A Quad Band Planar Inverted-F Antenna (PIFA) with Slotted Ground Plane

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Abstract- Planar inverted-F antennas are miniature designs that offer considerable versatility for both mobile and other wireless applications. The design is particularly suited for mobile devices. In this paper the design and of a compact quad band planar inverted-F antenna (PIFA) is proposed for mobile handset applications. The proposed antenna is a PIFA with slots inserted in top radiating patch as well as ground plane to get multi-band operation. The antenna covers GSM900, GPS, GSM1900 and UMTS bands. The antenna consists of a rectangular planar element suspended above the FR4 dielectric substrate. The ground plane is on the bottom side of the substrate. The antenna is having a simple structure, small size, wide bandwidth and good gain. The antenna geometry, simulations of return loss, hardware implementation and measured results are also discussed.

Index Terms- PIFA, internal antenna, FR4 dielectric, planar element, return loss, VSWR

I. Introduction

Rapid growth in wireless communications all over the world has lead to the development of multiple wireless standards and portable communication devices .The key to the operation of these devices is the antenna and hence there is a great demand of developing miniaturized antennas that can be easily integrated within the space available inside the portable devices. Such antennas should be less prone to damage, compact in total size and aesthetic from the appearance point of view. Conventional microstrip antenna designs are based on half-wavelength of operation, while the Planar Inverted-F Antenna designs invoke the quarter-wavelength operation. The quarter wavelength of PIFA operation is due to the connection of the radiating element to the ground plane through a shorting strip or pin. Thus planar inverted-F antenna (PIFA) is a promising structure to meet these requirements of portable devices [1].

PIFA is extended form of Inverted F antenna (IFA) which have a plate in place of wire radiator element to expand the bandwidth. By integrating this type of mobile phone antenna into a handset, several advantages are possible compared to conventional antennas, such as monopole or spiral antennas. They are easy to fabricate, have a simple structure, small volume, low manufacturing cost. PIFA structure is easy to hide in the casing of the mobile handset as compared to monopole, rod & helix antennas. Also, PIFA has reduced backward radiation towards user's head and body which further minimizes SAR and improves performance [2]. They can resonate at much smaller antenna size and by cutting slots in radiating patch, resonance can be modified. Proper changes results in multiband operation.

In this paper, the design of a quad band planar inverted F-antenna (PIFA) working in GSM900, GPS, GSM1800 and UMTS bands is presented. The radiating element presents an omni-directional radiation pattern, a relatively high gain and at the same time, is having a simple structure. Suitable dimensions are selected for the antenna to achieve the required bandwidth [3].

Next section explains the basic structure of simple PIFA and discusses the relationship between various parameters. Section III discusses the design of the proposed antenna and its properties using HFSS simulation software. Section IV provides conclusion and section VI is acknowledgement.

II. PIFA Theory

PIFA Structure

PIFA structure consists of a ground plane, a resonating metallic plate i.e. a patch, a feed wire & one or more shorting pins or plates to connect the top patch and the ground plane. Fig. 1 shows a basic PIFA structure which is fed at the base by a feed wire. In a PIFA structure there are several design variables which can be varied and the performance of the desired antenna is achieved [4]-[5]. Some of the design variables are width, length and height of the top radiating patch, width and position of shorting pin or plate, location of the feed point, dimensions of the ground plane.

The performance of the antenna can be enhanced by varying ground plane length. Optimum length of the ground plane is 0.4λ at the operating frequency [6]. In several designs, position of the antenna on the dielectric substrate is important as enhancement in the operating bandwidth can be achieved to few more percentage. The antenna is fed through feeding pin which connects to the ground plane. This type of feeding technique allows designer to place it at any desired location in the patch. The shorting pin and shorting plate allows good impedance matching achieved with the patch above ground plane of size less than λ/4. Resulting PIFA structure is of compact size than conventional λ/2 patch antennas.

