and loop antenna cannot cover the required bandwidth of the LTE/WWAN (GSM 850 / GSM 900 / GSM 1800/ GSM 1900 / UMTS/ LTE 2300/ LTE 2500) in restricted space. Thus, for multiband operation, a complicated and/or large sized conventional antenna is required. To solve these problems, a reconfigurable antenna has been studied. Frequency reconfigurable antenna is an effective solution for multi-band antenna designs. Different operating modes such as PIFA and loop antenna mode with different resonance frequencies are reconfigured using the same antenna structure without increasing the antenna size. A reconfigurable antenna can reuse its entire volume to operate in different operating bands so that the physical size of the multiband antenna remains compact. Many types of reconfigurable antennas using various switching techniques, such as micro electromechanical systems (MEMS) [6], PIN diodes [7], and varactor diodes [8], have been widely studied and adopted for use in mobile phone applications.

In this paper, we presented a frequency reconfigurable antenna for mobile phone applications. The proposed structure is a combination of a PIFA mode and a loop antenna mode which is controlled by the biasing of the PIN diode. In the PIFA mode, the proposed antenna has a dual resonance at 860 MHz and 2540 MHz, which covers GSM 850, GSM 900, LTE 2300 and LTE 2500 applications. In Loop antenna mode, antenna covers DCS, PCS, and UMTS applications and is having a resonance at 1960 MHz. The proposed structure has a compact size and is easy to implement at low cost by printing on the system circuit board of the mobile handset.

2. Antenna design

Figure 1 shows the 3D geometry and top view of the proposed folded compact multiband reconfigurable antenna for LTE/WWAN mobile applications. The proposed reconfigurable antenna is designed on the top side of 1.6 mm thick FR4 substrate (permittivity = 4.4, loss tangent = 0.02) of size 75× 45 mm^2. The ground plane is printed on the bottom side of the substrate. The radiating element of size 13.5 × 45 mm^2 is made of copper sheet of thickness 0.3 mm. The radiating element is at a height of 4 mm above the ground. The distance between feeding strip and shorting strip is 19 mm. The proposed antenna operates in loop mode, when positive DC voltage is applied at the feed which makes PIN diode in ON state. Whereas negative DC bias at the feed reverses the switching conditions of the diode to make the antenna operates in PIFA antenna mode. With this switching condition of diode, ə/4-PIFA radiator is designed to resonate at 860 MHz which is near about centre frequency of lower operating frequency bands. However, the simulated results (Figure 2) show that the radiator resonates at 735 MHz and 2845 MHz (due to generation of higher order mode corresponds to 3ə/4) in PIFA mode (case 1, Figure 2). On reversing the switching condition of PIN diode, the overall length of the radiator become ə/2 (corresponding to loop mode) and radiator resonates at 2270 MHz. The impedance mismatch is observed in middle band (case 2, Figure 2). The obtained bandwidth is not sufficient to cover the desired

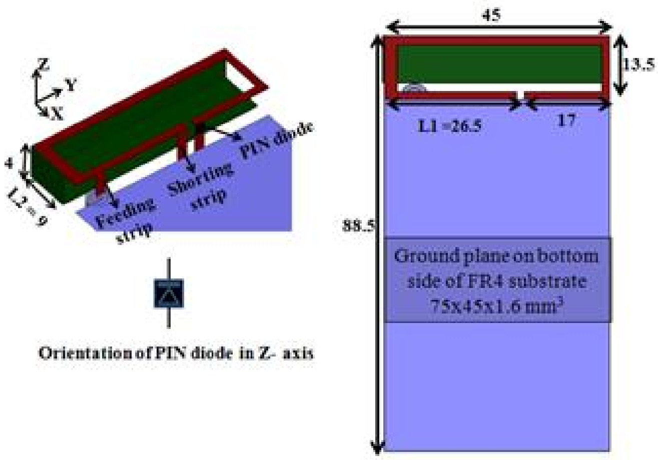


Fig. 1. (a) 3D configuration, (b) Top view of the proposed antenna (All dimensions are in ómmô)

frequency bands. So, a bent metal is connected to the main radiator which shifts the lower resonating frequency towards the higher frequency side and higher resonating frequency towards the lower frequency side in PIFA mode (case 3, Figure 2), and simultaneously improves the antenna reflection coefficient characteristics in Loop mode (case 4, Figure 2). It is observed from the figure that the optimized antenna has triple resonances with the bandwidth of 23.28 % (774 - 978 MHz) at lower band and of 18.9% (2262- 2790 MHz) at the higher band while working in PIFA mode, and of 26.35% (1690 ï 2203 MHz) at the middle band while working in Loop antenna mode, and thus covering GSM850, GSM900, DCS, PCS, UMTS, LTE 2300 and LTE 2500 frequency bands.

