International Journal For Technological Research In Engineering
Volume 4, Issue 10, June-2017 *ISSN (Online): 2347 - 4718*

STUDY PERFORMANCE OF INDUCTIVELY LOADED PIFA ANTENNAS FOR MOBILE APPLICATIONS

Vanita[1], Kanchan Yadav[2]
[1]HOD ECE, [2]M.TECH SCHOLORS, MRKIET REWARI

Abstract: The rapid advancement in the mobile technology has demanded a sophisticated antenna catering all its needs. The planar inverted F antenna is a promising antenna with multiband operations. The PIFA antennas are generally held at a height from the ground plane, which increases the volume occupied by the device. This space constraint is addressed by printed PIFA antennas. In this work, novel configurations of PIFA antennas are proposed. To reduce the volume of the PIFA structure, the air gap between the radiating antenna and the ground plane is removed. The miniaturization of antenna is obtained by meandered line technique, which also improves the antenna performance to dual band. To accommodate other communication bands, new resonances are obtained by introduction of inductive loading elements. A dual band PIFA which supports 610 MHz bandwidth at 2.40 GHz frequency and having a second resonance at 5.42 GHz is designed. This antenna is modified and loaded with an inverted L shaped metallic strip to enhance the antenna performance and to get a third resonance at 3.62 GHz with 170 MHz impedance bandwidth. This inductor loaded antenna gives three resonances at 2.44 GHz, 3.62 GHz and 5.80 GHz respectively. This antenna finds applications in 4G operations (2.3 − 2.4 GHz and 2.50 − 2.69 GHz), Wi-Max band (3.3 − 3.8 GHz) and Wi-Fi band (5.15 − 5.80 GHz).

I. INTRODUCTION

In the recent years, rapid progress has been accomplished in mobile phone antenna. Due to the alterations in mobile communication receivers the antennas have to accommodate large data transfer rates along with compatibility with the mobile environment. It is clearly evident that the communication devices working in wireless fidelity (Wi-Fi) and world interoperability for microwave access (WiMax) band are left with very small volume for accommodating the antenna into the device. In this concern researchers are working on compact, low profile and small-sized antenna with optimum performance. Antennas with high radiation efficiency, nearly omni directional radiation characteristics, occupying minimum volume and easy fabrication are the demand of the day. Due to its promising applications planar inverted F antennas (PIFA), are widely accepted in all communication devices. PIFA antenna resembles an inverted letter ‘F’ and resonates at quarter wavelength. These antennas also have less specific absorption rate (SAR) compared to remaining low profile antennas. The evolution and performance of global system for mo- bile communications(GSM) antenna is shown in Figure , where planar monopole antenna (PMA) is defined as inverted F antenna with no ground plane parallel to the antenna. In past the most conventional antenna for GSM mobile communication was helix antenna but as the thickness of mobile phone decreases the helix antenna has high specific absorption rate (SAR) and low radiation efficiency whereas the PIFA antenna has shown less SAR and better radiation efficiency. PIFA antennas have many advantages compared to other mobile antennas. They are easily integrated with the other mobile circuitry and fits completely inside the device unlike whip (monopole) antenna and helix antenna. Also PIFA antennas have less backward radiation compared to the whip or helix antennas. Wide research is going on in the existing single band and dual band PIFA models, their feeding techniques, capacitive loading, shorting techniques and insertion of different slots.

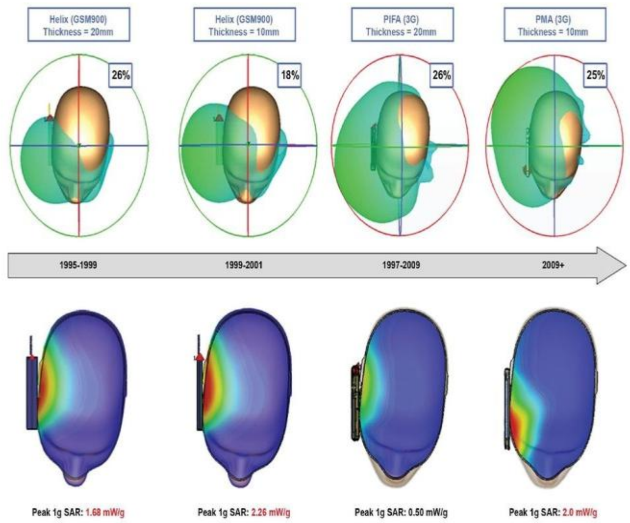


Figure: Evolution and performance of GSM antenna types from 1995 to 2011 (Courtesy: Mobile-Phone Antenna Design, Corbett Rowell and Edmund Y. Lam, IEEE Antennas and Propagation Magazine, Vol. 54, No. 4, August 2012).

PIFA antennas have moderate gain in both vertical and horizontal states of polarization thus making it useful in wireless communication devices where antenna orientation is not fixed and reflections are present from all the corners of the environment. They are widely used in mobile phone antennas. The Figure shows different inverted F antennas used

Figure Different Inverted F antennas fitted inside a mobile phone (Courtesy: www.antennatheory.com). inside a mobile phone for various applications.

II. INTRODUCTION TO PLANAR INVERTED F ANTENNAS

The basic PIFA structure is shown in Figure, where an inverted letter F can be observed excluding the ground plane. The radiating part shown in the figure can be a wire or patch of length 'L', which can be shorted by a pin or conducting plate of height 'H'. The feeding can be done to the radiating metallic strip or patch by different techniques. In this Figure, a coaxial feed is given at a distance of 'd' from the shorting pin.

The resonant frequency of basic PIFA structure shown in Figure is calculated by the equation

$L + H \approx \lambda/4$ (1.1)

where λ is the resonating wavelength for a fully shorted planar Inverted F antenna. The 3D view of a basic planar PIFA shorted with a partial metallic strip on one side is

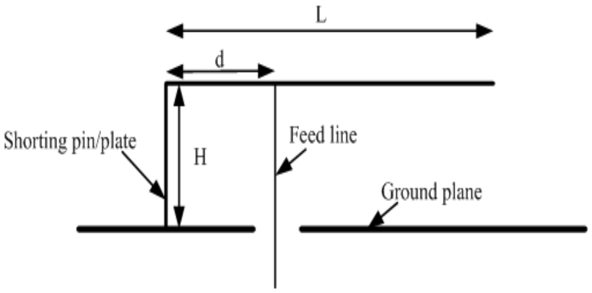


Figure : Side view of basic PIFA antenna with radiating strip of length L, shorted by a pin from a height of H.