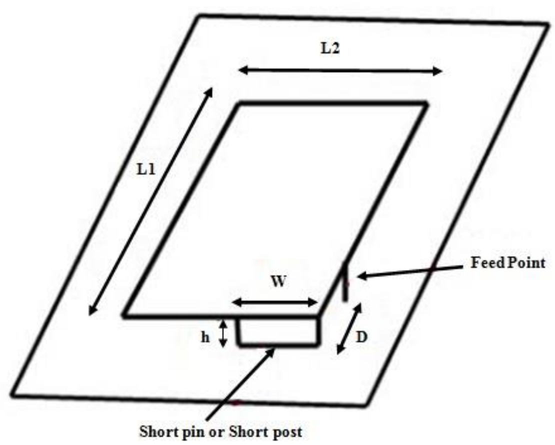

Fig.1: Basic PIFA Structure

B. Basic Design Equation

The frequency at which PIFA resonates can be calculated by using a basic formula as given below

$$L_1+L_2-W = \lambda_g/4 \qquad (1)$$

Where L_1 is Top patch length
L_2 is Top patch Width

λ is wavelength corresponding to resonant- frequency

The wavelength here is the guided wavelength which is given as

$$\lambda_g = \lambda_{0/}\varepsilon_r \qquad (2)$$

This equation stems from the theory that if we arbitrarily take a point far away from the short circuit edge on the top radiating patch , and calculate the current path , on an average it will be equal to L_1+L_2-W

$$\text{But } \lambda_0 = c/f \qquad (3)$$

Also PIFA sits on top of a dielectric substrate with permittivity ε_r

Therefore the above equation can be written as

$$L_1 + L_2-W = c\ /4f\sqrt{\varepsilon_r} \qquad (4)$$

Where c is the speed of light,
f is the resonant frequency

Above equation represents that the resonant frequency is dependent on width and length of the top plate, the width of the shorting plate and the substrate used. Further more if the height of PIFA is taken as a parameter and if permittivity is taken as the effective permittivity respective to each substrate then the equation can be modified as

$$L_1 + L_2-W+h = c\ /4f\sqrt{\varepsilon_{reff}} \qquad (4)$$

Where the effective permittivity respective to each substrate is approximated using Equation:

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2}\ .$$

The equation shows that the sum of the width and length of the top plate should be λ/4. This approximation is very rough and does not cover all the parameters that significantly affects the resonant frequency of the antenna [7]. As width of the shorting plate also affects resonant frequency of the antenna. So, reduction in the width of shorting plate results in lowering the resonant frequency and vice versa.

By analyzing the resonant frequency and bandwidth characteristics we can determine the optimum location of the feed point, at which minimum return loss is to be obtained. By optimizing the spacing between feed point and shorting point impedance matching of the PIFA can be obtained .To broaden the bandwidth of PIFA structure various techniques have been employed and the most widely used method is to increase the height of the shorting plate which finally results in increase of volume[8]. Several other techniques can also be used to enhance the bandwidth of a PIFA namely using dielectric material of high permittivity [9], using capacitive loading, using additional shorting plate etc.

III. Proposed Antenna

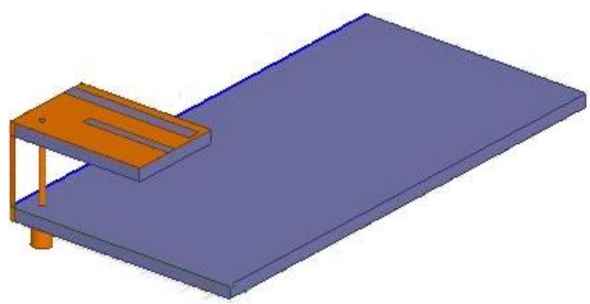

Fig.2: 3-D view of proposed antenna structure

The structure of the proposed PIFA antenna is shown in Fig.2 The proposed PIFA antenna consists of main radiating patch, a rectangular ground plane, a shorting plate, coaxial feed and a ground plane. Slots are inserted in the top radiating patch as well as ground plane so as to obtain multi-band operation. The antenna is designed using a dielectric material as FR-4 which has loss tangent, δ=0.02, dielectric constant, εr = 4.4 and substrate height, h = 1.6 mm.

