Design of Planar Inverted-F Antenna (PIFA) and Study of Ground Plane Effects on its Performance

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Abstract: The design of miniaturized antenna plays a very important role in development of portable communication systems. The resonance frequency, bandwidth and gain of an antenna directly depend on its dimensions. The idea is to find best geometry and structure. The planar inverted –F antenna is very popular for such portable wireless devices because of its compact size and low profile. In this paper, four designs of planar inverted –F antenna (PIFA) with a small square shape radiating element has been introduced to work between 1.67 GHz to 1.8 GHz for UAV, DCS and GSM applications. These antennas are low cost simple in design and easy to fabricate. The bandwidth provided by the PIFA is wide as compared to a conventional micro strip patch antenna of half wavelength. The dimensions of antenna have been optimized to have a wide bandwidth (9.47 %) with air as dielectric used in this design. The effect of different ground plane sizes has been analyzed. The results will be very useful in the design of PIFA for applications requiring a small ground plane. Simulated and measured results are presented for smallest structure.

***Keywords**: Planar inverted-F antenna, PIFA, Ground plane, Resonant frequency, Efficiency Bandwidth, DCS, GSM.*

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I. Introduction

In the design of PIFA, the most popular model for a ground plane is perfect ground plane which is assumed to be a perfectly conducting infinite size planar ground. The real ground plane is metallic sheet with finite size. Therefore there is a trade-off between geometry of antenna and ground plane size for desired electrical performance. The PIFAs are mostly used in portable wireless devices as they are capable of working in wireless bands. The geometry of PIFA requires very small ground plane so that it can be incorporated in small devices. The truncation of ground plane shows variation in efficiency [1]. Size reduction is usually achieved using shorting pins, stubs, capacitive loading and folding or meandering the resonators in an appropriate **f**orm [2]. Frequency tunable antenna is proposed in [3] to reduce the length of PIFA to λ/4 by placing a via patch under conventional PIFA. A slotted ground plane [4] is used to improve the bandwidth of antenna. In [5], a parasitic element top loading is used for bandwidth enhancement. A multiband response is obtained with slots and parasitic element introduced in the radiator [6], [7]. The proposed PIFA in this work, consists of a conducting plate called radiating patch used at a height parallel to a ground plane and is connected to ground by shorting pins enabling it to radiate at the frequency corresponding to quarter wavelength (λ/4) [8]. The single probe feed is kept at optimized distance from shorting pins.

II. Antenna design

The structure of PIFA is shown in fig. 1 and fig.2. The dimensions of radiating patch are 20x20 mm². Its height from ground plane is 10 mm. The separation between shorting pins is 5mm and radius of probe feed is 1.0 mm. The shorting pins are used to reduce antenna size and achieve wide bandwidth. The distance between shorting pins helps in increasing bandwidth. The distance between shorting pins and feed point varies the input impedance of the antenna. The location of pins, distance between them and distance of feed point from the pins has been adjusted to obtain a good bandwidth of 9.47 %. The dimensions of ground plane are also 20x20 mm².The dielectric used between top plate and ground plane is air. The top and ground plates are made up of copper with thickness of 0.5 mm.. As the dielectric constant of foam is approximately equal to air, it has been used as dielectric in fabricated design in place of air to support the top plate in air. The fabricated PIFA is shown in fig.9. The standard formula for PIFA dimensions is [8]:

$$f_0 = \frac{c}{4(L+W)\sqrt{\epsilon_r}}$$

Where,

f_0 is the resonant frequency , L is the length of radiating patch, W is the width of the radiating patch, c is the velocity of light in free space and ϵ_r is the dielectric constant of substrate. Length of top plate and length of shorting pins make the antenna size equal to quarter wavelength monopole. Thus this antenna is an unbalanced antenna [5].

