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Proposed Algorithm and Parametric Study of Planar Inverted F-Antenna for Wi-Fi Band

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Abstract

This paper presents a comprehensive experimental study of Planar Inverted-F Antennas (PIFA) involving all the parameters which may affect the characteristics of PIFA. It is found that PIFA characteristics are affected by a number of parameters including the dimensions of the ground plane, length, width, height and position of the top plate, positions and widths of shorting pin/plate. These results are very useful for aiding PIFA design in practical applications. A new unique algorithm is designed and reported in this paper to determine the parameters of PIFA for different substrates. A novel technique for obtaining a single band antenna fed with co-axial probe is proposed and demonstrated.

Keywords- *PIFA, Single-Band, IEEE802.11, Wi-Fi, RF antenna.*

I. INTRODUCTION

With the rapid growth of the wireless mobile communication technology, the future technologies need a very small antenna and also the need of multiband antenna is increased to avoid using two antennas and to allow video, voice and data information to be transmitted. The advantage of planar inverted-F antenna (PIFA) makes them popular in many applications requiring a low profile antenna. PIFA antenna is promising to be a good candidate for the future technology due to the flexibility of the structure as it can be easily incorporate into the communication equipments [1].

PIFA can be considered as a kind of linear Inverted F antenna (IFA) with the wire radiator element replaced by a plate to expand the bandwidth. The PIFA has many advantages, that is, easy fabrication, low manufacturing cost, and simple structure. PIFA can be hiding in the housing of the mobile phone when comparable to whip/ rod/ helix antennas. Besides, PIFA has reduced backward radiation towards the user's head, minimizing the electromagnetic wave power absorption (SAR) and enhance antenna performance. It exhibits moderate to high gain in both vertical and horizontal states of polarization. This feature is very useful in certain wireless communications where the antenna orientation is not fixed and the reflections are present from the different corners of the environment. In those cases, the important parameter to be considered is the total field that is the vector sum of horizontal and vertical states of polarization [2].

Planar Inverted F Antenna (PIFA) consists of rectangular planar element located above a ground plane, a short circuiting plate and a feeding mechanism for the planar element. The PIFA is a variant of the monopole where the top section has been folded down so as to be parallel with the ground plane. This is done to reduce the height of the antenna, while maintaining a resonant trace length. This parallel section introduces capacitance to the input impedance of the antenna, which is compensated by implementing a short-circuit plate. The stub's end is connected to the ground plane via the short circuiting plate on the edge of the antenna, whose function is to extend the bandwidth of the PIFA. The ground plane of the antenna plays a significant role in its operation. In general, the required PCB ground plane length should be at least one quarter ($\lambda/4$) of the operating wavelength. If the ground plane is much longer than $\lambda/4$, the radiation pattern will become increasingly 'multi-lobed'. On the other hand, if the ground plane is significantly smaller than $\lambda/4$, then tuning becomes increasingly difficult and the overall performance degrades.
Many researchers have performed parametric study on PIFA. The empirical equation reported in [3] was useful during initial research to get a sense of each parameter of the PIFA. Single band PIFA from [2] was also referred to understand the concept of PIFA. The values of different substrates from [4] are used in this paper. Equations from [4][5] were referred to design a unique algorithm which is reported in this paper. Approach to perform parametric study was referred using [3] [6] [7].

Based on the above analysis, this paper presents a comprehensive experimental investigation on PIFA for Wi-Fi band that includes all the parameters that may affect its characteristics. Also a unique algorithm is designed and reported to design PIFA using different substrates. Experimental study was conducted using FR4, RogersRT5880 and RogersRO3006 substrates to verify the reported algorithm. The effects on the characteristics of PIFA due to changes in the dimensions of ground plane, the position of PIFA on ground plane, the length, width, and height of the top radiating plate, and the width of the shorting plate are discussed in this paper.