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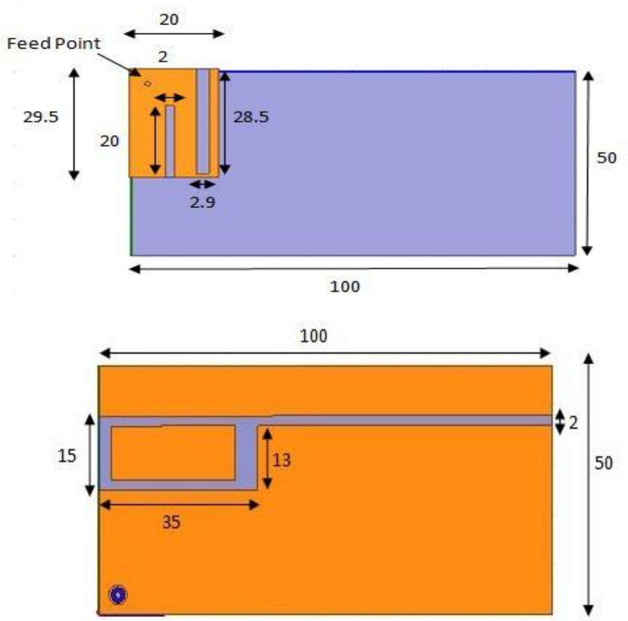

Fig.2: Dimensions of a)Top Radiating Patch b)Ground plane

Feeding point source is used to excite the structure. Total dimensions of the radiating parts of the antenna are 20 x 28.5 mm^2. And that of ground plane are 120 x 50 mm^2. Height of the antenna is 8mm.It can be observed that radiating parts covers small portion of the total size of the antenna leaving more space available for other electronic components [10].

Table 1 shows the detailed dimensions of the proposed antenna having a rectangular radiating patch and ground plane

TABLE 1: Detailed Dimensions of Proposed Antenna

Parameter	Value (mm)
$L_{(ground)}$	100
$W_{(ground)}$	50
$L_{(patch)}$	50
$W_{(Patch)}$	21
$W_{(Short)}$	10
$h_{(short)}$	8

The simulation and analysis of the proposed antenna is done using High Frequency Structure Simulator (HFSS). The simulated reflection coefficient (S11) also known as return loss is presented in Fig. 3. It can be observed from S11 plot that the antenna covers the 850 MHz GSM band. The cellular and non-cellular bands covered by the proposed antenna are GSM900, GPS, GSM1900, PCS and UMTS bands.

The space between ground plane and top plate is air filled; here air is used as dielectric material [11]. Using a dielectric material between ground plane and top plate has effect on gain and bandwidth of PIFA antenna**.** To get good return loss and gain, the height of top plate selected is 10 mm. The ground plane, shorting plate and top plate are made perfect electrical conductor (pec) [12].

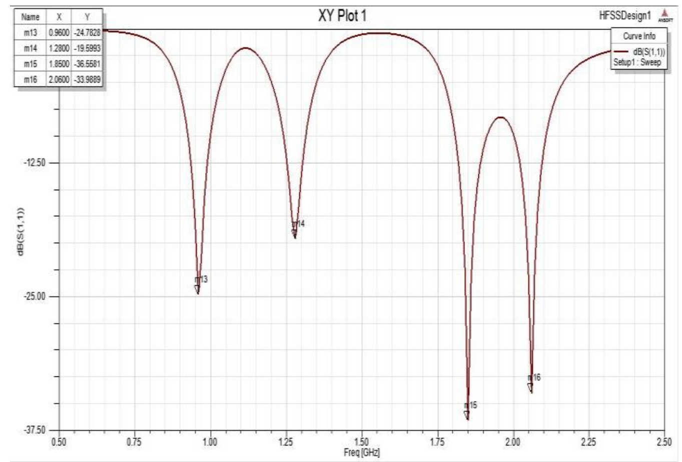

Fig. 3: The Simulated S11 (dB) of proposed PIFA

The bandwidth here can be specified as impedance bandwidth for which return loss S11 is -6 dB as this value is good enough for mobile handset applications. Also frequency bandwidth can be specified for voltage standing wave ratio (VSWR) less than 2:1 which is equivalent to 10 dB level.

