DESIGN OF PLANAR INVERTED -F ANTENNA FOR WIRELESS APPLICATIONS

Dr.S.RAGHAVAN*, N.JAYANTHI

* Senior Professor
Department of Electronics and Communication Engineering
National Institute of Technology
Tiruchirappalli, INDIA
E-mail: raghavan@nitt.edu
www.nitt.edu

*Abstract:-*The design of single feed dual band PIFA operating at 2.25and 3.546 GHz is presented. Two dimensional method of moments (MOM) electromagnetic simulator, IE3D version: 12, is used in the design simulation of this dual band antenna. The results exhibit a proper operation of the antenna in terms of return loss, bandwidth, efficiency, gain at both bands.ISM,Bluetooth,Wi-max, IEEE 802.11b, 802.11g, 802.11n, 802.16e, WiFi, Wi-max are the most important applications within the above mentioned frequency bands. Simulation tool, based on the method of moments (ZELAND IE3D version 12.0) has been used to analyze and optimize the antenna. The measured and simulated results are presented and all are acceptable to the standard antennas.

Keywords: ISM, Bluetooth, Wi-max, PIFA, Method of Moments, NLOS, WiFi.

1 Introduction

Planar Inverted-F Antenna (PIFA) and Microstrip Antenna (MSA) have been popular for handling wireless devices because these antennas have low profile geometry instead of protruding as most antennas do on handheld radios. PIFA is a quarter wavelength shorted patch, which consists of a finite ground plane, a top radiator, a coaxial probe and a shorting mechanism that short the top radiator to the ground plane. These antennas can be further optimized by adding new parameters in the design, such as strategically shaping the conductive plate, or judiciously locating loads. The major limitation of many low profile antenna narrow bandwidth. Bandwidth in these antennas is almost always limited by impedance matching. In this design using slots on the patch, miniaturization of the PIFA is achieved from [3].Among other types of radiators, inverted-F Antennas (IFAs) (wire element, planar or printed ones) have been utilized in diverse areas of communication systems , exhibiting low profile structure and flexibility in impedance matching [4]. Furthermore, previous works showed that planar IFAs constitute good candidates for dual-frequency, triple and Quad-band of operation [1-2]. With the advance of wireless communication systems and increasing importance of other wireless applications in recent years, small size Multiband antennas are in great demand for both commercial and military applications. Meander line and zig-zag antennas have been studied for their capability in antenna size-reduction. However, the fractal concept can also be used to reduce antenna size. Cohen [1] was the first to develop an antenna element using the concept of fractals, reducing antenna size without degrading the performance. It can be hiding in to the housing of the mobile when comparable to whip, rod and helix antenna. It is having reduced backward radiation towards the user's head, minimizing the electromagnetic wave power absorption (SAR) and enhances antenna performances. Instead of wire radiator in IFA, PIFA has a patch type of radiator above certain height from the ground plane, and the shorting pin which shorts the ground plane and the radiating patch and it consists of co-axial probe feed. Different from Euclidean geometries, fractal geometries have two common properties, space-filling and self-similarity. It has been shown that the self-similarity property of fractal shapes can be successfully applied to the design of Multiband fractal antennas, such as the Sierpinski Gasket Antenna, while the space-filling property of fractals can be utilized to reduce antenna size [2-4].

Fractals can be used to miniaturize patch elements as well as wire elements, due to their space filling properties [5-6]. The same concept of increasing the electrical length of a radiator can be applied to a patch element. The patch antenna can be viewed as a Microstrip transmission line [7]. Therefore, if the current can be forced to travel along the convoluted path of a fractal instead of a straight Euclidean path, the area required to occupy the resonant transmission line can be reduced. This technique has been applied to patch antennas in various forms [8].

The Front view details of the proposed dual band Planar inverted –F antenna is shown in Fig (1), 2-D Top view of the proposed PIFA is shown in the Fig. 2 and Fig. 3 shows detail dimension of the radiating patch. Wireless communication have progressed very rapidly in recent years, and many mobile units are becoming smaller and smaller. To meet the miniaturization requirement, the antennas employed in mobile terminals must have their dimensions reduced accordingly [4]. The same concept of increasing the electrical length of a radiator can be applied to a patch element. The patch antenna can be viewed as a Microstrip transmission line [8]. Therefore, if the current can be forced to travel along the convoluted path of a fractal instead of a straight Euclidean path, the area required to occupy the resonant transmission line can be reduced. This technique has been applied to patch antennas in various forms [9]. The antenna is fed by a probe coaxial feed and Simulated using Zeland IE3D [10].