3. Parametric analysis

The parametric study for some of the critical shape parameters of the antenna is carried out to analyze their effect on the operating frequency bands using Ansys HFSS [9].

Figures 3(a) and (b) show the simulated reflection coefficient of the proposed antenna relative to the change in length L2 for PIFA mode and loop mode respectively.

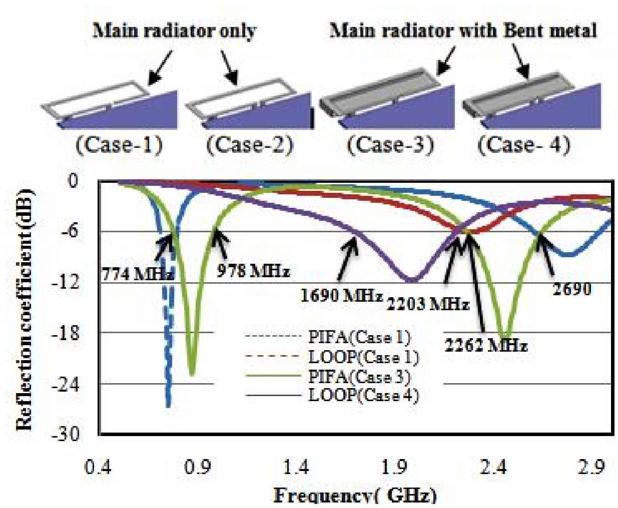


Fig. 2. Reflection coefficient of the proposed antenna.

In PIFA mode increment in L2 results into the shifting of resonance frequency towards the higher frequency side of lower band, as well as the resonance frequency of higher band is shifted towards the lower frequency side (Figure.3: (a)). When antenna is operated in loop mode, the effect of increment in L2 ensures the enhancement of the antenna bandwidth in middle band, as depicted in the Figure 3(b). The optimum result which covers the desired wireless band is obtained at specific value of L1 (5 mm) while antenna is working PIFA as well as Loop mode (Figures 3 (c) and (d)).

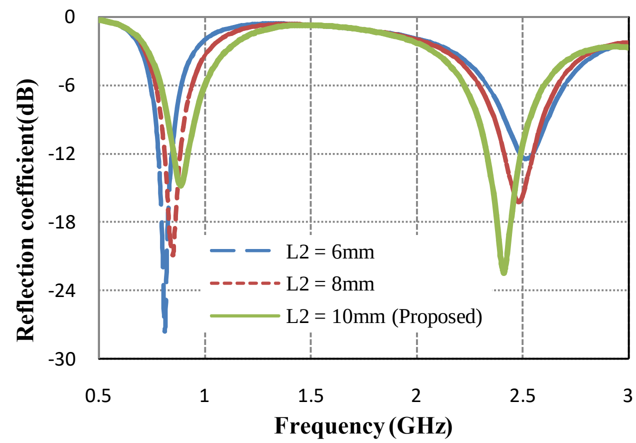


Fig. 3: (a) Simulated *S*-parameters as a function of the bent length (PIFA mode)

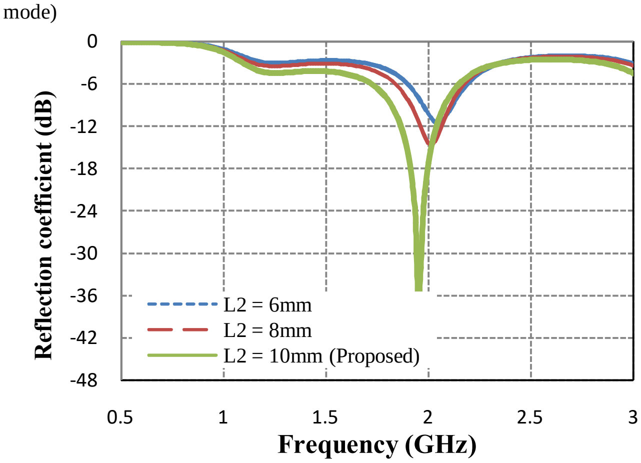


Fig. 3: (b) Simulated *S*-parameters as a function of the bent length (Loop antenna mode)