II. PROPOSED ALGORITHM

1] Select the frequency of operation (Fr).
2] Select the substrate with dielectric constant (εr) and thickness (h) for top patch and ground plane.
3] Calculate the width (W)

$$W = \frac{C_0}{2Fr}\sqrt{\frac{2}{\varepsilon r + 1}} \quad \text{- - - - - - - - - - - - (1)}$$

Where, C_0 is velocity of light.
(consider this output as width (W) of the top plate).
Again start from step 1 and jump from step2 to step 4 (bypassing step3) to calculate the length (L) of the top plate.
4] Select the required total height (T)
5] Calculate the height of air gap (Δ1)

$$\Delta 1 = T - 2(h) \quad \text{- - - - - - - - - - - - - - - - - - (2)}$$

6] Calculate dielectric constant of the composite medium (εeq)

$$\varepsilon eq = \frac{\varepsilon r(2(h) + \Delta 1)}{\varepsilon r(\Delta 1) + 2(h)} \quad \text{- - - - - - - - - - - - - - - (3)}$$

composite medium is a combination of substrate and air.

7] Calculate the width (W1)

$$W1 = \frac{C_0}{2Fr}\sqrt{\frac{2}{\varepsilon eq + 1}} \quad \text{- - - - - - - - - - - - - - - (4)}$$

8] Calculate the effective dielectric constant (εeff)

$$\varepsilon_{eff} = \frac{\varepsilon eq + 1}{2} + \frac{\varepsilon eq - 1}{2}\left[1 + 12\frac{T}{W1}\right]^{-\frac{1}{2}} \quad \text{- - - - - - - - - (5)}$$

9] Calculate the extended incremental length of the patch (ΔL)

$$\Delta L = 0.412T\frac{[\varepsilon_{eff} + 0.3][\frac{W1}{T} + 0.264]}{[\varepsilon_{eff} - 0.258][\frac{W1}{T} + 0.8]} \quad \text{- - - - - - - - (6)}$$

10] Calculate the effective length (L_{eff})

$$L_{eff} = \frac{C_0}{2Fr\sqrt{\varepsilon_{eff}}} \quad \text{- - - - - - - - - - - - - - - (7)}$$

11] Calculate length (half wavelength) of the patch (L1)

$$L1 = L_{eff} - 2\Delta L \quad \text{- - - - - - - - - - - - - - - (8)}$$

12] Calculate length (quarter wavelength) of the patch (L)

$$L = L1/2 \quad \text{- - - - - - - - - - - - - - - - (9)}$$

(consider this output as length (L) of the top plate).

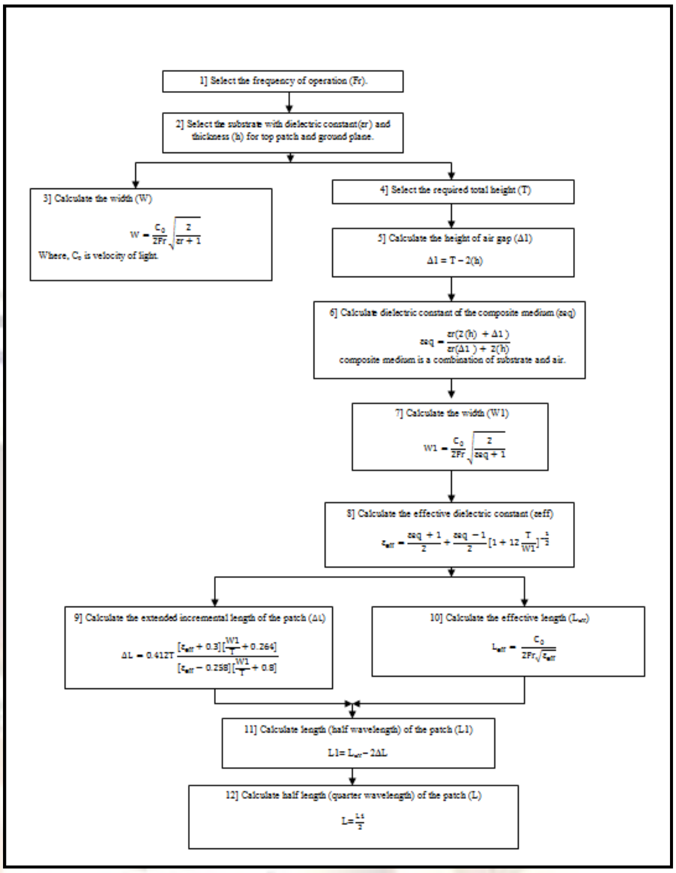

Figure 1: Flowchart for the above proposed algorithm.