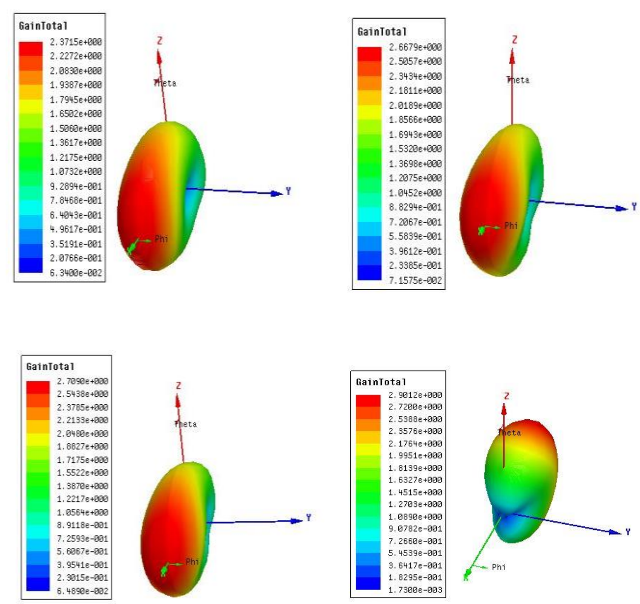

Fig. 4: The Simulated 3-D radiation pattern of proposed PIFA at a)960 MHz b)1.28GHz c)1.85GHz d)2.06 GHz

At this level 10% of the incident power is reflected back at the source.Therefore, the impedance bandwidth of the proposed PIFA design is the difference between upper and lower frequency which is 0.096 GHz, 0.075GHz, 0.105GHz, and 0.113GHz.

The simulated radiation patterns at resonant frequencies are given Fig. 4. The radiation pattern is the relative distribution of power radiated as a function of direction. Usually radiation pattern is determined in the far-field region. It can be seen that the antenna has a an Omni-directional radiation pattern in the three bands and a near omni-directional pattern in the fourth band. It shows that the antenna is a perfect radiator of electro-magnetic energy.

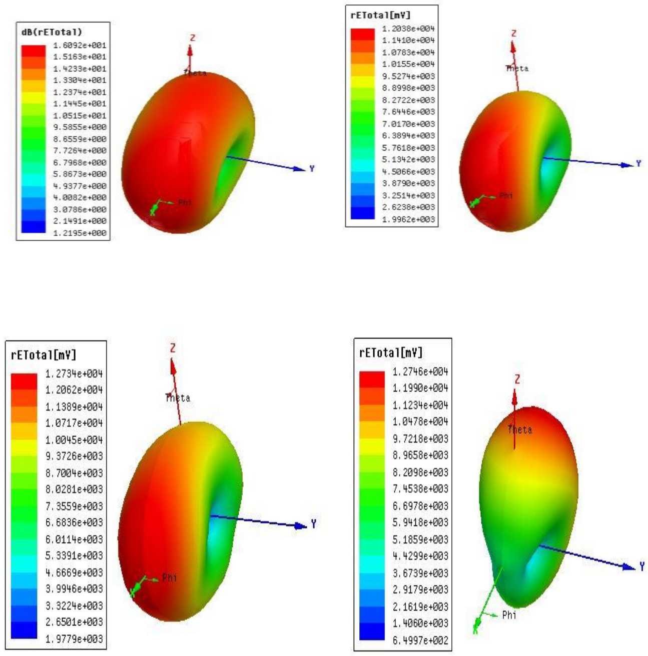

Fig. 4: The Simulated gain of proposed PIFA at a)960 MHz b)1.28GHz c)1.85GHz d)2.06 GHz

The gain is one of the important figure of merit of the antenna. The overall gain of the antenna obtained after simulation is shown in Fig. 4.4. A peak gain of 2.322 dB is observed at 867 MHz , 2.476 dB is observed at 1899 MHz and 4.516 dB is observed at 2.42 GHz.