Planar antennas, such as Microstrip and printed antennas have the attractive features of low profile, small size, and conformability to mounting hosts and are very promising candidates for satisfying this design consideration. The major limitation of many low-profile antennas is narrow bandwidth. Bandwidth in these antennas is almost always limited by impedance matching. Study also shows that resonant frequency decreases as the width of the shorting pin decreases and also the finite ground plane plays important role in PIFA [1]. Here the antenna designed for the bands extend from 2.41GHz to 2.92 GHz and 2.54 to 3.1176 GHz is presented.

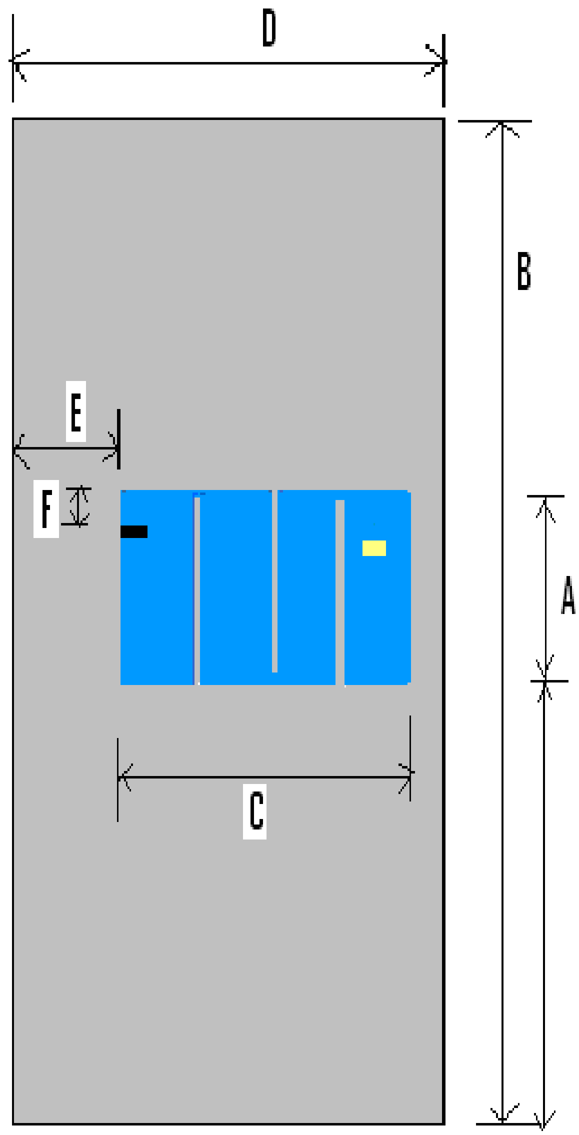

Fig.1 Proposed dual band PIFA

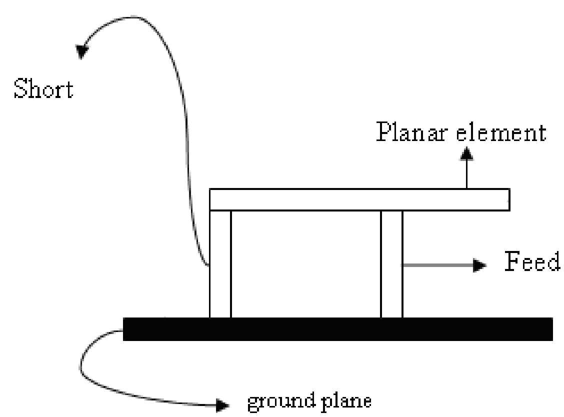

Fig.2 proposed dual band PIFA Front view

(all dimensions are in mm)

Dimension of the ground plane (40,100)

Dimension of the radiating patch (18.5, 10)

Feed-Probe Radius (0.635)

Width of the short circuit plate 1

Height of the short circuit plate 10.8

Spacing between the feed and the short is 11.5

Air gap is 10

FR-4 substrate thickness is 0.8 mm

These dimensions are selected to give a resonant frequency in ISM Band Bluetooth, Wi-Max application.

