Response Of Planar Inverted F Antenna Over Different Dielectric Substrates

Ankit P Dabhi, Shobhit K Patel

Abstract: In modern era, a demand has increased to design antennas having multiband and wideband characteristics for mobile terminals. This paper expresses the bandwidth, return loss and gain variations of a Planar Inverted F Antenna. Here, the antenna is built on a small ground plane size of 60mm x 60mm. In this paper, Planar Inverted F Antenna with a radiating patch of fixed dimensions of 15.3mm x 15.3mm is studied using different dielectric substrates. The causes of the dielectric constant of perfect substrates and lossy substrates on the return loss, impedance bandwidth, resonant frequency and the gain are explored.

Index Terms: Planar Antennas, PIFA, bandwidth, return loss, low profile, different substrate materials, miniaturization, meandering technique.

1 INTRODUCTION

There has been always eternal demand for cheaper, small and dense wireless systems. The demand of reduced size of the wireless systems can be accomplished through small scale and compressed antennas. In order to have such antennas, Planar Inverted F Antenna is the best choice [2]. The Fig. 1 shows the basic structure of the planar inverted F Antenna. The Planar Inverted F Antenna is mainly used as fix antenna mobile handsets. It can be easily mounted on portable equipments because of its small size, low weight and height. The main elements of PIFA are rectangular planar element, [4] ground plane and the short circuit strip. In PIFA, a short circuit plate is placed between the radiator plate and the ground plane in order to reduce the length of the rectangular element.The variation in the size of the ground plane certainly affects the impedance bandwidth of the antenna. The appropriate positioning of feed pin and ground aids to better impedance matching of PIFA. The use of high dielectric materials reduces the size of PIFA on the cost of degraded performance of the antenna. The height of the antenna is very crucial, widening the air gap between the radiating element and ground provides better gain and broad bandwidth [3].

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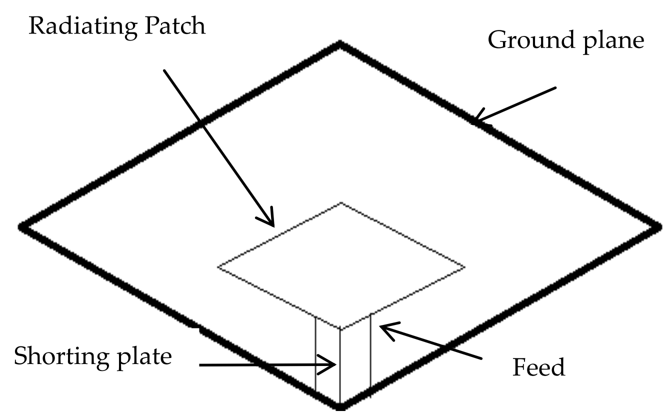

Fig. 1 Structure of PIFA

PIFA reveals fair gain in both vertical and horizontal polarization so it is beneficial in certain wireless systems where direction is not decided [5]. Antenna parameters like resonant frequency, gain, impedance bandwidth and polarization are mainly influenced by the substrate permittivity. Patch antenna theory [6], [7], [8] specifies that using high dielectric substrates ruins the performance of an antenna. The increases in permittivity miniaturize the size of an antenna but factors like gain and bandwidth humiliates. In this paper, the estimation of these parameters is carried out keeping the dimensions of an antenna fix. The evaluation is performed using software Ansoft HFSS v13. HFSS [12] provides various dielectric materials to the measure the performance of the PIFA like air, fr4, duroid, mica, rogers3210, silicon nitrate and so on. In this paper, a specific methodology is used for evaluating the performance variations of the PIFA. Here, the physical dimensions of the rectangular radiating patch of the antenna are kept fixed. The performance parameters of an antenna are evaluated by altering the different dielectric substrates only [9]. Here, the loss tangent is taken into account for the evaluation purpose of PIFA. Some dielectric materials act as perfect dielectrics [10] which have loss tangent equal to zero while others have loss tangent greater than zero referred to as lossy materials. In this methodology, the distance between feed and the short circuit plate is kept minimum. The variation in the impedance of PIFA can be managed through the distance between feeding pin and short pin. A return path is created by the short circuit plate for the forward currents of the antenna and resonance occurs for the dimensions lower than half a wavelength [7]. The resonant frequency of the PIFA is given by [11]:

$$f_r = c/4\sqrt{\varepsilon_r}\,(L_1 + L_2 + H - W) \quad (1)$$

Where c is the velocity in free space, ε_r is the permittivity of the substrate, L_1 and L_2 are the dimensions of the radiating element, W is the width of the short circuit plate and H is the thickness of the substrate or height at which radiating patch is placed. From (1), it can be seen that the physical dimensions of the patch ($L_1$and L_2), width of the short circuit plate (W) and the thickness of the substrate (H) affects the resonant frequency of the PIFA. Impedance bandwidth and gain of PIFA are certainly affected by substrate's properties and thickness. Generally, antennas are incorporated with thick substrates which have low loss tangent because substrates with high loss tangent are lossy and result in low gain [8].

2 Simulation Setup

The PIFA is simulated with fixed physical dimensions using Ansoft HFSS v13. The physical patch lengths L_1 and L_2 are 15.3mm and 15.3mm respectively. The width of the short circuit plate is 1mm and the thickness of the substrate is 8mm. Therefore, (1) can be expressed as:

$$f_r = c/4\sqrt{\varepsilon_r}\,(L_1 + L_2) \quad (2)$$

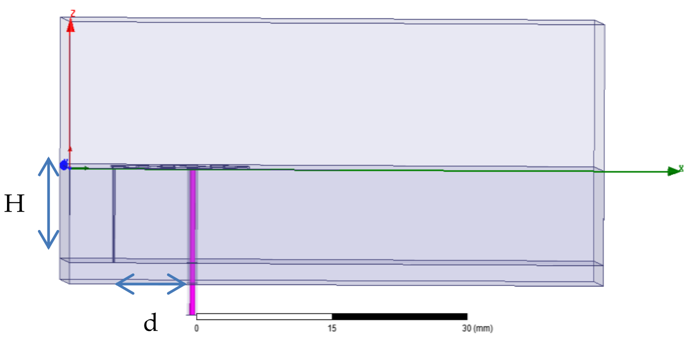

Fig. 2 Side view of proposed PIFA

Figure (2) depicts the side view of the proposed PIFA. The radiating patch is placed at the height (H) of 8mm from the ground plane. The height (H) of the short circuit strip is 8mm. In this fig.2, the distance (d) is the distance between the short circuit strip and the feeding line which is about 14mm. The proposed antenna structure is incorporated in air box widely known as radiation box or boundary. The excitation of the structure is done through wave port. The position of the feeding pin is kept changeable for matching purpose.

Table 1.Dimensions and Specifications of Proposed PIFA

Parameter	Specification	Dimensions
W_g	Width of the ground plane	60mm
L_g	Length of the ground plane	60mm
L_1	Length of the patch	15.3mm
L_2	Width of the patch	15.3mm
W	Width of the short circuit strip	1mm
H	Height of the substrate	8mm
l_s	Length of each slot	12mm
w_s	Width of each slot	1.39mm
D	Distance between feed line and short circuit strip	14mm

The table (1) shows the specifications of the proposed structure in brief. The ground plane has great influence on the resonant frequency, bandwidth and gain. The fig. 3 shows the top view of the proposed PIFA where L_g and W_g are the length and width of the ground plane respectively. To achieve best performance with better gain and broad bandwidth, the location of the radiating patch or say PIFA must be at one corner of the ground plane. In order to achieve sufficient gain, the size of the ground plane must be half of its wavelength. The proposed PIFA structure has the ground plane size of 60mm x 60mm. The type of feeding used in the proposed PIFA is coaxial feed which has a height of 14mm.