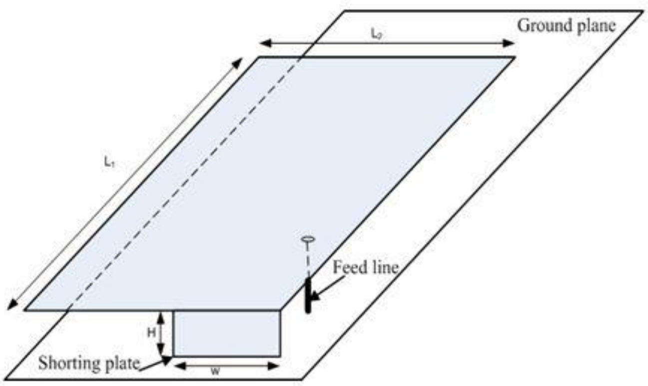


Figure : Basic PIFA antenna with radiating patch of dimensions L1 and L2 shorted by a pin from a height of H. shown in Figure . In the Figure , if the length of the shorting strip 'w' is equal to the width of the patch L2, then L1 is the value of L and resonant frequency is calculated from the equation (1.1). If the shorting is done through a partial conducting strip as shown in Figure, the resonant frequency is calculated from the equation given below.

$L1 + L2 + H \approx \lambda/4$ (1.2)

III. DESIGN TECHNIQUES OF DUAL BAND PIFA

The PIFA antenna can be made to resonate at two different frequencies by

Using the first two harmonics or resonant frequencies of a single resonant path; here the same patch resonating at quarter wavelength will be again resonating at half wavelength. This is achieved by introducing a single slot (branch line-slit) in a radiating patch or using a shorted spiral strip, where the resonating length is increased .

Using the two different resonant paths to generate two separate resonant modes. This is achieved by disturbing the current path using different shaped slots so that there are two different paths for the current distribution.

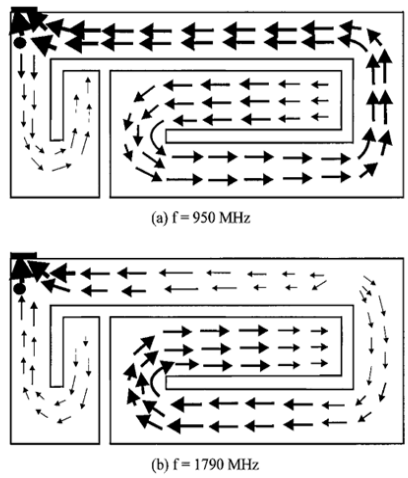
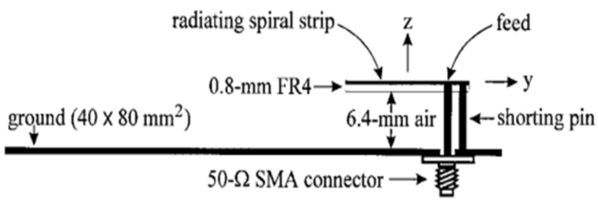


Figure : Surface current distributions of the PIFA (Courtesy: F. R. Hsiao, H. T. Chen, T. W. Chiou, G. Y. Lee and K. L. Wong, "A dual-band planar inverted-F patch antenna with a branch-line slit" in Microw. Opt. Technol. Lett.2002, 32: 310-312.)



side view

Figure: Geometry of the dual frequency PIFA with a rectangular spiral strip and chip inductor (a) side view of PIFA mounted on a ground plane, (b) top view of radiating patch of PIFA (Courtesy: S. H. Yeh and K. L. Wong, Compact dual-frequency PIFA with a chip- inductor-loaded rectangular spiral strip, in Microw. Opt. Technol. Lett. 2002, 33: 394-397).

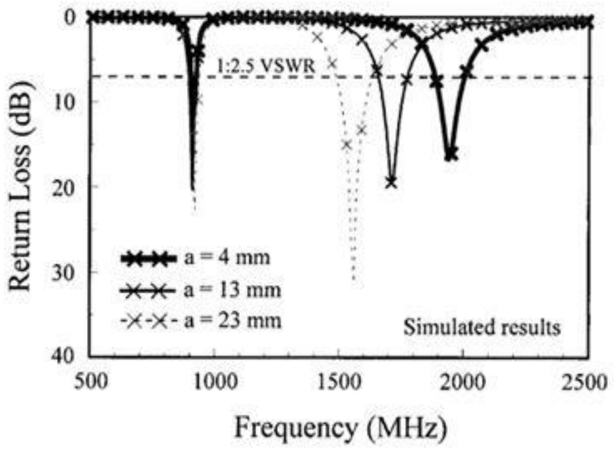


Figure: Simulated Return loss with variation of chip inductor position on the PIFA .

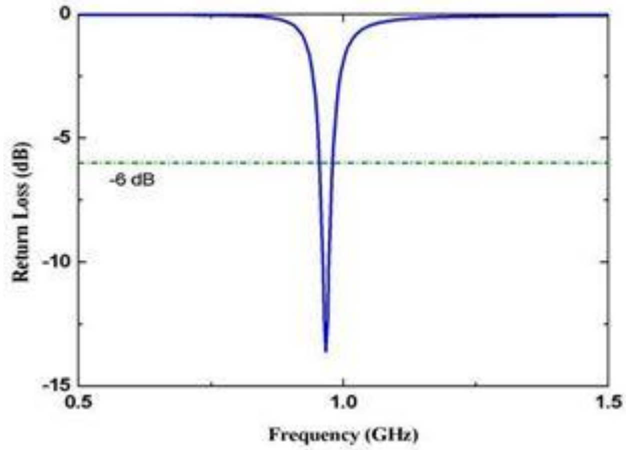


Figure : Simulated return loss of the single band PIFA antenna.