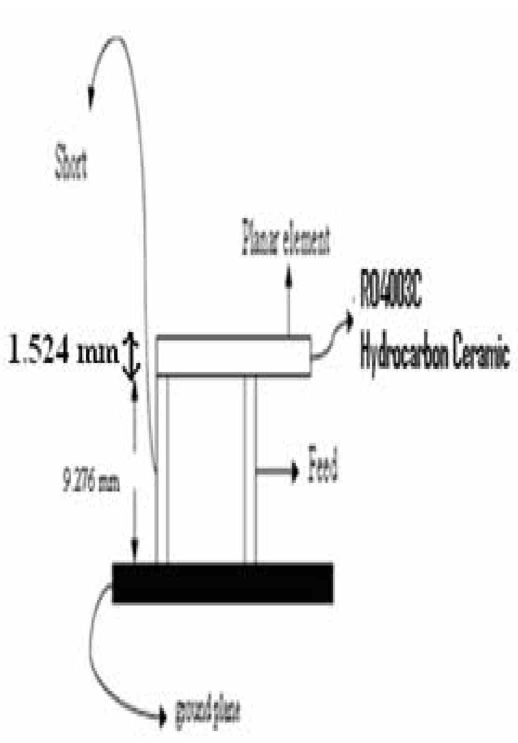

Fig.3 proposed dual band PIFA Top view

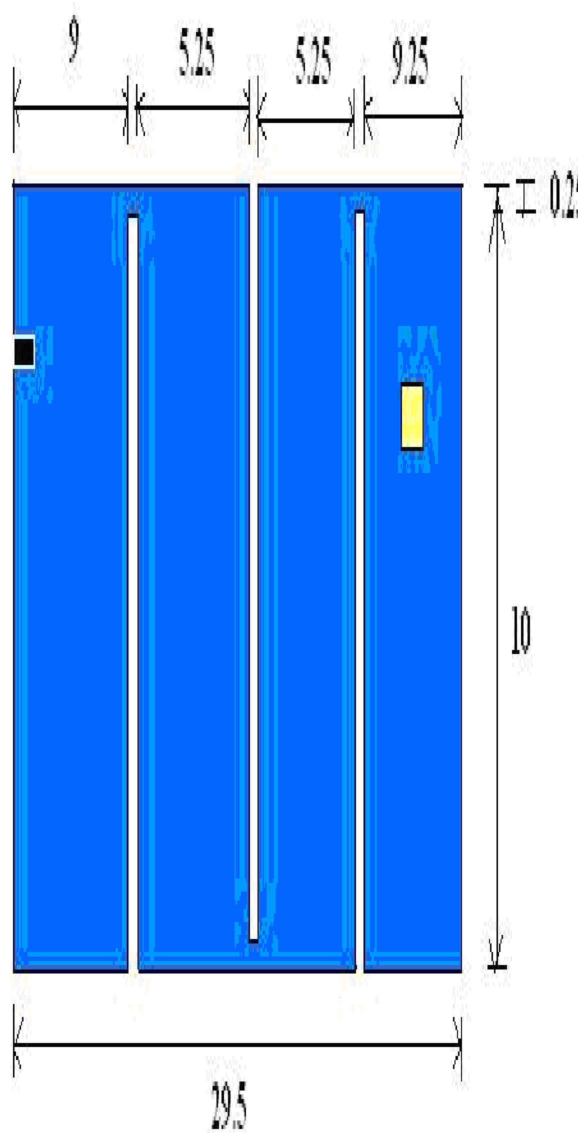

Fig.4 Detailed Dimensions of the radiating Patch

All measurements are in mm. Ash color denotes ground plane, Blue area denotes Metal, Right yellow area denotes Probe feed (0.6- Radius) and the left small black area denotes **Shorting plate** of dimension **(1×0.5).**

2 Antenna design and Structure

A=10, B=100, C=29.5, D=42, E=11.5, F=2.5 for the fig (1). Probe feed center point is at (27.5, 7), and the top radiating patch is 10.8mm height above the ground plane.

Equation for the PIFA (if the width of the radiating patch is not equal to the width of the shorting pin) is given below:

$$f_r = l_1 + l_2 + h - w = \frac{\lambda_0}{3}$$

Where l_1, l_2 length and width of the radiating patch, h is the height of the patch from the ground plane
The resonant frequency of the antenna can be computed using the following equations,

$$L_2 + \mathrm{H} = \frac{\lambda_0}{4} \quad (1)$$

Where λ_0 is the wavelength. Resonant frequency associated with W = L1 calculated from equation (1).

$$f_1 = \frac{c}{4(L_2 + H)} \quad (2)$$

Where c is the speed of light. The other case is for W = 0. A short-circuit plate with a width of zero can be physically represented by a thin short circuit pin. The effective length of the current is then L_1+L_2+H. For this case, the resonance condition is expressed by,

$$L_1 + L_2 + H = \frac{\lambda_0}{4} \quad (3)$$

The other resonant frequency that is part of the linear combination is associated with the case $0<W<L_1$ and is expressed as,

$$f_2 = \frac{c}{4(L_1 + L_2 + H - W)} \quad (4)$$

For the case when $0<W/L_1<1$, the resonant frequency f_r is a linear combination of the resonant frequencies associated with the limiting cases. The resonant frequency f_r is found using the experiment for f_1 and f_2 above in the following:

$$f_r = rf_1 + (1-r)f_2 \qquad \text{for } \frac{L_1}{L_2} \le 1 \quad (5)$$

$$f_r = r^k . f_1 + (1-r^k).f_2 \qquad \text{for } \frac{L_1}{L_2} \ge 1 \quad (6)$$

Where, $r = W/L_1$ and $k = L_1/L_2$

The PIFA design using the procedure illustrated above is not unique. One can find many cases in which the specifications are satisfied. Currently, a design procedure to optimize the size of a PIFA does not exist. A more through study of the parameters of the PIFA has to be performed to further characterize the antenna.