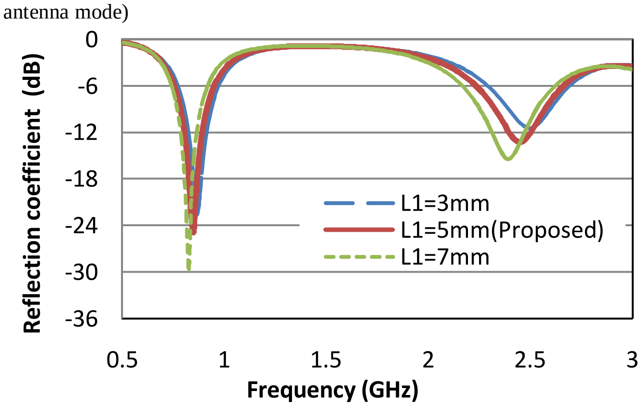


Fig. 3: (c) Simulated *S*-parameters as a function of the Feed position (PIFA mode)

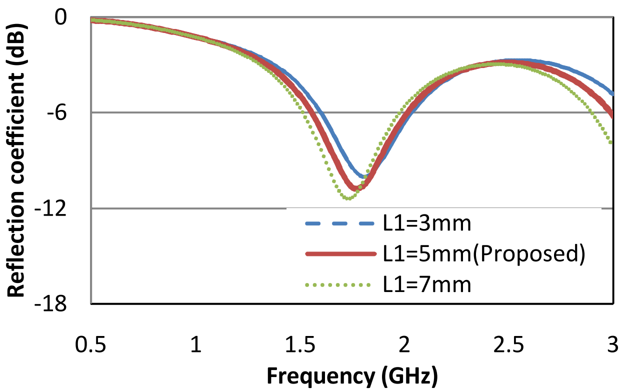


Fig. 3: (d) Simulated *S*-parameters as a function of the Feed position (Loop antenna mode)

4. Current distribution and radiation pattern

To understand the radiation mechanism of the proposed antenna, vector surface current distributions at three resonating frequencies (860 MHz, 1940 MHz, and 2540 MHz) are plotted, and are shown in Figure 4. It is observed that at 860 MHz, maximum current is concentrated along the main radiator and bent metal line section which is responsible for maximum radiation. When frequency increases, the current null appears in middle (at the middle of the main radiator) and higher band (at a right of the middle of the main radiator) at the resonating frequencies of 1940 MHz and 2540 MHz. Further, it is observed from Figure 4 (a) and (c) that minimum amount of current is flowing through the diode as it is off and configure the proposed antenna in PIFA mode. The small amount of current seen in the diode branch is due to the proximity of radiator and the ground plane. The proposed antenna works in loop mode (at the ON state of diode) and resonates at 1940 MHz, and this can be verified by observing Figure 4 (b).

Figure 5 shows the simulated 2-D radiation patterns of the proposed antenna at three resonating frequencies of 860 MHz, 1940 MHz and 2540 MHz. The radiation patterns are presented in the *xy*, *xz*, and *yz* planes. It is observed that the proposed antenna is having wide beamwidth in all the planes and pattern is nearly omni-directional in the *yz*-plane for all the resonating frequencies.