Based on equations specified in the above proposed algorithm, the parameters were calculated for three different substrates namely FR4, RogersRT5880 and RogersRO3006. The frequency of operation (Fr) was selected as 2.4GHz for all three substrates. Considering equation (1), width was calculated for these three substrates. The results are mentioned in tabular form below.

Substrate	FR4	RogersRT5880	Rogers RO3006
Dielectric constant (εr)	4.4	2.2	6.15
thickness (h)	1.6 mm	0.787 mm	1.28 mm
Loss tangent	0.025	0.0009	0.002
Width (W)	38.03 mm	49.41 mm	33.05 mm

After calculating width for the respective substrates, length (L) was calculated from equations (2 to 9) for each substrate. Varying only the total height (T), calculations were performed to get Air gap height (Δ), dielectric constant of composite medium (εeq) and length (L). The results are mentioned in tabular form below. Also a graph is plotted to get a sense of change in Dielectric constant of composite medium (εeq).

1] FR4:

Total height (T)	Air gap height (Δ)	Dielectric constant of composite medium (εeq)	length (L)
6.75 mm	3.55 mm	1.57	21.98 mm
7.75 mm	4.55 mm	1.46	22.21 mm
8.75 mm	5.55 mm	1.39	22.19 mm
9.75 mm	6.55 mm	1.33	22.09 mm
10.75 mm	7.55 mm	1.29	21.85 mm

2] RogersRT5880

Total height (T)	Air gap height (Δ)	Dielectric constant of composite medium (εeq)	length (L)
6.75 mm	5.176 mm	1.14	25.25 mm
7.75 mm	6.176 mm	1.12	24.84 mm
8.75 mm	7.176 mm	1.10	24.44 mm
9.75 mm	8.176 mm	1.09	23.94 mm
10.75 mm	9.176 mm	1.08	23.44 mm

3] Rogers RO3006

Total height (T)	Air gap height (Δ)	Dielectric constant of composite medium (εeq)	length (L)
6.75 mm	4.19 mm	1.46	22.70 mm
7.75 mm	5.19 mm	1.38	22.76 mm
8.75 mm	6.19 mm	1.32	22.68 mm
9.75 mm	7.19 mm	1.28	22.44 mm
10.75 mm	8.19 mm	1.24	22.20 mm

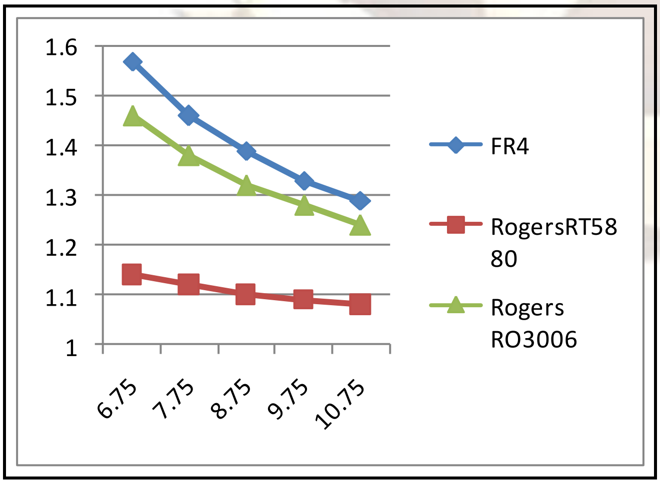

Figure 2: Plot of Total height (T) v/s Dielectric constant of composite medium (εeq) for three different substrates.