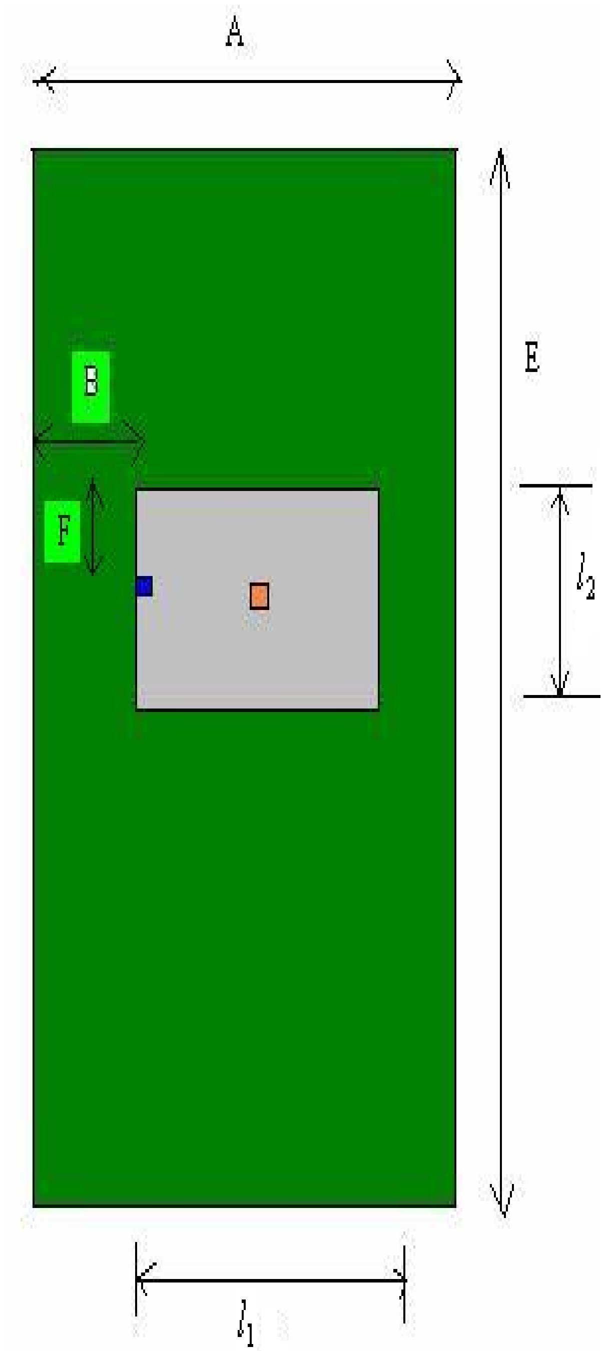

Fig.5 Proposed PIFA Antenna Structure

Fig.6 Photograph of the Proposed Antenna

3 Substrate details

The substrate height from the ground plane 0mm to 9.276mm is air. And from 9.276mm to 10.8mm, the substrate which is used in this Antenna is RO4003C Hydrocarbon ceramic with Dielectric Constant $\varepsilon_{r} = 3.33$,Loss tangent Tan $\delta = 0.027$and the thickness =1.524 mm.These dimensions are also selected to give resonant frequency in ISM, Bluetooth, Wi-max application.

4 Comparison of Measured and Simulated Results

The simulations were carried out on a package software IE3D [5] from Zeland.
Table I and II shows the comparison of antenna parameters for antenna I (without substrate) and II (with substrate) respectively.

Antenna I	Resonant frequency (GHz)	Bandwidth (MHz)	Return loss (dB)	F_L (GHz)	F_H (GHz)	Gain
Simulation results	2.67	557	-34.72	2.366	2.894	θ=0° is -10 dBi and θ=45° is 3.5dBi (peak gain)
Measured results	2.64	510	-18.15	2.41	2.92	θ=0° is -9 dBi and θ=45° is dBi 2.1 (peak gain)

Table I Comparison of Antenna Parameters for Antenna I

Radiation pattern is nearly Omni directional radiation pattern in azimuth plane and peak gain 2.1, 2.9 dBi occurs at θ=45º for antenna I antenna II respectively Simulation Vs measured Return loss plot is shown in Fig (c) and Fig (d) for antenna I and II respectively. The simulated radiation patterns for θ=45º is shown in fig (e) and (f) for antenna I and II respectively. Simulation results of PIFA I has a gain of -10dBi in the horizontal field (θ=0º). E_θ is maximum at θ=45º with the peak gain of +3.5 dBi. PIFA II has a gain of -9dBi in the horizontal field (θ=0º). E_θ is maximum at θ=45º with the peak gain of +4.25 dBi. These radiation characteristics will be useful for NLOS (non line of sight) application. Proper positioning of feed and the short will provide excellent impedance matching of the antenna and it is shown in the smith chart in Fig (g)