IV. DESIGN EXAMPLES OF PIFA

Single Band PIFA Antenna

Gert Frolund Peterson and Jorgen Bach Andersen proposed an integrated antenna for hand- held telephones with low absorption . To study the behaviour of a simple PIFA antenna, we have simulated the structure shown in Figure in HFSS finite element solver.

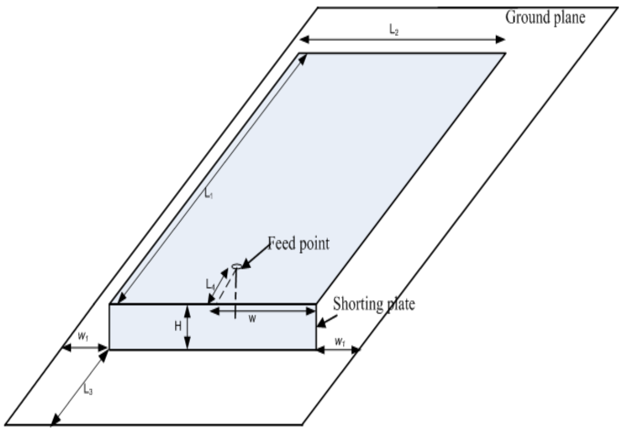


Figure : Geometry of the single band PIFA antenna with dimensions L1 = 69 mm, L2 = 50 mm, L3 = 20 mm, L4 = 7.5 mm, w = 25 mm, w1 = 5 mm and H = 7 mm.

The rectangular planar structure of length L1 and width L2 shorted completely on one side will radiate at quarter wavelength resonance. Considering the dimensions of the Figure and equation (2.1), the resonant frequency is 986 MHz and by simulation, resonance obtained at 965 MHz. In the equation (2.1), H represents the height of the radiating patch from the ground plane, it is designed to be 7 mm and L is the length of the patch which is 69 mm in the single band PIFA shown in Figure. The simulated return loss characteristics are shown in Figure . The electric field distribution in Figure clearly shows the radiation at open end of patch. Thus by shorting a patch, the open end resonates at quarter wave resonance. Here coaxial bottom feeding is used where an air substrate lies in between the radiating patch and ground plane.

$$L + H \approx \lambda/4 \qquad (2.1)$$

V. DUAL BAND PIFA ANTENNA WITH MEANDERED STRIPS

To achieve dual band PIFA, slots are introduced into the radiating planar elements . To further improve its properties and decrease the height of antenna from the ground plane, the radiating elements are printed on a substrate and then held over a ground plane with air gap.

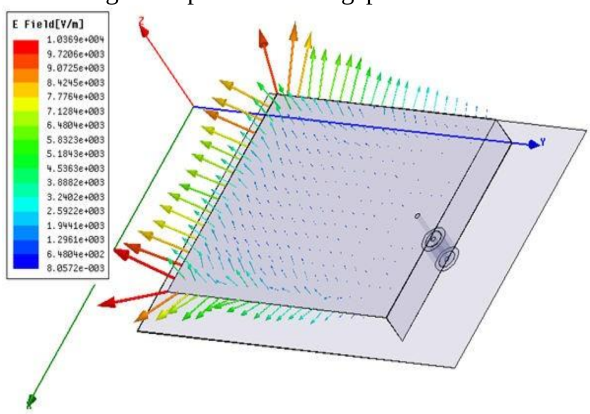


Figure: Simulated electric field distribution of the PIFA antenna at 965 MHz.

The design of dual band PIFA antenna is shown in Figure .
To explain the dual band performance of PIFA antenna, the proposed structure in , is simulated here. The antenna geometry is shown in Figure , the antenna contains three resonant elements, two meandered metallic strips of slightly different lengths and one nearly rectangular patch. All the three elements are shorted at the same place using a pin. The antenna occupies a volume of 24 × 37 × 8.4 mm3. The two strips of different lengths (about 84 mm, 86 mm) have their first or fundamental modes (quarter wavelength) at 920 and 900 MHz respectively. These two modes comprise the lower band of the antenna. The second higher order mode of the two strips along with the patch resonance, give a wide bandwidth forming the upper band. The return loss and surface current distribution of the dual band antenna are shown in Figure and Figure respectively. Taking minimum return loss of 6 dB, this structure has impedance bandwidth of 50 MHz (0.87 − 0.92 GHz) and 240 MHz (1.74 − 1.98

GHz), which makes it applicable for GSM/ DCS applications. In this structure, different length meandered strips and their resonant modes are used to obtain dual frequency operation and wide bandwidth.

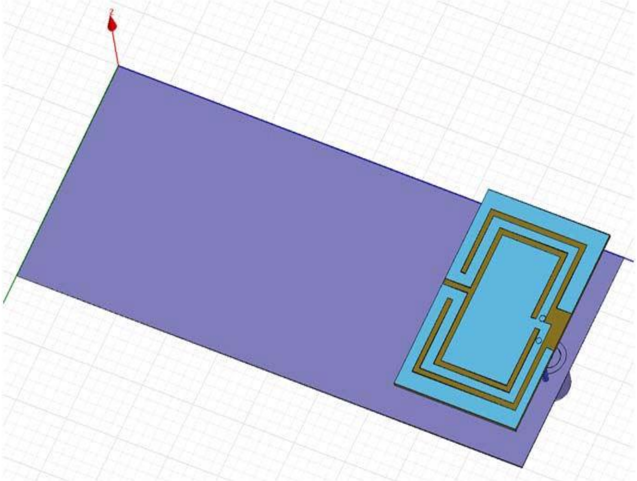


Figure : Design of dual band PIFA antenna.

Multiband Printed Inverted F monopole Antenna
The drawback of heightening of PIFA has been resolved by printing the antenna directly on a substrate and air gap has been removed between substrate and ground plane. The antenna is shorted by using a via connecting the radiating antenna and bottom ground plane. This design is explained using the structure proposed in , where different resonant paths are designed for multi frequency operation.