III. ANTENNA CONFIGURATIONS

The antenna has a simple structure fed by 0.5mm radius using probe fed technique. Fig 3 demonstrates the 3D view of the proposed antenna used for simulated study. The dielectric material selected for the design is FR-4 which has dielectric constant of 4.4 and height of dielectric substrate (h) = 1.6 mm. Generally the overall dimension of the antenna is 22.4 x 38 x 7.75 mm. The parameters of the proposed antenna are shown in Fig 4 and Fig 5. Zeland IE3D V.14.10 package is used to obtain the return loss, the gain, bandwidth and the radiation patterns. Fig. 6 shows the simulated S11 of the proposed PIFA antenna. The simulated return loss shows single band at 2.4GHz. The proposed antenna satisfies the requirement to cover Wireless Local Area Network (WLAN/Wi-Fi/Bluetooth IEEE 802.11). Some parameters are affecting the characteristic of the response. The design started with the main radiated top patch which can be calculated by using equations (1 to 9). The width was finalized from equation (1) and the length was considered from equation (9). Then the top patch was fed using probe fed technique with the impedance matching of 50 Ohms. The dimensions of the ground plane were then entered and ground plane was inserted to the PIFA design.

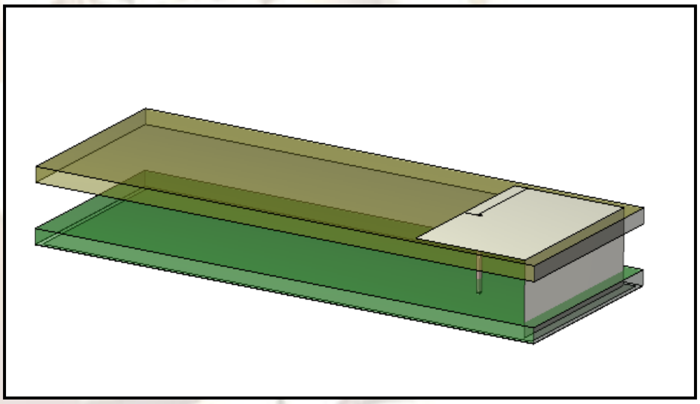

Figure 3: 3D view of the proposed antenna.

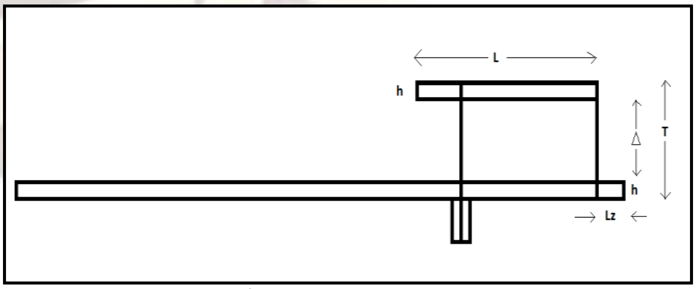

Figure 4: Front view of the proposed antenna.

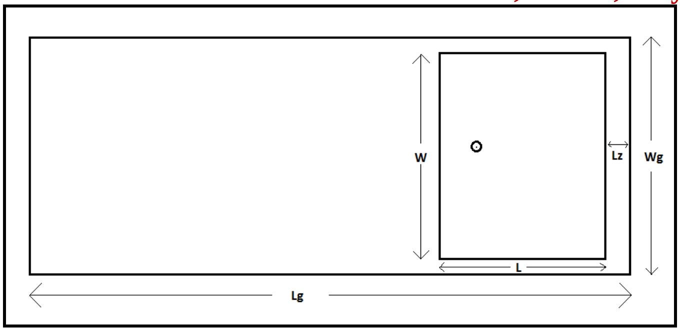

Figure 5: Top view of the proposed antenna.

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For an antenna working at 2.4GHz the patch dimensions are:
Type of feed – Coaxial feed at (-8.19, 0) from center.

L = 22.4 mm
W = 38 mm
T = 7.75 mm
h = 1.6 mm
ε_r = 4.4
εeq = 1.46
Ws = 38 mm
Δ = 4.55 mm
Lg = 100 mm
Wg = 40 mm
Lz = 2 mm

IV. SIMULATION RESULTS

A. RETURN LOSS:

The practical circuit realization suffers with the mismatch between the available source power and the power delivered. This mismatch is known as return loss.

