# Design of a Compact PIFA for PCS Applications

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*Abstract* — **The recent advances in RF and microwave high-density packaging technologies in multifunction wireless communications systems have called for the parallel development of compact and efficient antennas that can be used over a wide frequency range. This paper addresses the development of compact and efficient Planar Inverted F Antennas (PIFA). It proposes some methods that can be used for improvement in bandwidth and reduction in volume of these antennas. It also presents the design and characterization of a compact tapered PIFA which is improved in volume and bandwidth. The designed tapered PIFA is operated at the conventional PCS frequency band (1800 MHz) and can be implemented on mobile phones.**

## I. Introduction

With the rapid development of mobile communications and miniaturization of mobile phones, requirements for small and low profile antennas are constantly growing. For optimum system performance, the antennas must have high radiation efficiency, small volume, isotropic radiation characteristics, simple and low-loss impedance matching to the receive and transmit paths, and simple mechanical construction. The major types of configurations of low-profile antennas with enhanced bandwidth performance include Planar inverted F Antennas, Radiation-Coupled Dual L Antenna and Diode-Tunable PIFA.

PIFA [1] 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. But the major disadvantage that keeps the basic PIFA from diverse application is its narrow bandwidth; therefore it is necessary to broaden bandwidth for use in mobile phones and other applications.

The next section describes the structure of a simple PIFA and discusses the relationship between its various parameters. The section discusses various modifications to the design in order to achieve reduction in size and improvement of bandwidth. Section III of the paper discusses the design details and the properties of a modified linearly tapered PIFA using HFSS software. Section IV provides concluding remarks and discusses the application and integration of these antennas into future wireless systems.

## II. Planar Inverted F Antenna (PIFA)

The PIFA consists of a ground plane, a top plate element, a feed wire attached between the ground plane and the top plate, and a shorting wire or strip that is connected between the ground plane and the top plate. Figure 1 shows a typical PIFA configuration. The antenna is fed at the base of the feed wire at the point where the wire connects to the ground plane. The PIFA is an attractive antenna for wireless systems where the space volume of the antenna for wireless systems where the space volume of the antenna is quite limited. It requires simple manufacturing, since the radiator must only be printed. The addition of a shorting strip allows good impedance match to be achieved with a top plate that is typically less than λ/4 long. The resulting PIFA is more compact than a conventional half-wavelength probe-fed patch antenna [2].

The design variables for this antenna are the height, width, and length of the top plate, the width and location of shorting plate, and the location of the feed wire. A semi-rigid coax with a centre conductor that extends beyond the end of the outer conductor is used to form the PIFA feed wire. The outer conductor of the coax is soldered to the edge of a small hole drilled in the ground plane at the specified feed point. The shorting post of usual PIFA types is a good method for reducing the antenna size, but results in narrow impedance bandwidth. Several modifications have been suggested to obtain a trade off between size, bandwidth and other properties of a PIFA.

### A. Techniques to increase the Bandwidth for the PIFA

The main relationships among various parameters having influence on bandwidth are follows;

$$Bandwidth = \frac{f_u - f_l}{f_r} \propto \frac{1}{Q} \qquad (1)$$

$$Q = \frac{\sqrt{L}}{R\sqrt{C}} \qquad (2)$$

$$Q \propto 1/S \qquad (3)$$

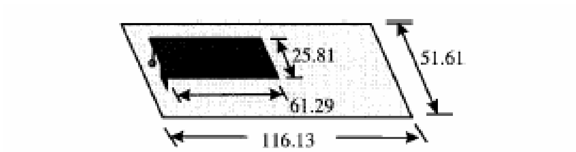


Fig.1. Geometry configuration of PIFA with shorting strip

where, $f_u$ and $f_l$ are upper and lower frequency of bandwidth, $f_r$ is resonant frequency, Q is quality factor, R is loss component of antenna, L is inductive component of antenna, C is capacitive component of antenna, S is volume of antenna.

The most frequently used method to broaden the bandwidth is to raise the height of the shorting plane i.e increase the volume. Bandwidth is affected very much by the size of the ground plane. By varying the size of the ground plane, the bandwidth of a PIFA can be adjusted. For example, reducing the ground plane can effectively broaden the bandwidth of the antenna system. Several slits at the ground plane edges can be inserted to reduce the quality factor of the structure (and to increase the bandwidth). Bandwidth enhancement of a PIFA can also be achieved by several efficient approaches, namely using dual resonance by additional patch that is adding capacitive load [3], loading dielectric with high permittivity [4], attaching chip resistor that is increasing loss term [5].