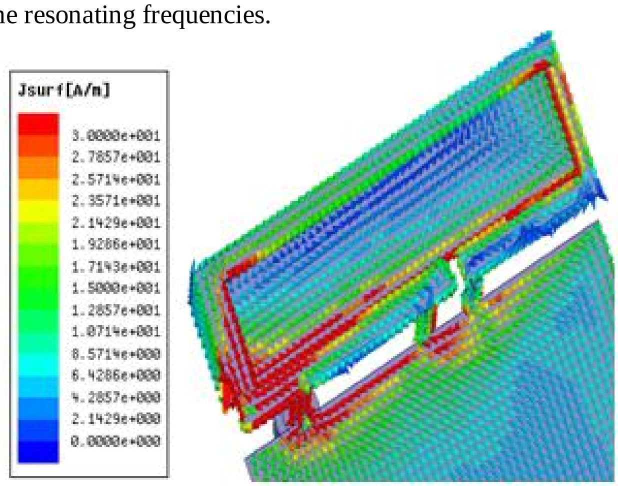


Fig. 4: (a) simulated surface current distribution at 860 MHz

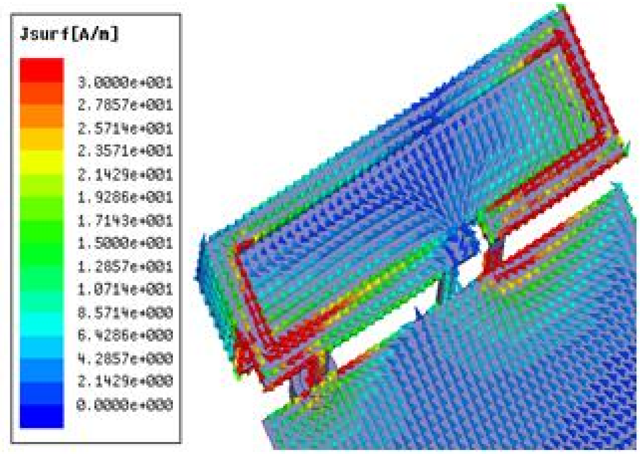


Fig. 4: (b) simulated surface current distribution at 1940 MHz

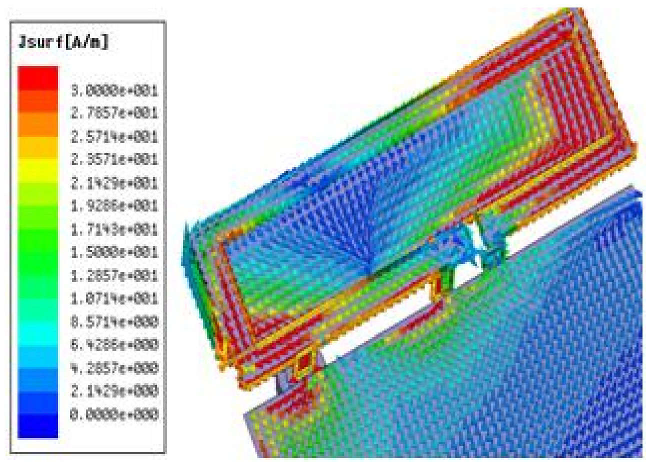


Fig. 4: (c) simulated surface current distribution at 2540 MHz

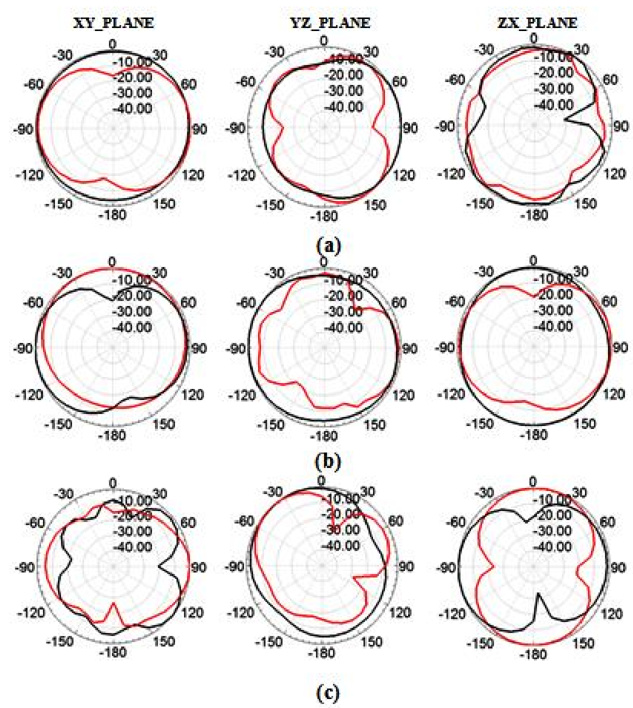


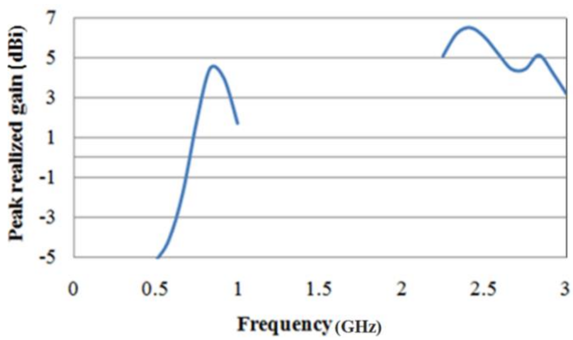
Fig. 5.Simulated 2-D radiation pattern of the proposed antenna at (a) 860, (b) 1940, (c) 2540 MHz (E_θ , E_φ).