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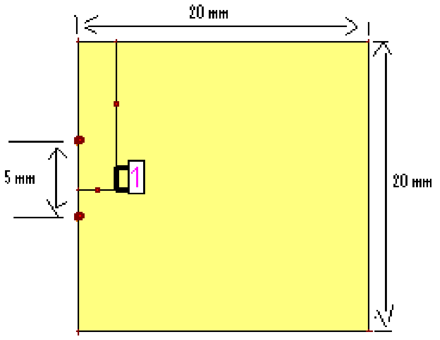

Fig.1 (Top view)

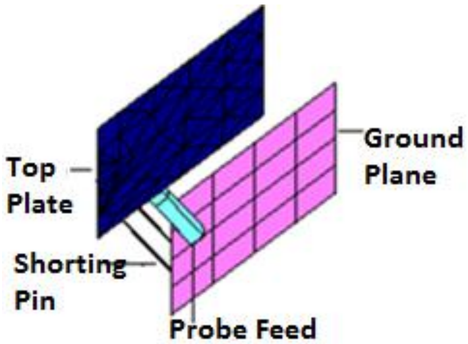

Fig.2 (Side view)

III. Design Analysis

The proposed antenna has been optimized and simulated on IE3D Zealand version10 software [9]. The results of return loss and efficiency on resonant frequency are shown in fig. 3 and 4 respectively. The comparison of simulated and measured results is shown in fig.5. The plot of total field gain versus frequency is shown in fig.6. The efficiency of antenna is more than 90 % at resonant frequency. The elevation pattern gain at **Φ= 0° , 90°** and **θ= 0°, 90°** are shown in fig. 7 and fig.8 respectively. The fabricated PIFA is shown in fig.9. Total electric field E is shown in fig.10. The graph of input impedance variation as per frequency is shown in fig. 11 and it is found that input impedance is close to 50 ohm at resonant frequency.