Antenna II	Resonant frequency (GHz)	Bandwidth (MHz)	Return loss (dB)	F_L (GHz)	F_H (GHz)	Gain (dBi)
Simulation results	2.40576	516	-34	2.17	2.687	θ=0° is -9 dBi and θ=45° is 4.25 dBi (peak gain)
Measured results	2.85	577	-35	2.54	3.1176	θ=0° is -11 dBi and θ=45° is 2.9 dBi (peak gain)

Table II Comparison of Antenna Parameters for Antenna II

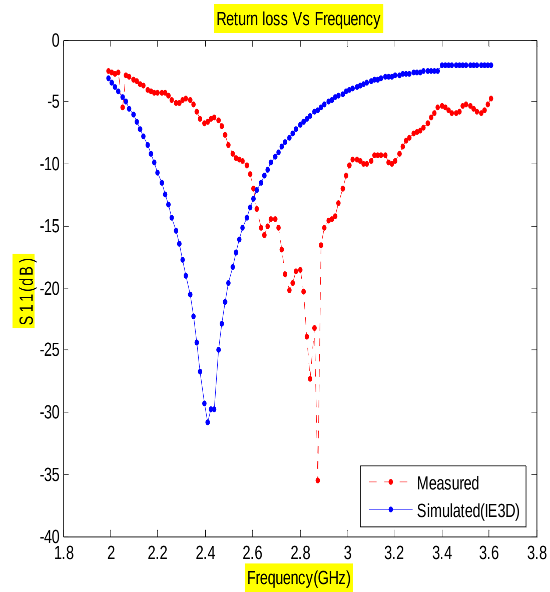

Fig.8 Simulation Vs measured Return loss for Antenna II

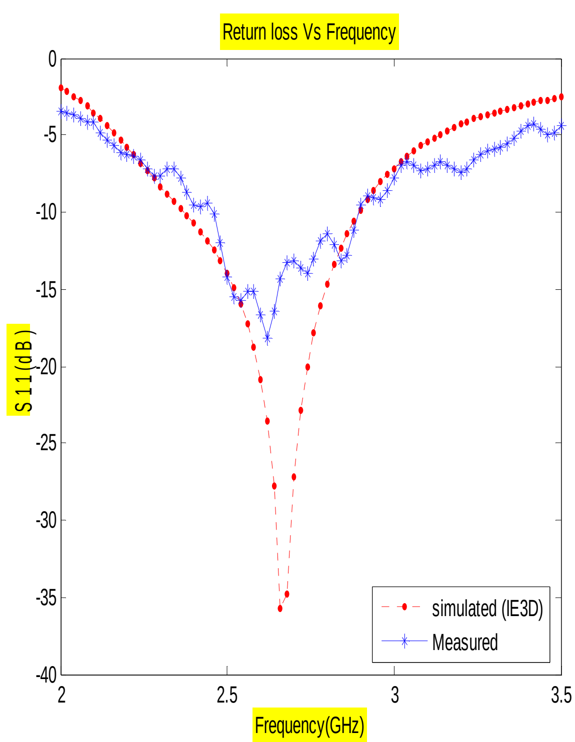

Fig.7 Simulation Vs measured Return loss for Antenna I

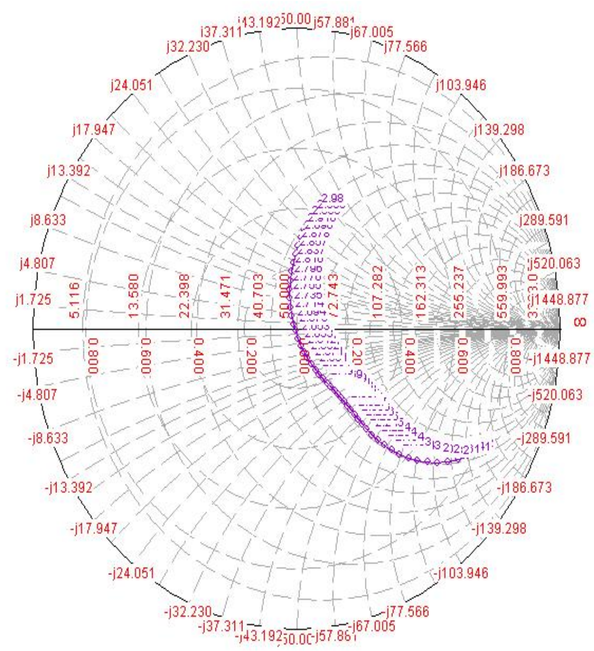

Fig. 9 Smith Chart for the Proposed Antenna

4 Results and Observations

Throughout the design process, simulations were carried out on a package software IE3D [6] from Zeland. The return loss (S_{11}) in dB (-39 decibel at 2.25 GHz) and (-24decibel at 3.546 GHz) vs. Frequency is shown in fig 4**.** Radiation pattern is nearly Omni directional in Azumithal plane cut at θ=45˚ for both the resonant frequencies (2.25 GHz and 3.546 GHz) is shown in the fig. 5 and fig.6. Efficiency at 2.25 GHz resonant frequency is 90% and at 3.546 GHz resonant frequency is 77%. Efficiency at both resonant frequencies is above the acceptable range. Narrow bandwidth is one of the limitations for its commercial applications for wireless mobile. Keeping the short post near to the feed probe point is a good method for reducing the antenna size, but