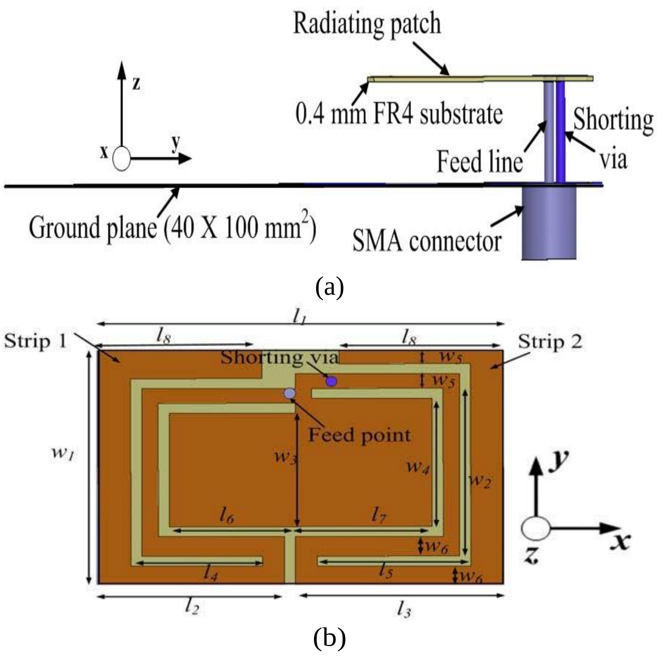


Figure: Geometry of the dual band PIFA antenna (a) side view and (b) top view of ra- diating patch with dimensions w_1 = 24 mm, w_2 = 17 mm, w_3 = 11.5 mm, w_4 = 13 mm, w_5 = 2 mm, w_6 = 1.5 mm, l_1 = 37 mm, l_2 = 17 mm, l_3 = 19 mm, l_4 = 12 mm, l_5 = 14 mm, l_6 = mm and l_7 = 12.5 mm.

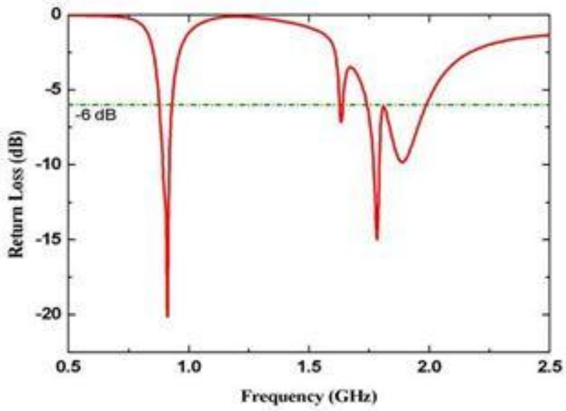


Figure : Simulated return loss of the dual band PIFA antenna.

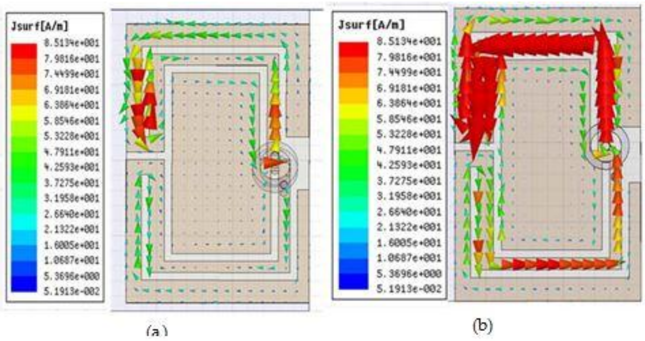


Figure : Simulated surface current distribution of the dual band PIFA antenna at (a) 0.91 GHz and (b) 1.78 GHz.

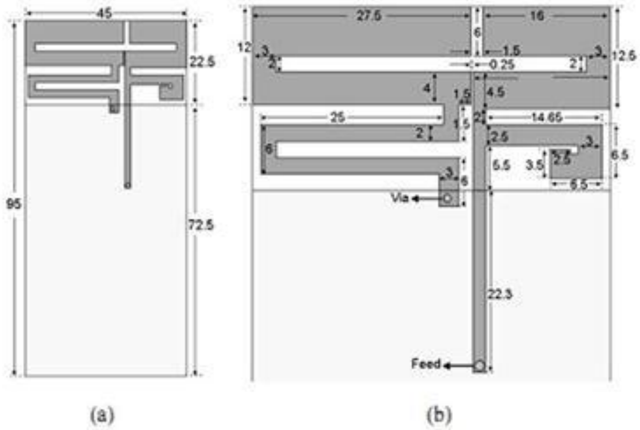


Figure : Geometry of the multi band PIFA antenna.

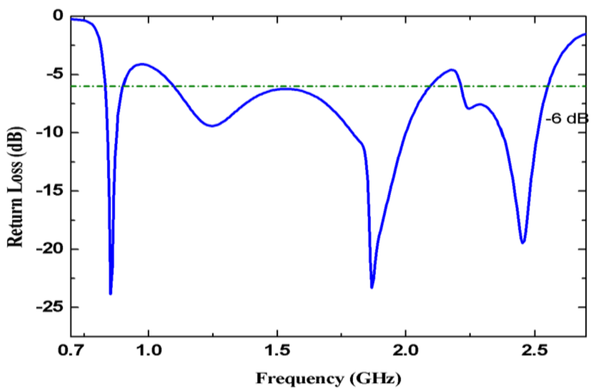


Figure : Simulated return loss of the multiband PIFA antenna.

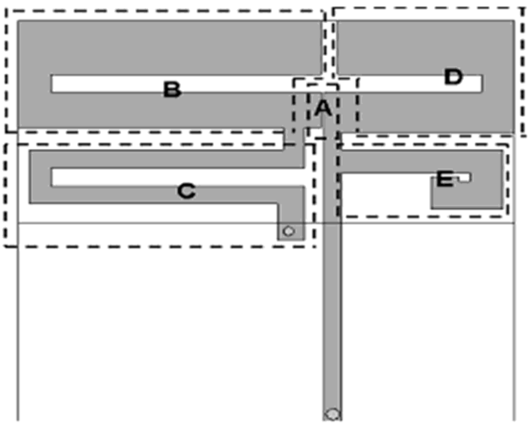


Figure : Structure of simulated printed multi band PIFA antenna with the meandered strips named as A, B, C, D and E for convenience.