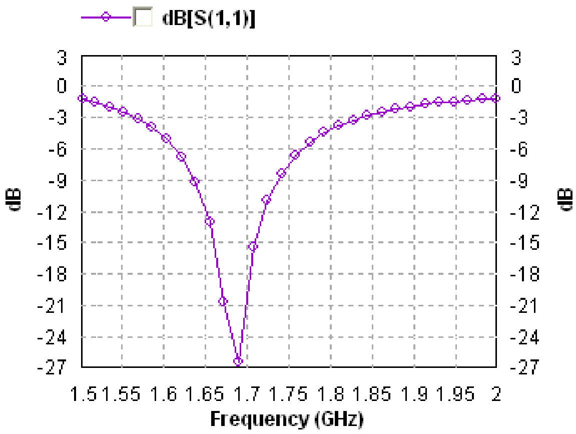

Fig. 3. Return Loss at 1.68 GHz

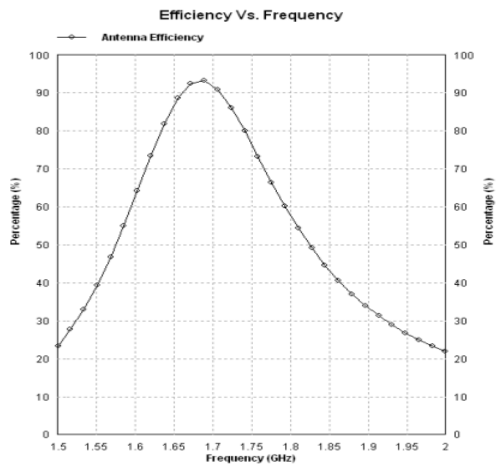

Fig. 4 Efficiency Vs frequency at 1.68 GHZ

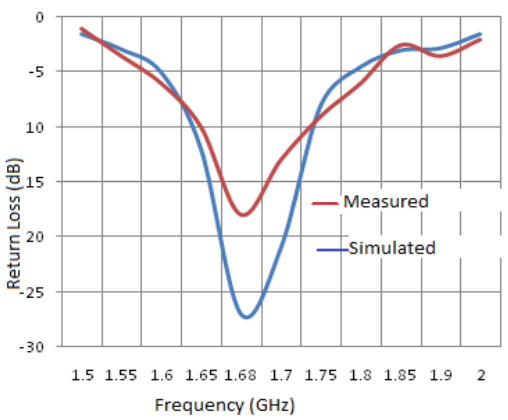

Fig.5 Measured and simulated return loss at 1.68 GHz

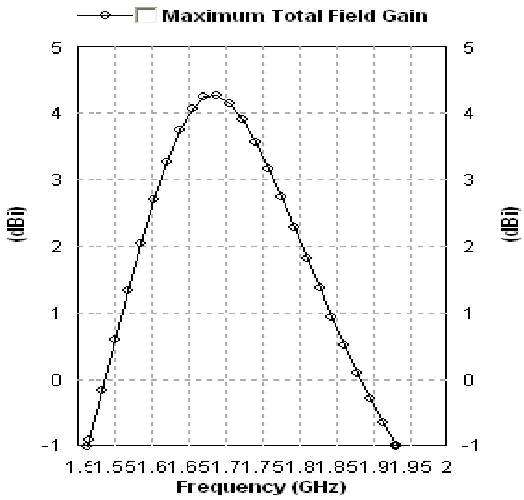

Fig. 6 Gain Vs frequency graph

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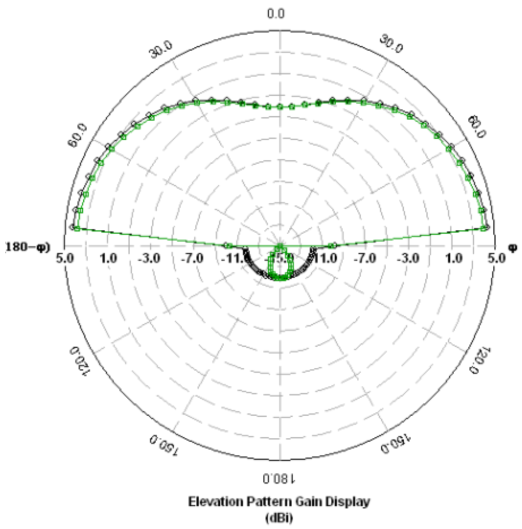