these results in narrow impedance bandwidth. Table 1 shows the antenna parameters like return loss bandwidth and gain for both the band of frequencies. Fig.7 shows total field gain and directivity Vs frequency plot. Gain and directivity are good enough in the specified bandwidth for mobile terminal Antennas.

Dual band antenna	Resonant frequency(GHz)	Bandwidth (MHz)	Return loss (dB)	F_L (GHz)	F_H(GHz)	Peak Gain (dBi)	Directivity (dBi)
Band I	2.25	530	-39	2.06	2.59	4.68 at (θ=45)	5.1
Band II	3.546	303	-24	3.146	3.719	3.67 at (θ=45)	4.8

Table III Antenna Parameters

Study shows that different ground plane dimensions leads to different antenna characteristics. Even, if the position of the PIFA is varied in a fixed finite ground plane results in different characteristics. fig (i) shows that the change in the position of the radiating patch in the finite ground plane results in a different return loss at different resonant frequencies. In the fig (i) the different point (x, y) denotes the centre point of the radiating patch, from the finite ground plane. Return loss versus frequency of the I antenna is shown in fig. 10. and radiation pattern of the I antenna is shown in fig. 11.

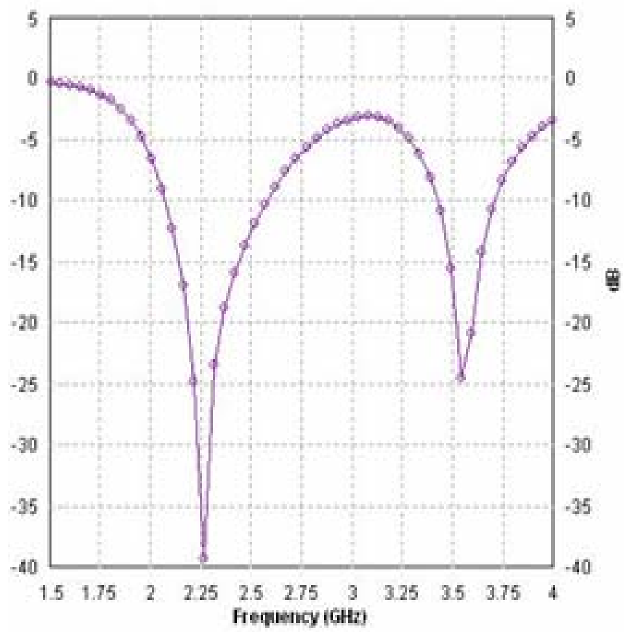

Fig.10 Return loss vs. Frequency

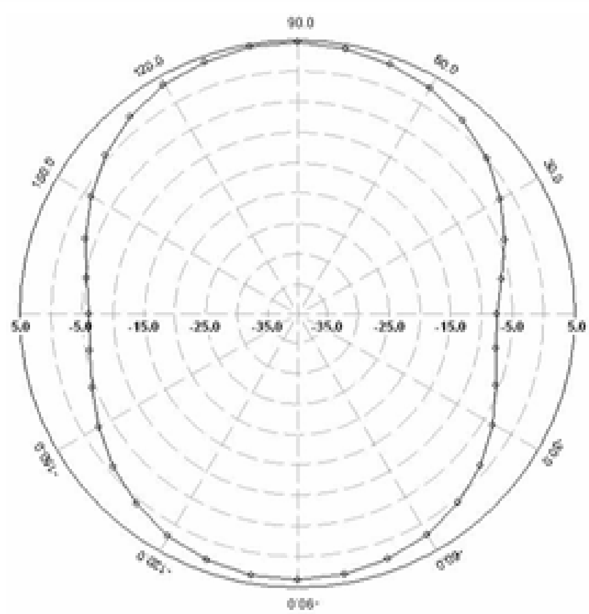

Fig.11 Radiation Pattern at 2.5 GHz

Radiation pattern at 3.54 GHz frequency is shown in fig. 12.