The cellular bands covered by the simulated antenna are are GSM900, GPS, GSM1900 , PCS and UMTS bands.The antenna has a fair bandwidth ,omni –directional radiation pattern and low value of return loss which makes it desirable to be used with hand held devices. The simulation results show that the performance parameters of the antenna are satisfying the requirements of advance wireless communication devices.

IV. Conclusion

The design of a quad-band PIFA having simple structure which can work in the GSM900, GPS, GSM1900 , PCS and UMTS bands have been presented and proposed. Simulation results have shown good performance characteristics in terms of return loss gain and radiation pattern. There is a good agreement between measured and simulated results .The design details of the antenna can be used as base for increasing the number of bands covering several communication standards.

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References

[1] K. Hirasawa and M. Haneishi, Eds "Analysis, Design, and Measurement of Small and Low"-Profile Antennas. Boston, MA: Artech House, 1992.

[2] Kin-Lu Wong, "Planar Antennas for Wireless Communication", Published by John Wiley & Sons, Inc., Chapter: 2, Page(s): 26-65, 2003.

[3] Naveen Kumar , Garima Saini ,A Novel Low profile Planar Inverted-F Antenna (PIFA) for Mobile Handsets,International Journal of Scientific and Research Publications, Volume 3, Issue 3, March 2013.

[4] Ray J.A, Chaudhuri S.R.B., "A review of PIFA technology", IEEE Indian Antenna week (IAW), Page(s): 1 – 4, Dec. 2011.

[5] Belhadef, Y.; Boukli Hacene, N., "PIFAS antennas design for mobile communications", 7th IEEE International Workshop on Systems, Signal Processing and their Applications (WOSSPA), Page(s): 119 – 122, May 2011.

[6] C. Picher, J. Angueral, A. Andújar, C. Puente1, and S. Kahng, "Analysis of the Human Head Interaction in Handset Antennas with Slotted Ground Planes", IEEE Antennas and Propagation Magazine, Vol. 54, No. 2, Page(s): 36 – 56, April 2012.

[7] W. Geyi, Q. Rao, S. Ali, and D. Wang, "Handset Antenna Design: Practice And Theory", Progress In Electromagnetic Research Journal (PIER) , Vol. 80, Page(s) : 123–160, 2008.

[8] Ray J.A, Chaudhuri S.R.B., "A review of PIFA technology", IEEE Indian Antenna week (IAW), Page(s): 1 – 4, Dec. 2011.

[9] Belhadef, Y.; Boukli Hacene, N., "PIFAS antennas design for mobile communications", 7th IEEE International Workshop on Systems, Signal Processing and their Applications (WOSSPA), Page(s): 119 – 122, May 2011.

[10] Hattan F. AbuTarboush, R. Nilavalan, T. Peter and S. W. Chuang, "Small and Thin Inverted-F Antenna with Insensitive Ground Plane for Mobile Handsets", IEEE Loughborough Antennas and Propagation Conference (LAPC), Page(s): 109 – 112, November 2010.

[11] Tefiku, F. , "A Mobile Phone PCS PIFA with Low SAR", IEEE Antennas and Propagation Society International Symposium, Page(s): 4685 – 4688, 2007.

[12] Krzysztofik, W.J.; Skikiewicz, A., "Tapered PIFA Antenna for Handsets Terminals", 17th IEEE International Conference on Microwaves, Radar and Wireless Communications (MIKON), Page(s): 1 – 4, May 2008.

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