*B. PIFA Dimensions*

One method of reducing PIFA size is simply by shortening the antenna. However, this approach affects the impedance at the antenna terminals such that the radiation resistance becomes reactive as well. This can be compensated with capacitive top loading. In practice, the missing antenna height is replaced with an equivalent circuit, which improves the impedance match and the efficiency. The capacitive loading reduces the resonance length from λ/4 to less than λ/8 at the expense of bandwidth and good matching. The capacitive load can be produced by adding a plate (parallel to the ground) to produce a parallel plate capacitor. [6]

*C. Resonant Frequency*

The resonant frequency of PIFA can be approximated with:

$$L1 + L2 = \lambda /4$$
$$\text{when, } W/L1=1 \text{ then } L1 + H = \lambda /4$$
$$\text{when, } W=0 \text{ then } L1 + L2 + H = \lambda /4$$

The introduction of an open slot reduces the frequency. This is due to the fact that there are currents flowing at

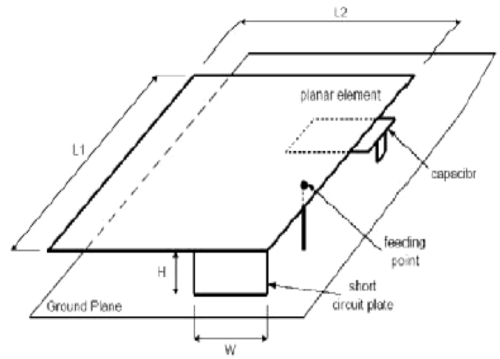


Fig.2. Configuration of a capacitively loaded PIFA

the edge of the shaped slot, therefore a capacitive loaded slot reduces the frequency and thus the antenna dimensions drastically. The same principle of making slots in the planar element can be applied for dual-frequency operation as well. Changes in the width of the planar element can also affect the determination of the resonant frequency. The width of the short circuit plate of the PIFA plays a very important role in governing its resonant frequency. Resonant frequency decreases with the decrease in short circuit plate width, W. Unlike micro-strip antennas that are conventionally made of half wavelength dimensions, PIFA's are made of just quarter-wavelength. Analyzing the resonant frequency and the bandwidth characteristics of the antenna can be easily done by determining the site of the feed point, at which the minimum reflection coefficient is to be obtained.

*D. Impedance Matching*

The impedance matching of the PIFA is obtained by positioning of the single feed and the shorting pin within the shaped slot, and by optimizing the space between feed and shorting pins. The main idea behind designing a PIFA is to avoid using any extra lumped components for matching network, and thus avoid any losses due to that.

*E. Radiation Pattern*

The radiation pattern of the PIFA is the relative distribution of radiated power as a function of direction in space. In the usual case the radiation pattern is determined in the far-field region and is represented as a function of directional coordinates. Radiation properties include power flux density, field strength, phase, and polarization.

*F. Electric Field Distribution*

The dominant component of the electric field $E_z$ is equal to zero at the short-circuit plate while the intensity of this field at the opposite edge of the planar element is significantly large. For fields $E_x$ and $E_y$, there is pointing part, which corresponds to the feed source. This means that the electric lines of force are directed from feed source to the ground plane. When the width of the short-circuit plate is narrower than the planar element, the electric fields $E_x$ and $E_y$ start generating at all open-circuit edges of the planar element. These fringing fields are the radiating sources in PIFA.

*H. Current Distribution*

PIFA has very large current flows on the undersurface of the planar element and the ground plane compared to the field on the upper surface of the element. Due to this behavior PIFA is on of the best candidate when is talking about the influence of the external objects that affect the antenna characteristics (e.g. mobile operator's hand/ head). PIFA surface current distribution varies for different widths of short-circuit plates. The maximum current distribution is close to the short pin and decreases away from it. The ground surface waves can produce spurious radiations or couple energy at discontinuities, leading to distortions in the main pattern, or unwanted loss of power. The surface wave effects can be controlled by the use of photonic band gap structures or simply by choosing air as the dielectric. This solves the limitation of poor efficiency as well along with certain degree of bandwidth enhancement.

*G. Effects of Substrates Parameters*

Impedance bandwidth of PIFA is inversely proportional to the quality factor Q that is defined for a resonator:

$$Q = Energy\ Stored\ /\ Power\ Lost$$

Substrates with high dielectric constant (εr) tend to store energy more than radiate it. This is equivalent by modeling the PIFA as a lossy capacitor with high εr, thus leading to high Q value and obviously reducing the bandwidth. Similarly when the substrate thickness is increased the inverse proportionality of thickness to the capacitance decreases the energy stored in the PIFA and the Q factor also. In summary, the increase in height and decrease of εr can be used to increase the bandwidth of the PIFA.

*H. Efficiency*

The efficiency of PIFA in its environment is reduced by all losses suffered by it, including: ohmic losses, mismatch losses, feedline transmission losses, edge power losses, external parasitic resonances, etc.

## III. Design Of A Linearly Tapered PIFA For PCS Applications

This section discusses a simple design of a PIFA with broad bandwidth and a flexible structure capable of being

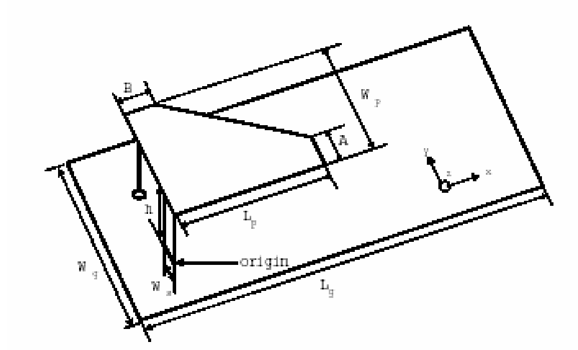


Fig.3. Configuration of a Linearly Tapered PIFA

realized in various application cases. The bandwidth will be specified as the frequency bandwidth in which the voltage standing wave ratio (VSWR) is less than 2:1. A 2:1 VSWR is equivalent to a 10 dB return loss, the level at which 10 % of the incident power is reflected back to source.