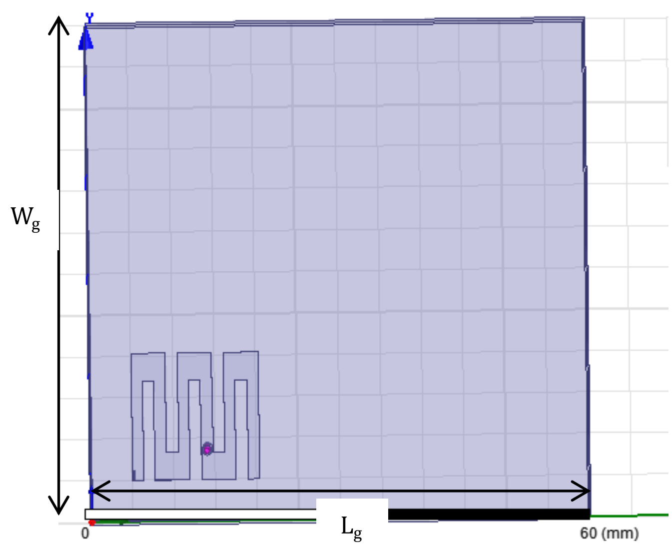

Fig.3 Top view of proposed PIFA

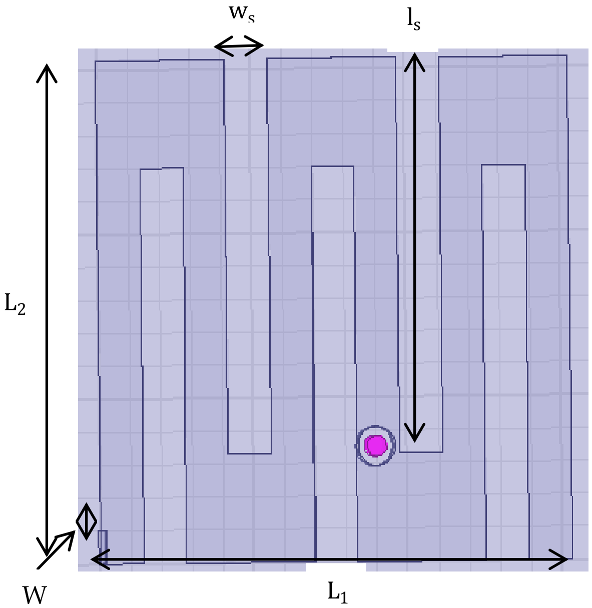

Fig.4 Layout of top layer of PIFA

The figure (4) shows the layout of the radiating patch of the proposed PIFA which is placed at the height of 8mm above the ground plane. In this figure, l_s and w_s indicates the length and width of each slot respectively, W is the width of short circuit strip while L_1 and L_2 are lengths of the radiating element. The thickness of the radiating patch is 0.2mm. The radiating patch has been given the meandered [1] shape in order to achieve the multiband operation of the PIFA and also to increase the electrical path for the purpose of miniaturization. The patch is divided into equal sized slots where the length of each slot is 12mm and the width of each slot is 1.39mm respectively. The width of the short circuit plate regulates the resonant frequency of the PIFA.

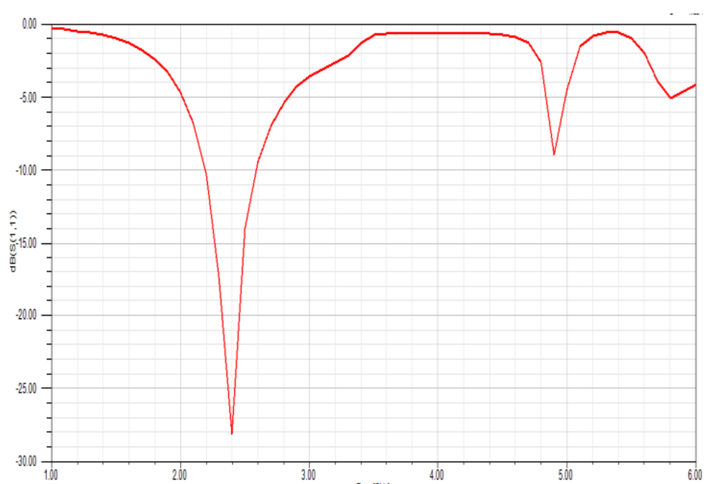

Fig.5 Return loss of PIFA (ε_r=1)

The simulations are performed for different configurations of proposed PIFA with substrates like air, fr4, duroid, mica, Rogers 3210 and silicon nitrate. The fig. 5 shows the graph of return loss at 2.45 GHz using air substrate having permittivity ε_r equal to 1. This graph depicts the return loss of 28.03 dB at the operating frequency 2.45 GHz. The bandwidth of PIFA having air as substrate is 2.2 GHz to 2.5 GHz band which is around 300 MHz. The figure (6) shows the gain plot of the proposed structure of PIFA incorporated with air substrate.

