International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 9 No. 3 Nov. 2014, pp. 1048-1055

http://www.ijias.issr-journals.org/

Design and simulation of a planar inverted-F antenna (PIFA) for Wi-Fi and LTE Applications

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ABSTRACT: In recent years planar inverted-F antenna stay as one of the most popular antenna used in mobile phone, because of its low profile, light weight and simple structure. This study presents a simulation of a planar inverted-F antenna (PIFA) with a radiating plate to the associated ground plane by a shorting plate and a FR-4 substrate between the ground plane and the radiating plate. The PIFA antenna is fed by a coaxial cable through a SMA connector. In this work the different parameters are changed to observe their effects on the characteristics of PIFA as the resonance frequency, the length of the bandwidth and the radiation pattern. The kind of this PIFA element is to cover a wide frequency band from 2.31 GHz to 2.71 GHz; therefore, we can find these applications: Wi-Fi (2.45GHz), Bluetooth (2.4 GHz) and the two Long Term Evolution bands (LTE 2.3GHz, LTE 2.5GHz) includes.

KEYWORDS: Antennas; PIFA; planar antennas; Wi-Fi; LTE.

1 INTRODUCTION

Recently, the increasing use of mobile communications systems requires antennas having different properties such as small size, high speed and moderate gain [1], and because of the limited space available in wireless devices, the request of the design of low cost and small size of the antenna is necessary. Today, there is a growing need to gather all the wireless services in one device, particularly, the integration of Bluetooth technology, Wi-Fi and LTE in some portable devices with a high-speed data transmission and high quality. However, this normally requires many antennas to cover each service, and it is not possible to fit them all in a small device. To address this requirement, antennas that operate in multiple bands are required to support multiple standards. So, the idea is to enhance the functionality and performance of wireless communication devices and to cover the existing wireless communication frequency bands. The planar inverted-F antennas (PIFAs), is particularly interesting due to their compactness and suitable performance. PIFA antenna has been adopted in portable wireless units because of its low profile, light weight, and conformal structure (Balanis, 1982).

Today, planar inverted F antenna (PIFA) remains as one of the most popular antenna used in mobile phones [2]. Because of the limited space availability in wireless devices, we keep the size of this type of antenna small and appropriate for portable wireless units without degradation of performance in terms of bandwidth and radiation patterns [3]; so, the radiation pattern should close to be omnidirectional and it should cover required operating frequency bands for the IEEE 802.11b/g/n standard. Because of price advantages and performance via Bluetooth and Wireless digital phone, wireless technology IEEE 802.11b and IEEE 802.11g which have been widely used in wireless Ethernet network.

In [4], Chattha and Huang presented Dual-feed PIFA with a height h = 10 mm and a minimum bandwidth of the two ports is 200 MHz, In [5] they presented a dual-feed PIFA with height h = 5 mm and a minimum bandwidth 50 MHz by the two ports and In [6]; Rao and Wang also presented a compact dual-port antenna for Long-Term Evolution with a height h = 7.5 mm and minimum bandwidth by the two ports is 200 MHz

In this paper, we propose a compact PIFA antenna h = 4.6 mm, with a simple structure and easy integration with active devices. The height h and the dimensions of the radiating plate are reduced and the minimum bandwidth is about 400 MHz (2.31 GHz to 2.71 GHz). We find that the radiation pattern in free space and the gain of the proposed antenna also meet the requirements of wireless communication terminals. The PIFA of the resonant frequency of 2.478 GHz and is satisfies the requirement to cover Wireless Local Area Network (WLAN), Bluetooth technologies and Long Term Evolution (LTE2300 and LTE2500) services. The antenna can be used in mobile phones and tablet computers.

2 ANTENNA CONFIGURATION

For the conventional PIFA antennas, each PIFA-patch element will be designed carefully based on approximately equation (1). This equation is a very rough approximation which does not cover all the parameters which significantly affect the resonance frequency of PIFA [7].

$$fr = \frac{c}{4(L_p+W_p)\sqrt{\varepsilon_r}} \quad (1)$$

Where:

- f_r is the resonance frequency at desired band.
- L_p is the length of the radiating element.
- W_p is the width of the radiating element.
- ε_r is the dielectric constant of the substrate.
- c is the speed of light.