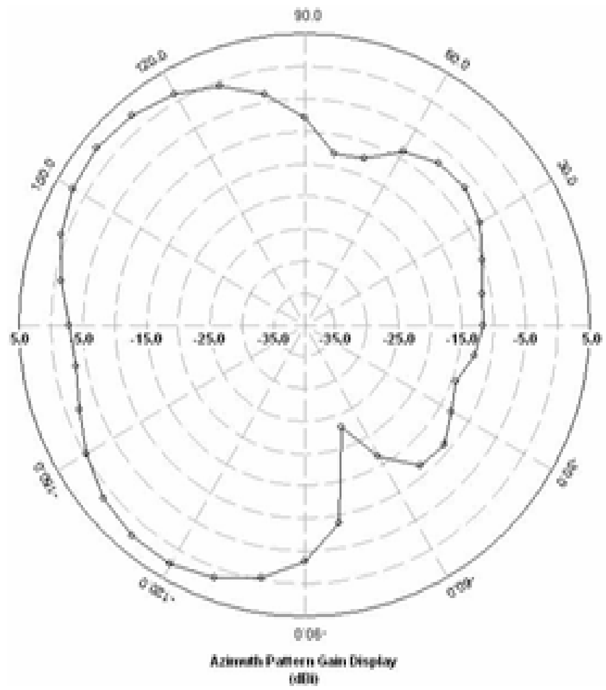

Fig. 12 Radiation Pattern at 3.54 GHz

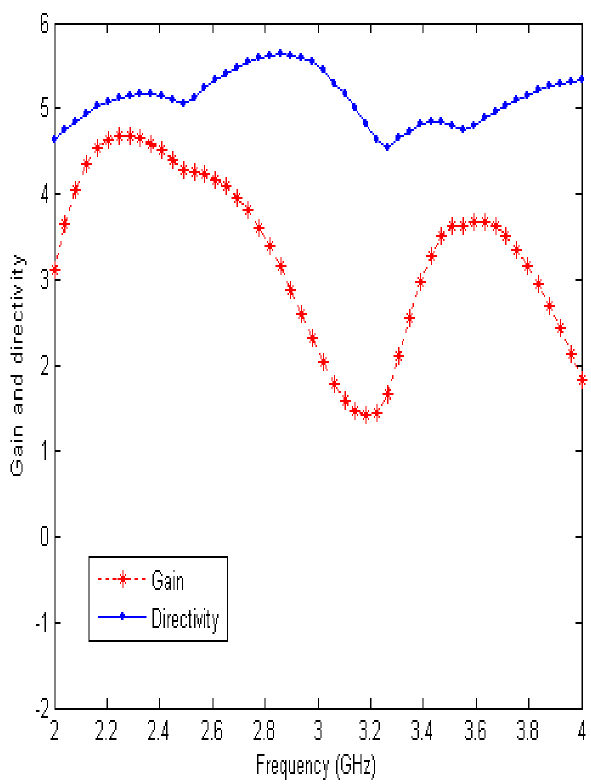

Fig. 13 Frequency vs Gain and Directivity

Radiation pattern is nearly Omni directional radiation pattern in azimuth plane and peak gain 2.1, 2.9 dBi occurs at θ=45º for antenna I antenna II respectively Simulation Vs measured Return loss plot is shown in The simulated radiation patterns for θ=45º is shown in fig.11 and fig.12 for antenna I and II respectively. Simulation results of PIFA I has a gain of -10dBi in the horizontal field (θ=0º). E_θ is maximum at θ=45º with the peak gain of +3.5 dBi. PIFA II has a gain of -9dBi in the horizontal field (θ=0º). E_θ is maximum at θ=45º with the peak gain of +4.25 dBi. These radiation characteristics will be useful for NLOS (non line of sight) application. Proper positioning of feed and the short will provide excellent impedance matching of the antenna and it is shown in the smith chart in Fig.9 and Frequency versus return loss is shown in fig. 14.