When the length from open end to short point was nearly 3λ/4, then the same left part resonates at 1.869 GHz, thus without any extra design the same path is used for multi resonance. Again at 2.247 GHz, when the length of the path is about 5λ/4, resonance is again observed.

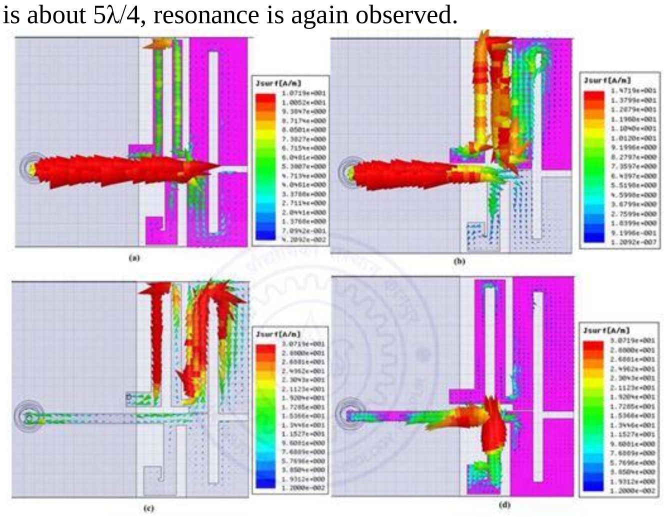


Figure: Simulated surface current distribution of the multiband PIFA antenna at (a) 0.854 GHz, (b) 1.244 GHz, (c) 1.869 GHz and (b) 2.453 GHz.

For resonance at 1.244 GHz, the upper division of right part (D) primarily contributes such that the length from feeding to open end is one quarter wavelength. At this frequency the ground part of left part acts as impedance matching. The lower right part E, contributes to the resonance at 2.453 GHz. Thus the antenna with meandered strips of different lengths printed on $95\times45\times0.8$ mm^3 FR4 substrate with partial ground of 72.5×45 mm^2 on backside of antenna can be used for GSM, DCS, PCS, UMTS and GPS applications.

VI. DUAL BAND MEANDER LINE PIFA ANTENNA

Antenna Design

The geometrical configuration of the dual band meander line PIFA antenna is shown in Figure. The designed antenna has a double layer copper metallic structure and is printed on an inexpensive FR4 substrate with a dielectric constant of 4.4 and thickness of 0.8 mm.

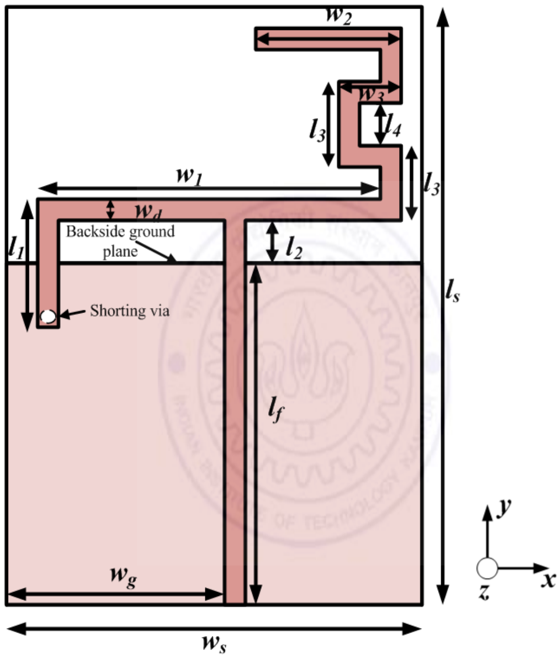


Figure : Geometry of the dual frequency meander line PIFA antenna with dimensions as ls = 35 mm, ws = 25 mm, wg = 13 mm, lf = 20 mm, l1 = 7 mm, l2 = 3 mm, l3 = 4 mm, l4 = 2 mm, wd = 1 mm, w1 = 22 mm, w2 = 8 mm and w3 = 4 mm.

meandering the microstrip line, the radiating length is increased thereby reducing the reso- nant frequency. Thus miniaturization is achieved as radiating frequency is lowered without change in dimension of structure.

Simulation Results

The return loss characteristics of the antenna are shown in Figure . The antenna achieves a −6 dB impedance bandwidth of 610 MHz ranging from 2.16 GHz to 2.77 GHz with a center frequency of 2.40 GHz and 1490 MHz bandwidth from 4.50 GHz to 5.99 GHz having center frequency of 5.42 GHz. The surface current distributions of the proposed antenna at 2.40 GHz and 5.42 GHz are shown in Figure . The simulated E field distribution magnitude plots are shown in the Figure . The E field distribution shows the distribution of nulls and maximum points where the field is radiated out at the open end point.

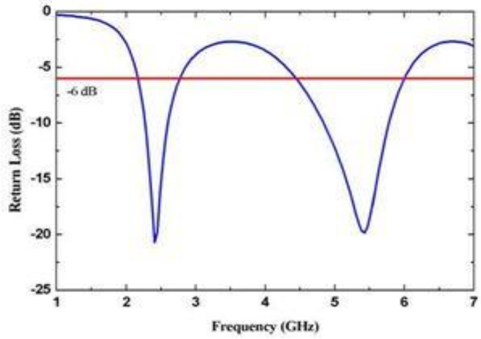


Figure : Simulated return loss characteristics of the dual band meander line PIFA antenna.

Radiation Properties

The fabricated single band PIFA antenna is shown in Figure where the front view is shown in Figure (a) and the back view is shown in Figure(b). The measured return loss characteristics are compared with the simulated characteristics in the Figure.