Return loss = -20log (Ţin)

Where, 'Ţin' is input reflection coefficient. The return loss of the antenna is obtained as -36.18 dB at 2.4GHz. So the designed antenna offers good gain and minimum losses at the specified frequency. It has a bandwidth of 360MHz. The return loss of the antenna is shown in Fig 6.

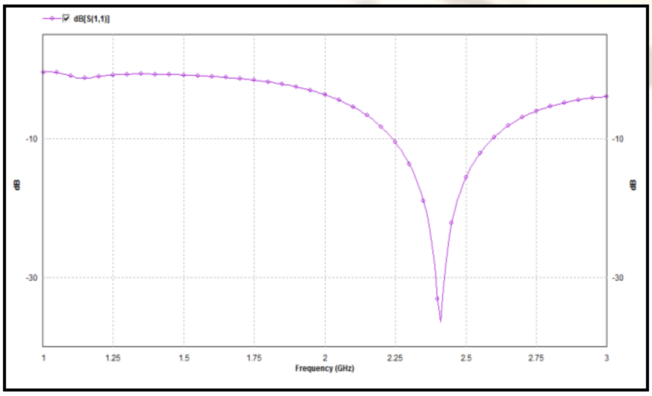

Figure 6: Plot of Return loss v/s Frequency.

B. *RADIATION PATTERN:*

A microstrip patch antenna (PIFA) radiates normal to its patch surface. The elevation pattern for Φ=0 and Φ=90 degrees would be important. Fig 7 shows the 2D radiation pattern of the antenna at the desired frequency of 2.4GHz for Φ=0 and Φ=90 degrees in polar plot. The calculated gain is 4.21dBi for this antenna.

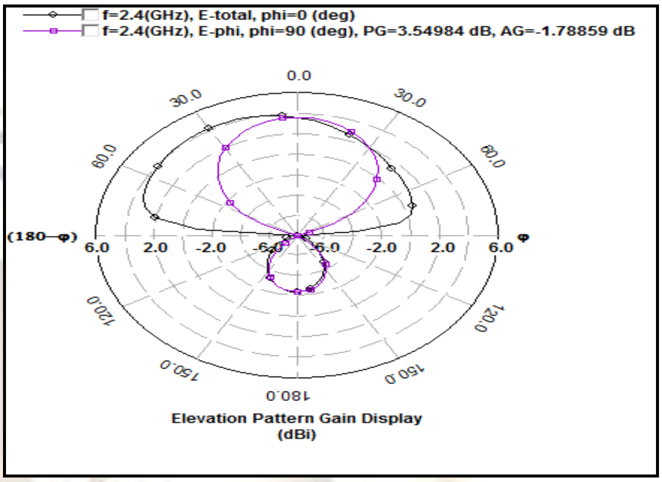

Figure 7: Elevation pattern gain display (dBi) at 2.4GHz.

C. VOLTAGE STANDING WAVE RATIO:

VSWR is a function of reflection coefficient, which describes the power reflected from the antenna. If the reflection coefficient is given by Ţ, then the VSWR is defined as

VSWR = (1 + |Ţ|) / (1 – |Ţ|)

As shown in fig 8, the VSWR of 1.03 was achieved for 2.4GHz from simulation results.

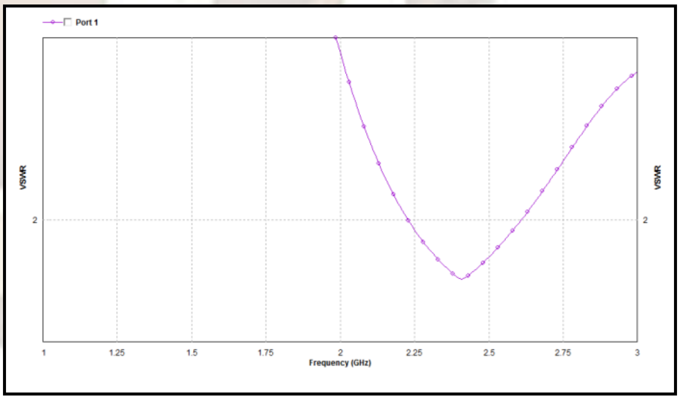

Figure 8: Plot of VSWR v/s Frequency.