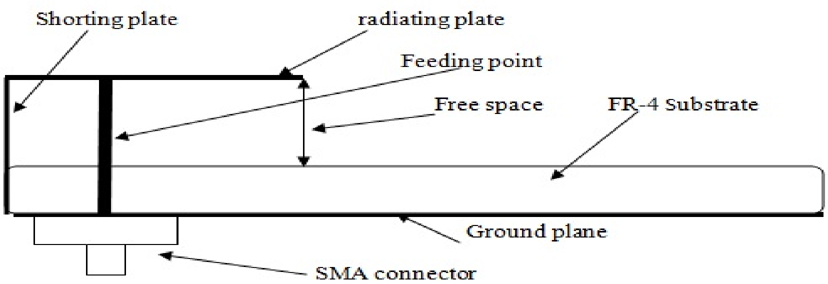

Fig. 1. the geometry of the PIFA antenna proposed

The configuration of the PIFA is shown in Figure 1. The radiating plate has the dimensions of Wp×Lp (Figure 2) and ground plane dimensions are Wg×Lg. There is an FR-4 substrate (hs=1.6mm) has a relative dielectric constant of 4.4 and it is between the rectangular ground plane and radiating plate. The antenna height is h=ha+hs and the space between the top plate and the substrate are also filled with air (free space). In practice, a substrate is generally just underneath the top plate, but this will make the top plate too heavy to be supported by the shorting and feeding plates. The shorting plate with the dimensions of Wsh×h is placed under the top corner of the top plate. The horizontal distance between shorting and feed plates is x. The distance between the coaxial cable and the right edge of the ground plane is Wp/2 and even for shorting plate. The PIFA antenna is fed by a coaxial cable through a subminiature version A (SMA) connector. The software package used for simulation is CST Microwave Studio v.11 and High Frequency Structure Simulator (HFSS).

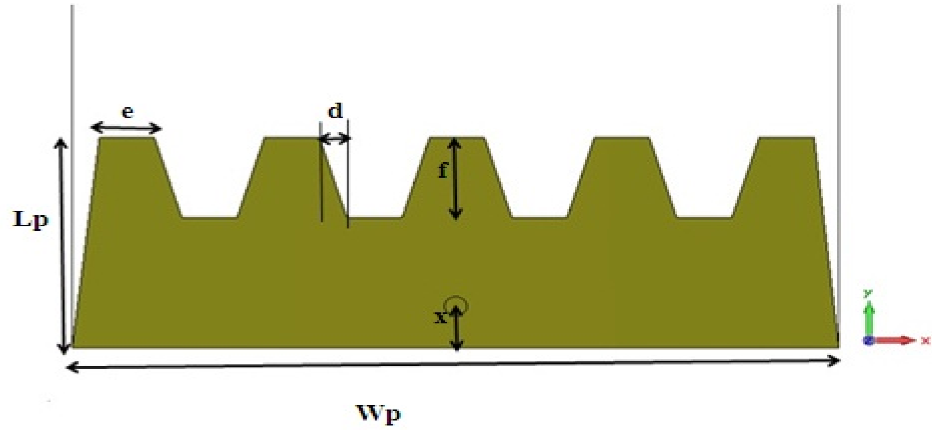

Fig. 2. the geometry of the top radiating plate

Table 1. Detailed dimension of the proposed antenna

Name of the parameter	Symbol	Value (mm)
Upper radiating patch length	Lp	10
Upper radiating patch width	Wp	30.7
Feed plate length	h	4.7
Feed plate width	Wsh	3
Ground plane length	Lg	90
Ground plane width	Wg	30.7
FR-4 substrate height	hs	1.6
FR-4 substrate length	Ls	90
FR-4 substrate width	Ws	30.7
Feed point location	(x, y)	(2, 0)
Feed pin radius	R	0.45
----	d	1.1
---	e	2.2
---	f	3.8

We changes the position of the feed pin by modifying the values of the horizontal distance x from 1.5 to 3.6 mm, the length of the radiating plate Lp from 8 to 20 mm, the width of the radiating plate Wp from 24 to 50 mm and height between substrate and the radiating plate ha from 3 to 10mm. we can observe this effects on PIFA characteristics while other parameters are constant. Table 1 lists the values of different variables of the PIFA proposed.

3 SIMULATED RESULTS

In this study of the antenna proposed we change one parameter to observe their effects on the characteristics of the PIFA and the other parameters are constant. There are many variables that may affect the PIFA antenna bandwidth and, therefore, numerical approaches are adopted.