Fig.3 depicts the configuration of the designed PIFA [7]. It comprises a tapered type top plate or radiating plate, ground plane, feed wire and shorting plate. As compared with the basic PIFA, a distinct difference is found on top plate. Referring to fig.1, the design parameters are the length and width of the top plate, the length A and B, the position of feeding point as well as the size of shorting plate. Among these parameters the most important parameter in our simulation is the height of shorting plate for built-in to the mobile phones. The design procedure of the designed antenna is simple and straightforward. First, a classical PIFA design technique is used to make a quarter–wavelength resonant patch of PIFA for PCS band while the height of the top plate above the ground is fixed. But taking into account cutting of a portion of the top plate and the fact that the dimension of the top plate are inversely proportional to the resonant frequency, the design frequency is somewhat lower than that of basic PIFA structure. The location of the shorting plane and feeding point may need to be changed to achieve the best matching. However, it is not easy to tune the optimized locations of feeding point and shorting plane. The length A and B are determined by design frequency as mentioned above.

The design shown in Fig.3 was simulated using HFSS software with the following set of parameters: Lp = 35 mm, Wp = 25 mm, Ws = 3.5 mm, h = 6 mm, A = 5 mm, B = 5 mm and feeding point (x, y, z) positioned at (2, 19, 6) mm on the top plate from origin. The left and top edge of top plate is 5 mm and 2.5 mm from that of ground plane, respectively. The ground plane was optimized on a (Lg, Wg )= (70, 30) mm. Between the top plate and the ground plane is the air-filled. The inner conductor of the coaxial feed wire is attached to the top plate going through the ground plane and the outer conductor of the coaxial wire is directly connected to the ground plane. The ground plane and the top plate, as well as the shorting plate are made perfect electrical

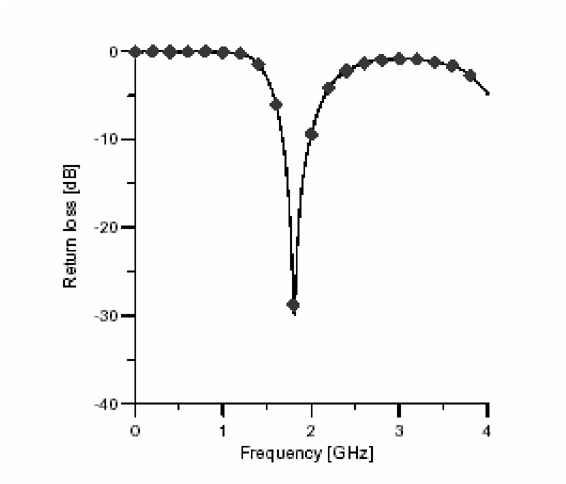


Fig.4. Simulated Results: Return Loss of a Linearly Tapered PIFA.

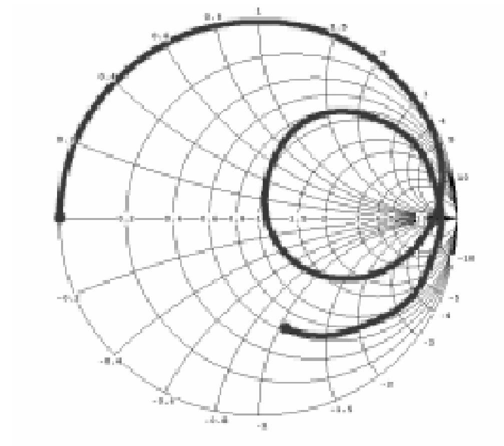

Fig.4. Simulated Results: Input Impedance of a Linearly Tapered PIFA.

conductor materials. The results obtained on simulation are shown in Fig.4 and 5. The maximum Return Loss is -28 dB at a frequency of 1.75 GHz. The resonance frequency is 1.75 GHz and at that frequency the impedance obtained is 54 + j 1.2. The upper and lower frequency is 1.94 GHz and 1.65 GHz, respectively. The difference between upper and lower frequency of the bandwidth is 0.29 GHz. Therefore, the bandwidth of the designed PIFA is 16.6%.

## IV. CONCLUSIONS

This paper has focused on the development of low-profile integrated antennas with enhanced bandwidth performance. The featured radiators have several advantages over other candidate antenna elements. The results for the PIFA, these antennas are potential low profile candidates for wireless communications systems. The PIFA can be designed for up to about 9.6% bandwidth. The design of a linearly tapered PIFA for mobile phones operating in PCS band is presented and executed using HFSS. The central aim in design is to broaden the bandwidth in limited height. A modified PIFA with linearly tapered top plate can be designed for 16.6 % bandwidth. . The results and design details on the antenna presented here can be used as beginning designs for engineers interested in utilizing PIFA where a flexible antenna structure is needed.

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