Fig. 7 E at theta=0,90 at 1.68 Ghz

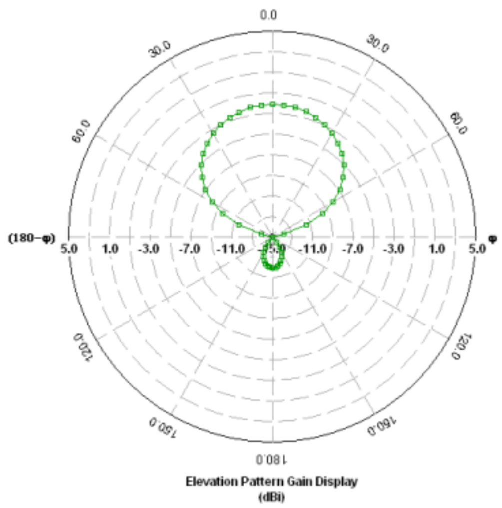

Fig. 8 E at Phi=0,90 at 1.68 Ghz

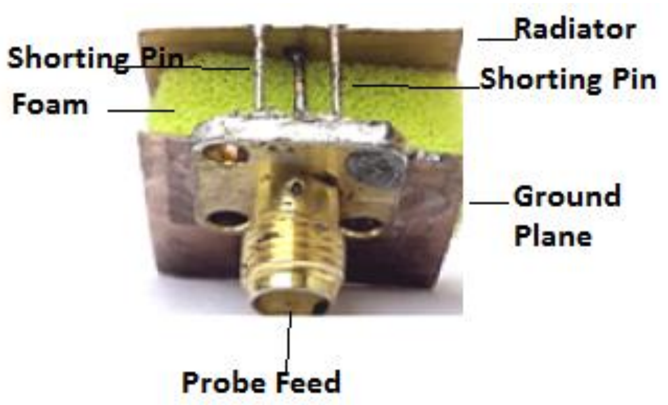

Fig.9 Fabricated PIFA at 1.68 GHz

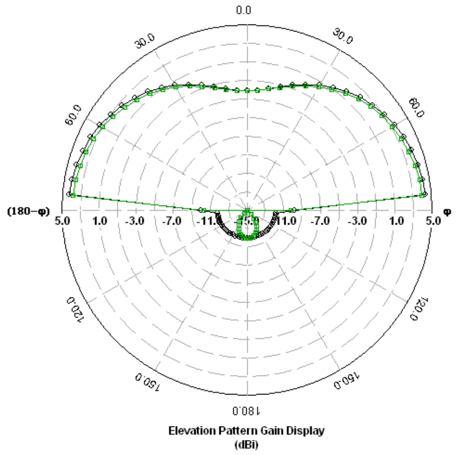

Fig. 10 E Total 1.68 GHz

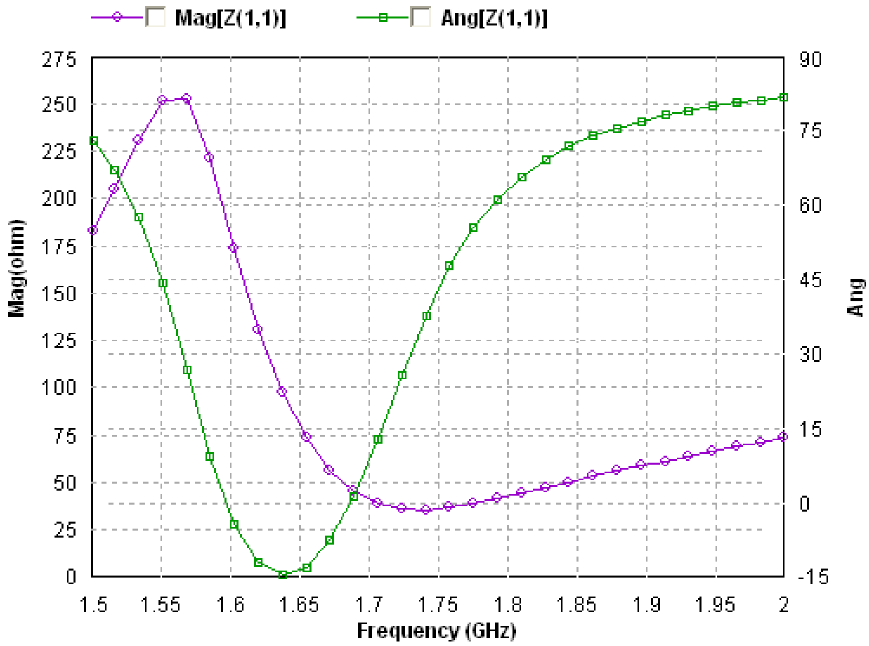

Fig. 11 Graph showing variation of input impedance With respect to frequency

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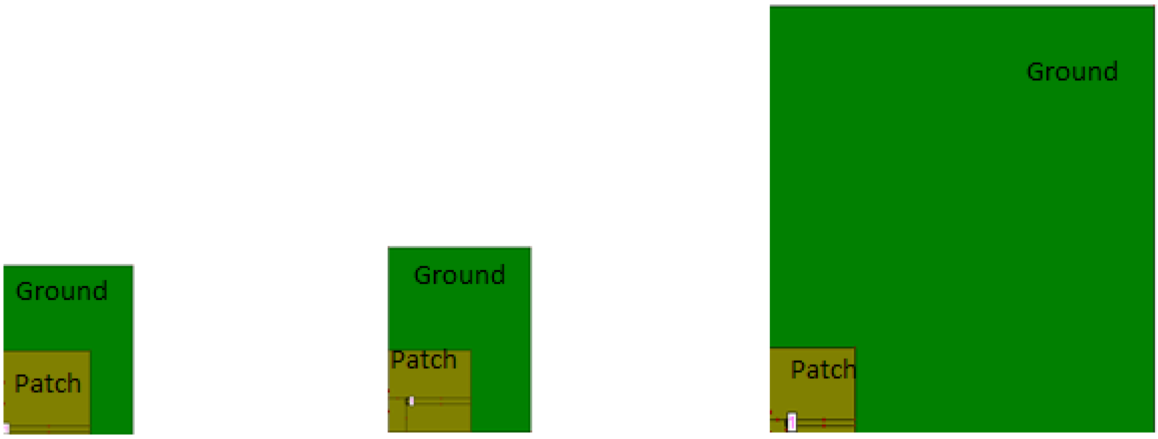
IV. Effects of Ground Plane