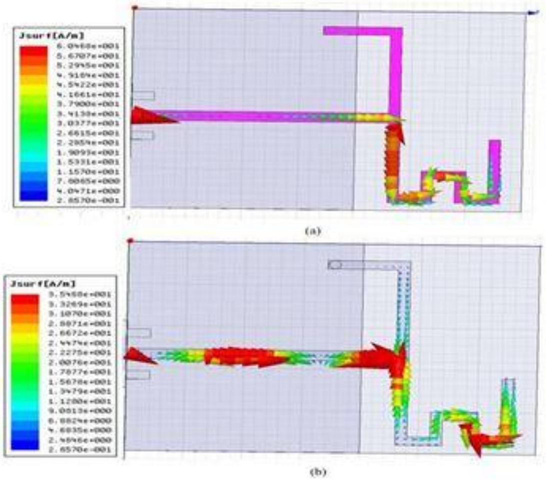


Figure : Simulated surface current distributions of the dual frequency PIFA antenna at (a) 2.40 GHz and (b) 5.42 GHz.

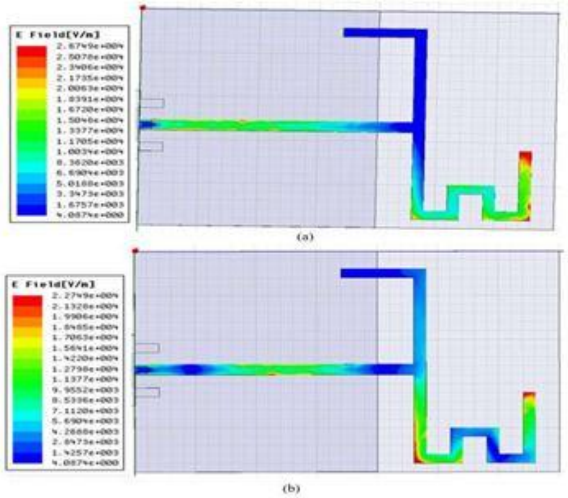


Figure : Simulated electric field distribution of dual frequency PIFA antenna at (a) 2.40 GHz and (b) 5.42 GHz.

VII. TRIPLE BAND INDUCTOR LOADED PIFA ANTENNA

Antenna Design

The geometrical configuration of the proposed inductor loaded PIFA antenna for wireless applications is shown in the Figure. The proposed antenna has an inverted L shaped metallic strip loading the meander line PIFA shown in Figure . The design is printed on the inexpensive FR4 substrate with a dielectric constant of 4.4 and thickness of 0.8 mm. To achieve the multiband operation and to increase the gain of the meander line PIFA, an L shaped loading is introduced. This L strip is shorted at one end which acts as a resonating structure at 3.62 GHz.

Simulation Results

The simulated return loss against frequency for the proposed inductor loaded PIFA antenna is shown in Figure . By varying the length of the L loading, the reflection coefficient can be tuned to achieve required bandwidth at 3.6 GHz without effecting the other bands significantly as shown in Figure. The antenna achieves a −6 dB impedance bandwidth of 27.86% ranging from 2.1 GHz to 2.78 GHz, with respect to the central frequency at 2.44 GHz. It has two other resonant bands with 4.69% and 17.75% impedance bandwidth (3.54-3.71 GHz) at center frequencies of 3.62 GHz and 5.80 GHz respectively. Hence the antenna can be operated over the bands which cover the required bandwidths of the IEEE 802.11 wireless local area network (WLAN) standards (2.4 − 2.4835 GHz and 5.15 − 5.725 GHz).

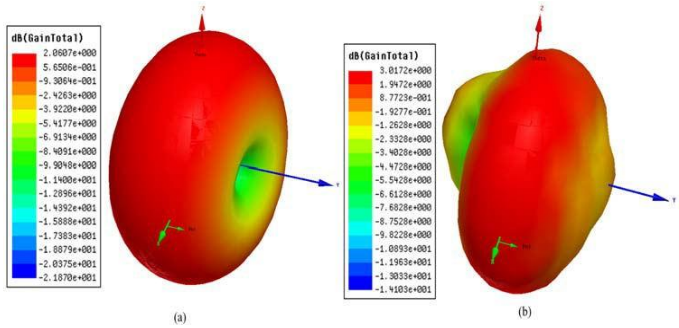


Figure : 3D gain plots of the dual band meander line PIFA antenna at (a) 2.40 GHz and (b) 5.42 GHz.

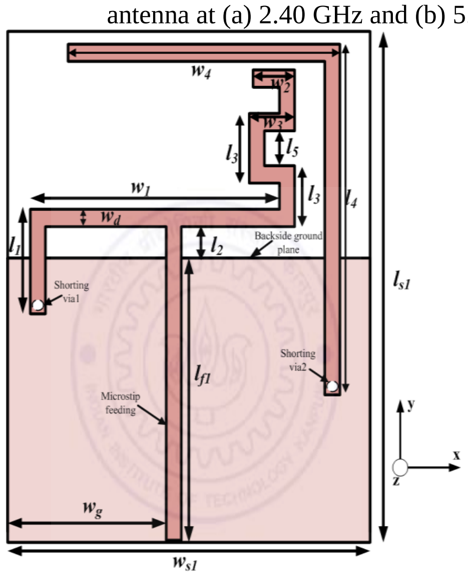


Figure : Geometrical configuration of the inductor loaded PIFA antenna with dimensions as ls1 = 39 mm, ws1 = 30 mm, wg = 13.5 mm, lf 1 = 22 mm, l1 = 7 mm, l2 = 3 mm, l3 = 4 mm, l4 = 24.5 mm, l5 = 2 mm, wd = 1 mm, w1 = 22 mm, w2 = 3 mm, w3 = 4 mm and w4 = 22 mm.

The proposed PIFA antenna has good impedance matching compared to the meander line PIFA antenna in the lower resonant band. The upper band is shifted to 5.8 GHz center frequency which covers the upper Wi-Max band operated for all wireless applications. The surface current distributions of the proposed antenna at 2.44 GHz, 3.62 GHz and 5.80 GHz are shown in Figure . The electric field distribution magnitude plots of the proposed inductively loaded antenna at 2.44 GHz, 3.62 GHz and 5.80 GHz are shown in Figure.