5. Antenna Gain

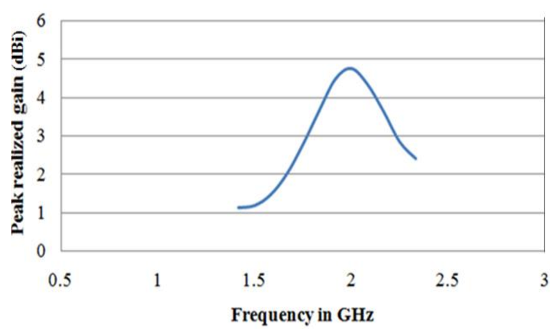
Figure. 6 shows the simulated peak realized gain of the proposed reconfigurable antenna. The peak realized gains at three resonating frequencies of 860 MHz, 1940 MHz, and 2540 MHz are 3.1dBi, 4.52 dBi and 4.89 dBi respectively. Table 1 summarizes the simulated bandwidth and 3D peak realized gain of the reconfigurable antenna.

Table 1: Simulated bandwidth and 3D peak realized gain

Band	Lower Band	Middle Band	Upper Band
Bandwidth (%)	23.28	26.35	18.90
Frequency (MHz)	860	1940	2540
Peak realized Gain (dBi)	3.1 dBi	4.52 dBi	4.89 dBi



(a)



(b)

Fig. 6. Simulated peak realized gain (a) PIFA mode and (b) Loop antenna mode).

6. Conclusion

A compact frequency reconfigurable hepta-band antenna for mobile applications is proposed with triple resonance covering GSM 850/900 / 1800 /1900, UMTS 2100, LTE 2300, LTE 2500 applications for the mobile handsets. In the proposed antenna, two single modes are reconfigured in a single structure. The proposed reconfigurable antenna can operate in PIFA and Loop antenna modes by adjusting the on/off states of the PIN diode without any modifications in the geometry of the radiating element. When operating in the PIFA mode, the -6 dB bandwidth covers 774- 978 MHz (lower band) and 2262-2790 MHz (upper band). When operating in the Loop antenna mode, the -6 dB bandwidth covers 1690-2203 MHz (middle band). The proposed reconfigurable antenna is having good radiation patterns and sufficient antenna gain. Therefore, the proposed antenna exhibits great potential for multiband mobile handset applications.

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Ashis Kumar Behera was born in Ganjam (Odisha), India, in 1987. He received B.Tech. degree in electronics and telecommunication engineering from Krupajala Engineering College (KEC), Bhubaneswar, Odisha and the M. Tech. degree in microwave engineering from the Indian Institute of Technology Roorkee, India, in 2009 and 2014, respectively. He is currently working toward the Ph.D. degree from the Indian Institute of Technology (Banaras Hindu University), Varanasi, India. His research interests include microwave remote sensing, microwave imaging, reconfigurable antennas for mobile devices, and metamaterial.

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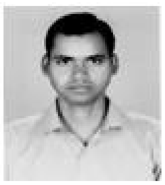

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Dr. Meshram is a senior member of IEEE, Member of the Indian Science Congress Association, India, Life Member of Indian Society of Technical Education (ISTE), India, and a Life Member of Institution of Electronics and Telecommunication Engineers (IETE), India. He received the Best Paper Award during the 87th session of the Indian Science Congress Association in January 2000 at Pune University, Pune, India. He was the recipient of INSA (Indian National Science Academy) visiting Fellowship 2008ï09 from Govt of India to visit South Korea under bilateral exchange program. He joined Hanyang University (Electronics and Computer Division) and worked on the design and development of antenna for WCDMA and Wi-Fi repeater. In 2010, he was awarded with the BOYSCAST (Better Opportunity to Young Scientist in Chosen Area of Science and Technology) fellowship for one year for conducting advance research at McMaster University (Electrical and Computer Engineering), Hamilton, Ontario, Canada, with Prof. Natalia K. Nikolova, where he was engaged in designed and development of UWB and MIMO antennas. He is the recipient of Gandhian Young Technological Innovation (GYTI) Award 2015. He is in the reviewerǿs list of several reference journals in India and abroad. He is the expert member of the project review committee of the Defence Avionics Research Establishment (DARE), Defence Research and Development Organization (DRDO), India. He has successfully accomplished the transfer of technology under CARS project of Defense Avionics Research Establishment (DARE), DRDO, India. He is managing editor of International Journal of Advances in Microwave Techniques (IJAMT).