The ground plane of the antenna plays a significant role in its operation. Excitation of currents in the printed IFA causes excitation of currents in the ground plane. The resulting electromagnetic field is formed by the interaction of the IFA and an image of itself below the ground plane. Its behavior as a perfect energy reflector is consistent only when the ground plane is infinite or very much larger in its dimensions than the monopole itself. In practice the metallic layers are of comparable dimensions to the monopole and act as the other part of the dipole. In general, the required PCB ground plane length is roughly one quarter (λ/4) of the operating wavelength. If the ground plane is much longer than λ/4, the radiation patterns will become increasingly multilobed. On the other hand, if the ground plane is significantly smaller than λ/4, then tuning becomes increasingly difficult and the overall performance degrades.

Extensive simulations have been carried out by varying the dimensions of ground plane. The other parameters like size and shape of radiating patch, its height from ground plane and dielectric medium have been kept constant as in design with 20 mm x20 mm ground plane. The effects of increasing ground plane size on the parameters [10] of PIFA like gain, bandwidth, return loss, resonant frequency and radiation pattern have been analyzed. The different ground plane sizes of 20x20 mm, 30x40 mm, 35x45 mm and 90x100 mm are randomly considered for simulation as shown in fig. 12. The variation in relative bandwidth and frequency are shown in fig.13 and fig.14 as per the variation in ground plane size .The obtained results of all the designs are given in table 1.



(a) (b) (c)

Fig. 12 Ground plane size (a) 30x40 mm (b) 35x45 mm (c) 90x100 mm

Table 1

Sl.No	Shape of ground plane	Ground plane size LxW(mm)	Resonant frequency (GHz)	Bandwidth (Mhz)	Variation in resonant frequency (GHz)	Return loss (dB)	Gain (dBi)
1	Square	20x20	1.68	180	0.220	-27	4.3
2	Rectangular	30x40	1.74	180	0.160	-33	4.5
3	Rectangular	35x45	1.67	100	0.230	-41	4.0
4	Rectangular	90x100	1.80	170	0.000	-45	5.5

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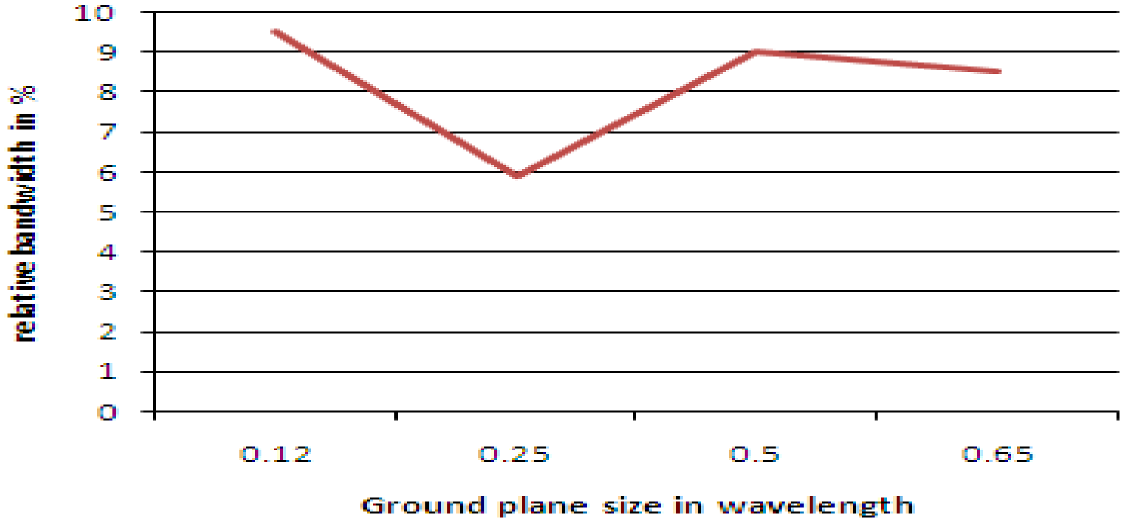