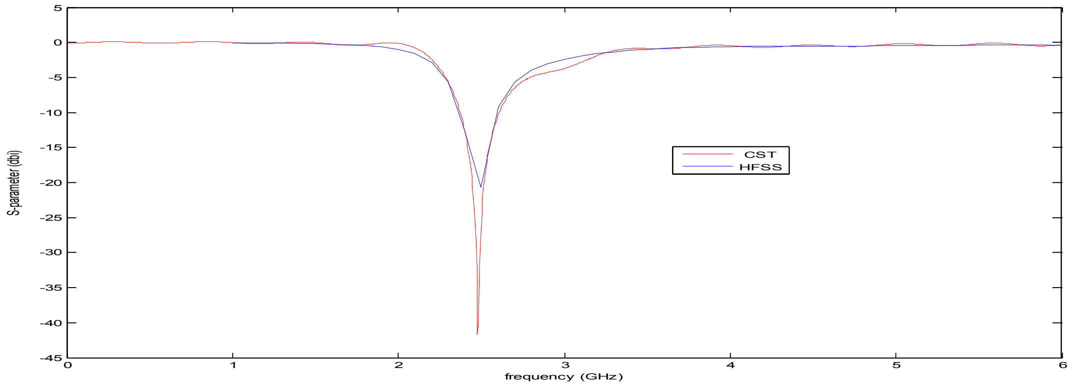

Fig. 3. The Simulated return loss for the proposed antenna

The S-parameter simulated with CST microwave studio and High Frequency Structure Simulator (HFSS) are shown in figure 3; we can see that the minimum bandwidth is about 400 MHz (2.31 GHz to 2.71 GHz).

How such a single element antenna works as a diversity antenna can be explained by the theory of characteristics modes: diversity gain can be achieved by exciting different modes of the antenna which result in different radiation patterns [8]. Here different modes on the radiator top plate and ground plane of the PIFA are excited to produce the desired diversity gain. It is observed from the parametric study that the dimension of ground plane greatly affects the resonant frequency [9].

3.1 THE CHANGES OF WIDTH AND LENGTH OF THE RADIATING PLATE

The changes are made in the width (Wp) and the length (Lp) of the top radiating plate and its effects are observed on the characteristic of PIFA. We change the width of the top radiating plate from 24 mm to 50 mm and length of the top radiating plate from 8 mm to 20 mm while all other parameters are constant, in Figure 4 (a, b) show that the increase in the width of top radiating plate decreases the resonance frequency and impedance bandwidth, in Figure 5 (a, b) show that the increase in the length of top radiating plate decreases the resonance frequency and impedance bandwidth.

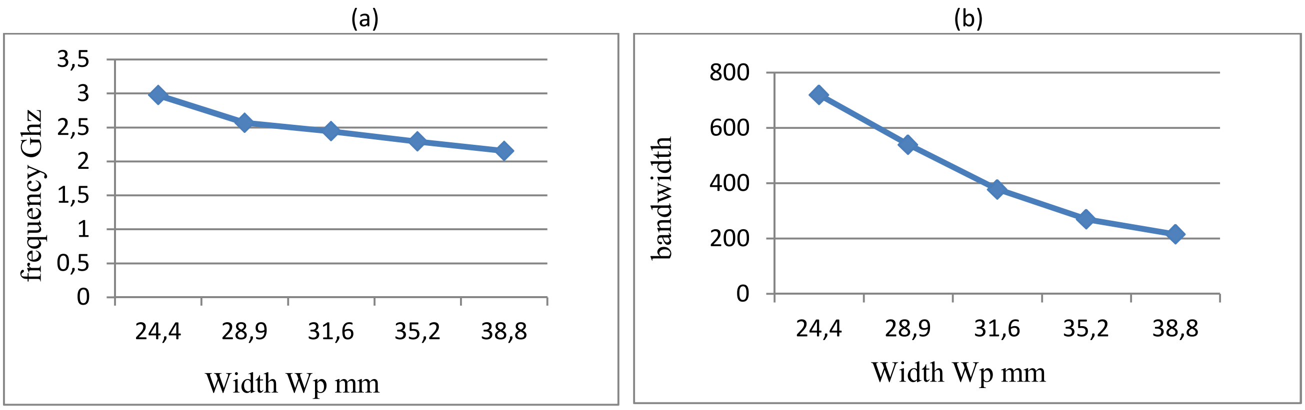

Fig. 4. Changes of width of the radiating plate according resonance frequency and bandwidth