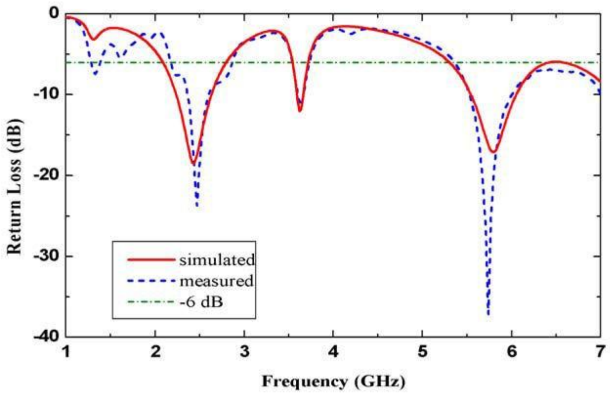


Figure: Simulated and measured return loss characteristics of the L loaded PIFA an- tenna.

Radiation Properties

The fabricated single band PIFA antenna is shown in Figure where the front view is shown in Figure) and the back view is shown in Figure. The proposed PIFA structure have resultant E field varying in a plane inclined to both xz and yz planes which

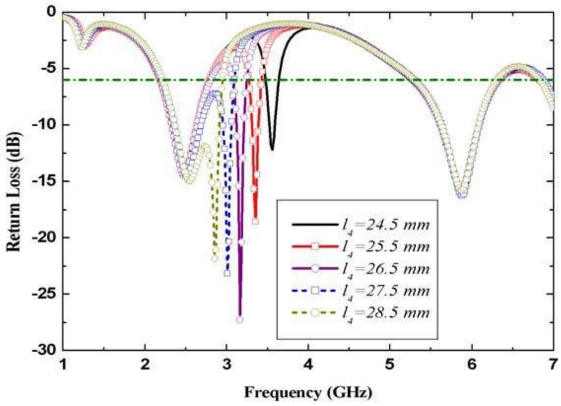


Figure: Variation of return loss characteristics for different lengths of inductor loading.

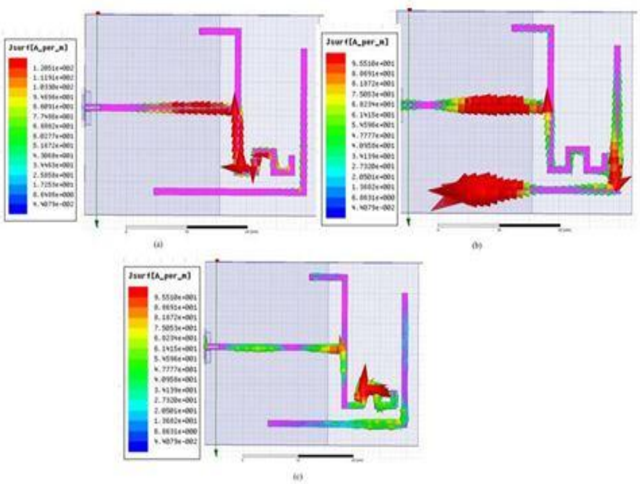


Figure: Simulated surface current distributions of the inductor loaded PIFA antenna at (a) 2.44 GHz, (b) 3.64 GHz and (b) 5.8 GHz.

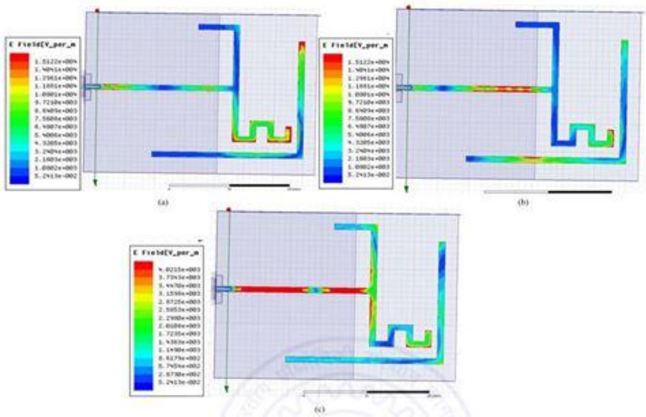
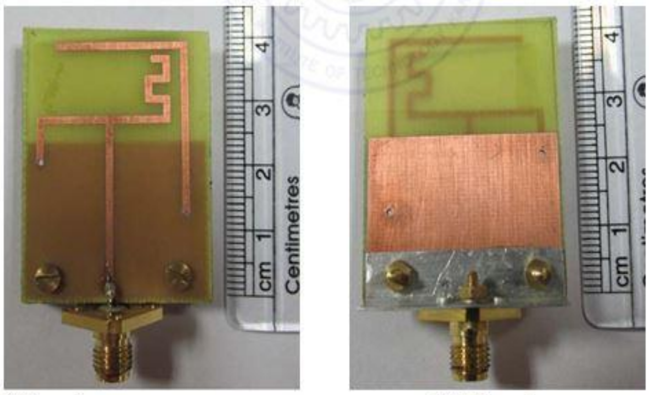


Figure: Simulated electric field distribution of inductor loaded PIFA antenna at (a) 2.44 GHz, (b) 3.62 GHz and (C) 5.8 GHz.



(a)Top view (b)Bottom view

Figure : Fabricated inductor loaded PIFA antenna.

gives an optimum radiation in all planes. The radiation patterns in all the three principal planes at 2.44 GHz, 3.62 GHz and 5.80 GHz of the proposed antenna are shown in Figure , Figure and Figure.

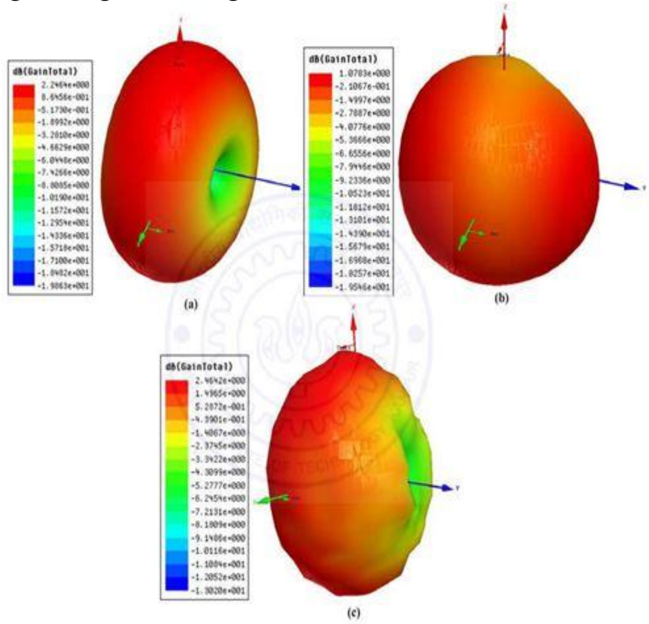


Figure : 3D gain plots of the L loaded PIFA antenna at (a) 2.44 GHz, (b)3.62 GHz and (c) 5.80 GHz.