Fig.13 Variation in relative bandwidth as per ground plane size

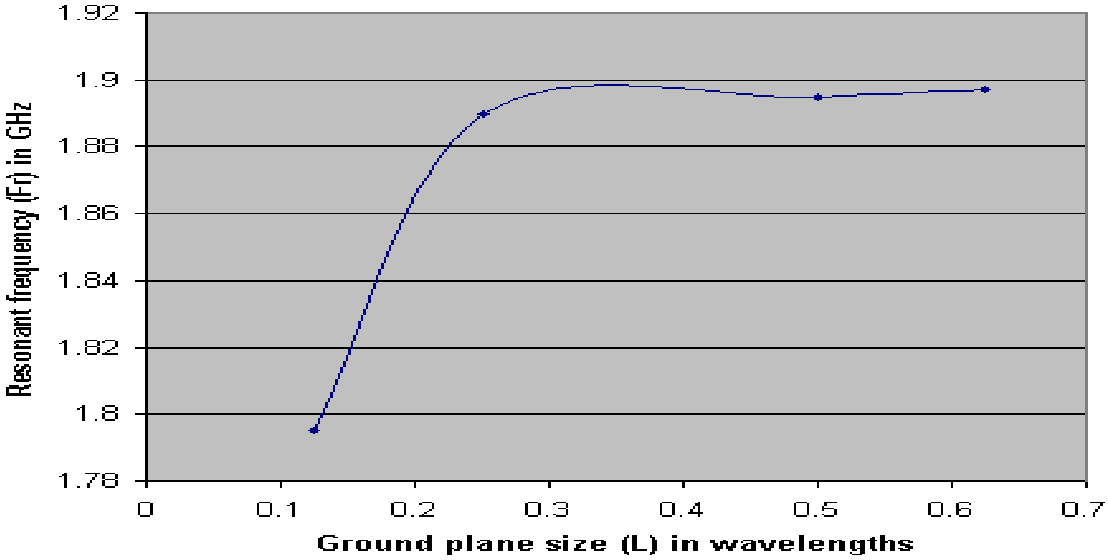

Fig. 14 Variation in resonant frequency as per ground plane size

V. Result and discussion

The simulations using IE3D design software on finite ground planes of different sizes of 20x20 mm,30x40 mm, 35x45 mm and 90x100 mm were performed .The variation in bandwidth was from 0.10 to 0.18 GHz. The variation in relative bandwidth (%) was from 5.9 to 9.5 %. The variation in resonant frequency was from 0.160 to 0.230 GHz. There was no significant effect on resonant frequency above ground plane size of 0.25 wavelength. The drift in resonant frequency has been found more below ground plane size of 0.25 wavelength. The gain of antenna increases as the ground plane size increases

VI. Conclusion

The different designs of PIFAs shown in table1 are useful for wireless communication such as UAV(Dragon Eye-1790 MHz)/ Raven-1707.5 MHz), DCS (1710–1880 MHz**)** and GSM (1800 MHz) .The experimented result is in good agreement with simulated result. The small size PIFA of 20 mm x 20 mm x 10 mm with 90 % efficiency and return loss of -27dB shows that it is a high performance antenna with such a small ground plane.

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