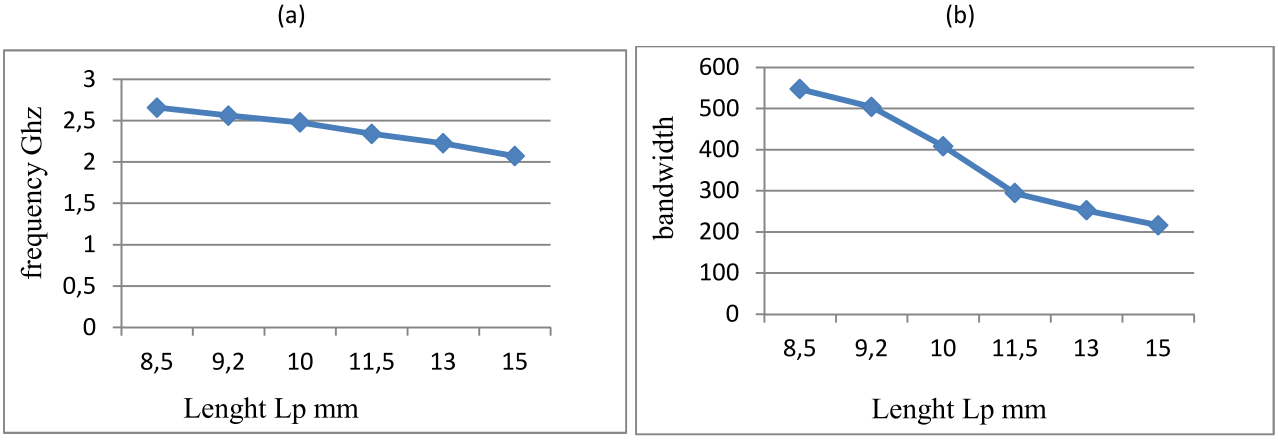

Fig. 5. Changes of length of the radiating plate according resonance frequency and bandwidth

The effect of changing the width of top plate Wp on the fractional bandwidth is shown in Figure 4 (b) and on resonance frequency is shown in Figure 4 (a). The effect of changing the length of top plate Lp on the resonant frequency is shown in Figure 5 (a) and on the bandwidth is shown in Figure 5 (b). It is evident that increasing the width of the feed plate increases the fractional bandwidth up to a particular value then further increase in the feed plate width only serves to decrease the fractional bandwidth.

3.2 THE CHANGES OF THE HEIGHT HA

The height of top plate h is varied from 3mm to 10mm to observe its effect while all other parameters are constant, simulated results is shown in Figure 6(a, b). The results show in Figure 6 (a) and Figure 6 (b) that the increase in height ha decreases the resonant frequency and the impedance bandwidth. This parameter can be decreased to enhance the impedance bandwidth and resonance frequency and is very critical as we need to have small antennas.

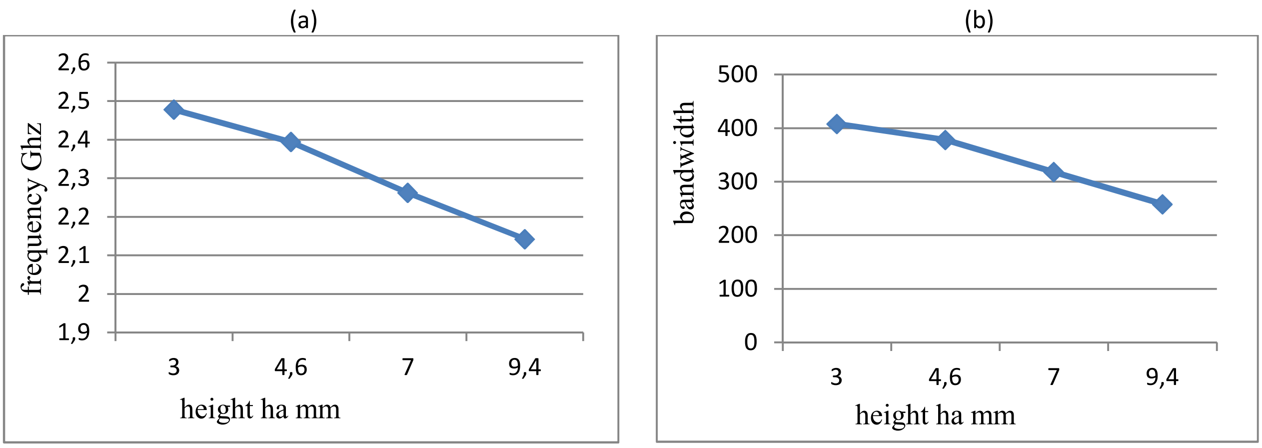

Fig. 6. Changes of the height ha according resonance frequency and bandwidth

3.3 THE CHANGES OF THE FEED PIN POSITION

The changes are made in the horizontal distance x of the PIFA from edge of ground plane to observe their effects on the characteristics of PIFA. The value of x is changed from 1 to 3.6mm while all other parameters are constant. The simulated results are shown in Figure 7 (a, b).