VIII. CONCLUSION AND FUTURE SCOPE

Conclusions

The antenna miniaturization process for PIFA antennas kept limitations on ground plane size. Also the heightening of radiating structure in PIFA antennas over the ground plane increases their volume. This is resolved by printing the radiating metallic strip directly on one side of the dielectric and shorting the radiating strip through a via to the bottom ground plane. The ground plane is generally a partial metal surface printed on the other side of substrate.

- A dual frequency meander line PIFA antenna of miniaturized size which can operate in WLAN (2.3-2.4 GHz)and WiMax (2.50-2.69 GHz) band has been designed. It satisfies the IEEE802.11 ac standards (2.4 − 2.4835 GHz and 5.15 − 5.725 GHz) and hence can be used in all indoor and outdoor communication devices.
- A triple-band PIFA antenna has been designed by introducing the L shaped loading. This antenna can be used in upper WiMax (2.50-2.69 GHz) band and 4G mobile applications as it satisfies the TD-LTE (2.3-2.4 GHz) band requirements.

Future Scope

The proposed inductor loaded PIFA antenna can be modified further to accommodate all the GSM bands by introducing new radiating strips at a proper distance from the shorted radiating strip. The loading techniques in this planar environment can be introduced to the curved planes or cylindrical ground planes where conformal PIFA antennas can be formed.

REFERENCES

[1] C. Rowell, E. Y. Lam, “Mobile-Phone Antenna Design,” in Antennas and Propagation Magazine, IEEE, vol. 54, no. 4, pp. 14-34, Aug. 2012.
[2] Kin-Lu Wong, Planar Antennas for Wireless Communications, John Wiley & Sons, New Jersey, 2008.
[3] C. A. Balanis, Antenna Theory, Third Edition, John Wiley & Sons, 2005.
[4] Carver, R. Keith, J. Mink, “Microstrip antenna technology,” in IEEE Trans- actions on Antennas and Propagation, vol. 29, no. 1, pp. 2-24, Jan 1981.
[5] Zhi Ning Chen and Michael Y. W. Chia, Broadband planar antennas : design and applications, John Wiley & Sons Ltd, 2006.
[6] [6] W. Menzel, W. Grabherr, “A microstrip patch antenna with coplanar feed line,” in Microwave and Guided Wave Letters, IEEE , vol. 1, no. 11, pp. 340- 342, Nov. 1991.
[7] Leo G. Maloratsky, Integrated Microwave Front-Ends with Avionics Applica- tions, Artech House, 2012.
[8] R. B. Waterhouse, “Small microstrip patch antenna,” in Electronics Letters, Vol. 31, pp. 604 - 605, Apr. 1995.
[9] R. B. Waterhouse, “Broadband stacked shorted patch,” in Electronics Letters, vol. 35, no. 2, pp. 98-100, 21 Jan 1999.
[10] H. K. Kan and R. B. Waterhouse, “Size reduction technique for shorted patches,” in Electronics Letters, Vol. 35, pp. 948-949, Jun. 1999.
[11] T. Taga, K. Tsunekawa, “Performance Analysis of a Built-in Planar Inverted-F Antenna for 800 MHz Band Portable Radio Units,” in IEEE Trans. Selected Areas in Communication, Vol. 5, No. 5, pp. 921-929, Jun 1987.
[12] Kyohei Fujimoto, J. R. James, Mobile Antenna Systems Handbook, Third Edition, Artech House Inc., Norwood, MA, 2008.
[13] R. Vaughan, “Model and Results for Single Mode PIFA Antenna,” in Antennas and Propagation Society International Symposium 2004 IEEE, vol. 4, pp. 4028- 4031, 20-25 June 2004.
[14] Zhu Qi, Fu Kan, Liang Tie-zhu, “ Analysis of Planar Inverted-F Antenna Using Equivalent Models,” in Antennas and Propagation Society International Symposium 2005 IEEE, vol. 3A, pp. 142-145, 3-8 July 2005.
[15] Kin-Lu Wong, Yuan-Chih Lin, Ting-Chih Tseng, “Thin internal GSM/DCS patch antenna for a portable mobile terminal,” in Antennas and Propagation, IEEE Transactions on, vol. 54, no. 1, pp. 238-242, Jan. 2006.
[16] S. H. Yeh, K. L. Wong, T. W. Chiou, and S. T. Fang, “Dual-band planar inverted-F antenna for GSM/DCS mobile phones,” in IEEE Transactions on Antennas and Propagation , Vol. 51, pp. 1124-1126, May 2003.
[17] C. H. Chang and K. L. Wong, “Printed λ/8 -PIFA for penta-band WWAN operation in the mobile phone,” in IEEE Transactions on Antennas and Prop- agation , vol. 57, no. 5, pp. 1373-1381, 2009.
[18] Kin-Lu Wong, Compact and Broadband Microstrip Antennas, John Wiley & Sons, New Jersey, 2002.
[19] W. P. Dou and Y. W. M. Chia, “Novel meandered planar inverted-F antenna for triple frequency operation,” in Microw. Opt. Technol. Lett., vol. 27, pp. 58-60, 2000.
[20] Lo, T. K. C., Yeongming Hwang, “Bandwidth enhancement of PIFA loaded with very high permittivity material using FDTD,” in Antennas and Propaga- tion Society International Symposium, 1998. IEEE , vol. 2, pp. 798-801, 21-26 Jun 1998.