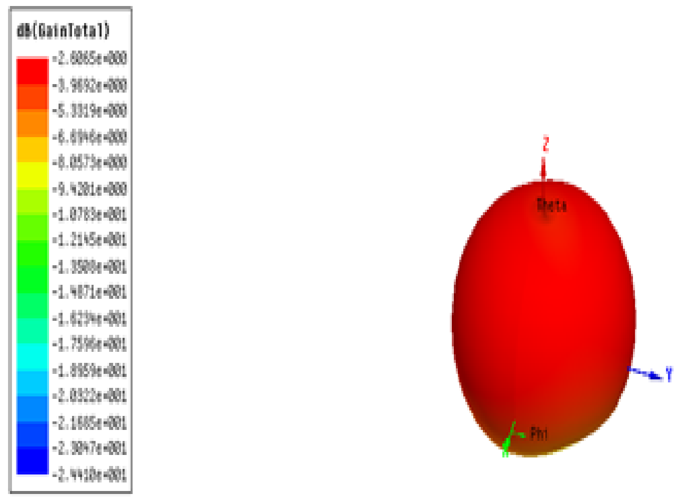

Fig.6 Gain plot (ε_r=1)

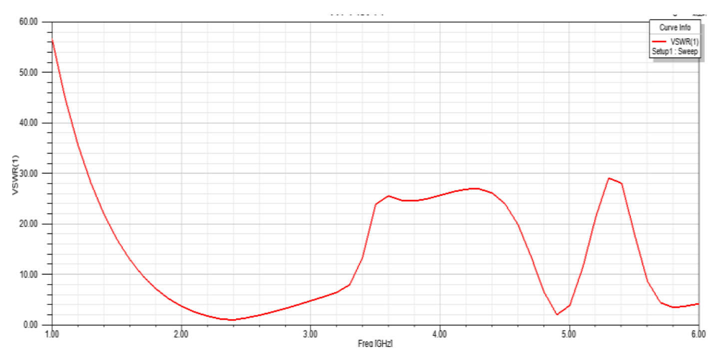

Fig.7 VSWR plot (ε_r=1)

The figure (7) shows the VSWR plot of the proposed PIFA structure which has air as a substrate. The VSWR at the operating frequency is 1.25 which inherently indicates that the antenna structure is well matched. The below table (2) shows the proposed PIFA results undertaken keeping the dimensions of the antenna fix and only varying different substrates. The table depicts that the rise in the substrate permittivity has deep effect mainly on the bandwidth. The bandwidth of the antenna starts degrading with the increase in the permittivity. It can be seen that in some substrates the calculated resonant frequency and the simulated resonant frequency are differing by some amount. The higher simulated resonant frequency of some substrates shows the miniaturization effect as it is known that frequency and the length or size of the antenna are inversely proportional to each other.

Table2.PIFA Results for fixed Dimensions & Varying Substrates

Substrate	Permittivity	Loss Tangent	Resonant Frequency		Bandwidth (MHz)	Return Loss (dB)
			Calculated (MHz)	Simulated (MHz)		
Air	1	0	2450	2450	300	-28.03
Duroid	2.2	0	1652	1678	-	-8.5
FR4	4.4	0.02	1168	1410	-	-6
Mica	5.7	0	1026	3692	230	-37.20
Silicon Nitrate	7	0	926	2492	60	-14.45
Rogers 3210	10.2	0.003	767	2891	150	-15.20

3 CONCLUSION

In this paper, the resonant frequency, return loss, impedance bandwidth and VSWR of a PIFA are simulated with the substrate permittivity varying from 1 to 10.2. Here, the PIFA having air substrate gives best performance in the terms of bandwidth compared to the other substrates while the gain varies differently in the different substrates based on their permittivity. The bandwidth obtained is 300 MHz while the VSWR is 1.25 when the structure is simulated using air substrate. The current distribution in PIFA using different substrates mainly varies in the meandered patch with reference to the short circuit plate. It is seen that as when the antenna dimensions are kept constant, the normalized simulated resonant frequencies tends to go down. The bandwidth is not much affected for lossy substrates but the gain drops linearly with the rise in the substrate permittivity. On the contrary, there is a considerable decrease in bandwidth and gain with the increase in permittivity for perfect dielectric.

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