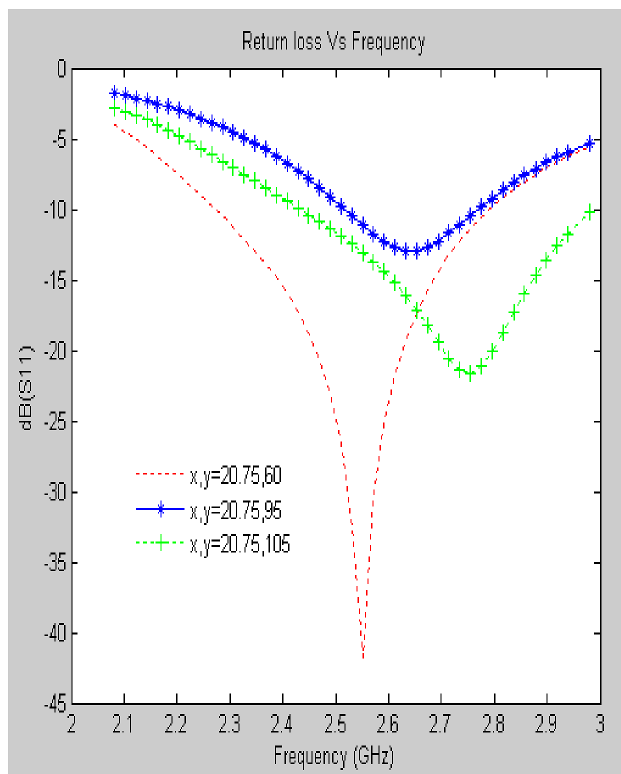

Fig.14 Frequency vs. Return Loss

5 Conclusion:

In this paper a compact dual band PIFA was presented. This antenna has a bandwidth of 530 and 303 MHz for 2.25 GHz and 3.546 GHz bands respectively, has an Omni directional radiation pattern and is very efficient. This antenna is suitable for ISM, Bluetooth, IEEE 802.11b, 802.11g, 802.11n, 802.16e, Wi-Fi, Wi-Max applications and this antenna design is mainly focusing on mobile terminal antennas. New applications are arising that will be included in mobile phones. If this antenna includes mobile application frequency bands then this will be very much useful. One prominent example is Bluetooth. A potential use for Bluetooth is the ability to walk into an office and set the mobile phone to synchronize with diary and email information on the desktop PC. Size reduction is needed also for antennas incorporated in wireless applications. The method of moments is then used to model the PIFA mounted on a finite ground plane. Extensive simulations using IE3D and measurements were performed to investigate the characteristics of these antennas. Novel design of single feed PIFA (width of the shorting pin is not equal to the width of the radiating patch) was presented. Antenna I and II has a bandwidth of 510 and 577 MHz respectively. This Omni directional radiation pattern of this type of antenna is very much useful for mobile devices, because the position of the user relative to the base station is not known. The antenna with different Substrates discussed in this paper is suitable for ISM, Bluetooth, Wi-Max, MMDS and NLOS applications. Therefore, designing an antenna that has multiple frequency bands of interest with one of them in the Bluetooth operating band is a useful structure in today's handheld wireless applications. New applications are arising that will be included in mobile phones. If this antenna includes mobile application frequency bands then this will be very much useful. One prominent example is Bluetooth. A potential useful use for Bluetooth is the ability to work into an office and set the mobile phone to synchronize with diary and email information on the desktop PC. Therefore, designing an antenna that has multiple frequency bands of interest with one of them in the Bluetooth operating band is a useful structure in today's handheld wireless applications.

Acknowledgement:

The authors would like to acknowledge the useful comments by Dr .Bharati Bhat, Professor (Rtd), IIT, Delhi.

References:

[1] Dalia Mohammed Nashant, Hala A.Elsadek Member, IEEE and Hani Ghali, Member, IEEE, "Single Feed Compact Quad-Band PIFA Antenna for wireless Communication Applications, IEEE Transaction on Antennas and propagation, Vol.3, No.8, August 2005.

[2] Tai-pin Huang "Design of triple wide bands and miniaturization PIFA for Microwave Communication"

[3] Kin-Lu Wong, "Planar antennas for wireless communications", John Wiley, 2003.

[4] "Design Guide for wireless device Antenna systems including: Bluetooth and 802.11 Applications, Centurion Wireless Technologies",

[5] Minh-Chau, T.Huynh "Numerical and Experimental investigation of planar Inverted –F Antennas for wireless communication Applications".

[6] IE3D version: 12, users Manual, Zealand Software.

[7] M.C Huynh and W.Stutzman, "Ground plane effects on the planar inverted-F antenna (PIFA) performance, "IEEE Proc. Microwave Antennas and propagation.

[8] M. Ismail, H. Elsadek, E. A. Abddallah and A. A. Ammar " Modified Pulse 2.45 Fractal Microstrip Antenna", WSEAS Transaction on Communications, Vol. 7, 2008, pp. 280-288.

[9] E. Hamiti, L. Ahma, and A. R. Sebak, Computer Aided Design of U-Shaped Rectangular Patch Microstrip Antenna for Base Station Antennas of 900 MHz System, WSEAS Transactions on Communications, Vol.5 , June 2006, pp. 961-970.

[10] G. S. Kliros, K. S. Liantzas, and A. A. Konstantinidis, Radiation Pattern Improvement of a Microstrip Patch Antenna using Electromagnetic Bandgap Substrate and Superstrate, WSEAS Transactions on

Communications, Vol.6 , Jan. 2007, pp. 45-52.

[11] *Z. Zaharis, D. Kampitaki, A. Papastergiou, A. Hatzigaidas, P. Lazaridis, M. Spasos* Optimal Design of a Linear Antenna Array using Particle Swarm Optimization," WSEAS Transactions on Communications, vol.5 , December 2005, pp.2142 – 2147.