V. PARAMETRIC STUDY

From the above proposed antenna, a parametric study was experimentally conducted to observe the shift in frequency, return loss, bandwidth and gain by varying each parameter of the antenna individually in the following cases. The results obtained after simulations are given in tabular form below.

Case1: Variation of top plate length (L)

Length (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
20	2.44	-19.45	330	4.36
21	2.38	-26.16	350	4.21
22	2.41	-39.96	360	4.12
23	2.33	-29.69	340	4.15
24	2.26	-21.50	340	4.03
25	2.29	-18.33	330	3.93

Case2: Variation of top plate width (W)

Width (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
14	3.46	-15.78	700	4.28
16	3.32	-16.39	680	4.16
18	3.18	-17.14	660	4.06
20	3.07	-18.89	660	3.94
22	2.95	-19.11	640	3.97
24	2.87	-19.67	630	3.90
26	2.77	-19.65	600	3.78
28	2.67	-21.41	460	4.13
30	2.61	-23.20	430	4.08
32	2.56	-24.23	400	4.07
34	2.50	-25.99	380	4.09
36	2.45	-29.62	370	4.15
38	2.40	-36.18	360	4.21

Case3 : Variation of width of the shorting plate (Ws)

Width of shorting plate (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
18	1.89	-17.00	570	5.81
20	1.92	-23.18	550	5.99
22	1.95	-49.95	530	6.08
24	2.19	-32.35	560	5.37
26	2.22	-32.64	470	5.21
28	2.25	-26.24	420	4.99
30	2.29	-23.85	360	4.74
32	2.33	-25.09	340	4.41
34	2.35	-27.75	350	4.22
36	2.38	-32.11	360	4.70
38	2.40	-36.18	360	4.21

Case4: Variation of total height (T)

Height (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
5.75	2.4	-12.7	240	3.43
6.75	2.4	-18.6	330	3.66
7.75	2.4	-36.18	360	4.21
8.75	2.4	-22.29	360	4.59
9.75	2.4	-16.05	330	4.86
10.75	2.4	-12.49	270	5.04

Case5: Variation of length of ground plane (Lg)

Length of ground plane (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
40	2.30	-38.08	390	3.51
60	2.38	-36.33	360	4.04
80	2.35	-40.56	360	4.02
100	2.40	-36.18	360	4.21
120	2.37	-36.45	360	4.37
140	2.35	-38.64	360	4.41
160	2.38	-35.22	350	4.50

Case6: Variation of width of the ground plane (Wg)

width of ground plane (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
39	2.14	-37.66	180	4.17
40	2.40	-36.18	360	4.21
41	2.41	-33.94	290	4.11
42	2.40	-35.43	350	4.00

Case7: Variation of position of top plate on ground plane (Lz)

position of top plate on ground plane (mm)	Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
0	2.41	-36.95	350	4.21
2	2.40	-36.18	360	4.21
4	2.28	-33.06	330	3.80
6	2.29	-30.05	310	3.95
8	2.39	-37.75	330	3.53
10	2.25	-33.30	330	3.23

VI. CONCLUSION

1) A new unique algorithm is designed and reported in this paper for single band PIFA. This algorithm is experimentally verified using FR4, RogersRT5880 and RogersRO3006 substrates and is proposed for further research.

2) Irrespective of the substrate, as the total height (T) is increased, there is a decrease in Dielectric constant of composite medium (εeq).

3) From the parametric study it is observed that as the length is increased, there is a decrease in gain and as the total height is increased, the gain also increases.

4) As the width of the top plate is increased the frequency increases and as the width of the shorting plate is increased the frequency decreases. Also as

both these widths are decreased, a wide increase in bandwidth is observed.

5) Whereas by varying the length of the ground plane, width of the ground plane and position of top plate on ground plane, a slight shift in frequency is observed but is close to Wi-Fi band.

6) The overall results obtained for Return loss, Bandwidth and Gain in each case of the parametric study are satisfactory and can be used for further research.

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