The results show that increase in distance x increases the resonant frequency (figure 7 a) and impedance bandwidth (figure 7 b). It is concluded that the placement of PIFA on ground plane significantly affects the characteristics of the PIFA and feed pin needs to be placed at maximum distance x of ground plane for maximum impedance bandwidth.

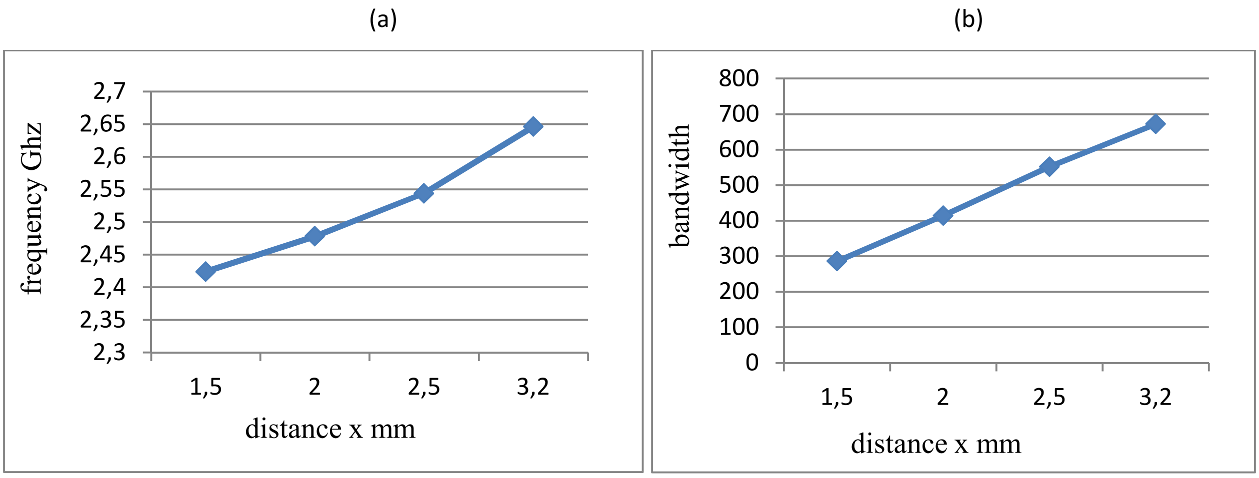

Fig. 7. Changes of the distance x according resonance frequency and bandwidth

Figures 8, 9 and 10 plot the simulated radiation patterns of antenna at the resonant frequency. In different planes the radiation patterns for resonant frequency are close to omnidirectional. The approximate omnidirectional characteristic of this new PIFA can be seen from the different horizontal and vertical patterns. However, the new PIFA is confirmed in its basic behavior as an acceptable omnidirectional radiator.

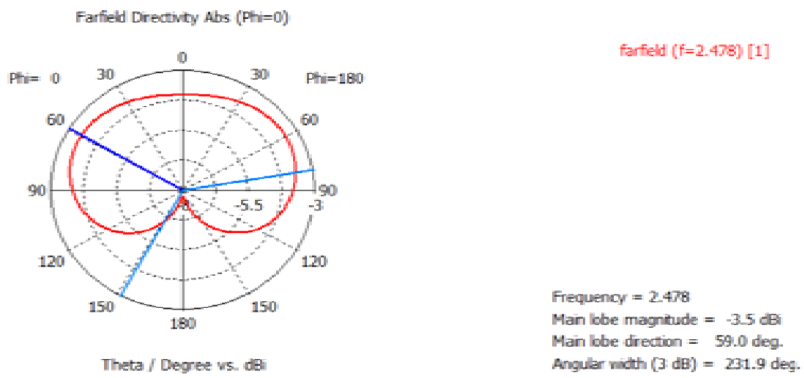

Fig. 8. Simulated radiation patterns in dB ($\varphi = 0$, x-z plane) at fr=2.478 GHz

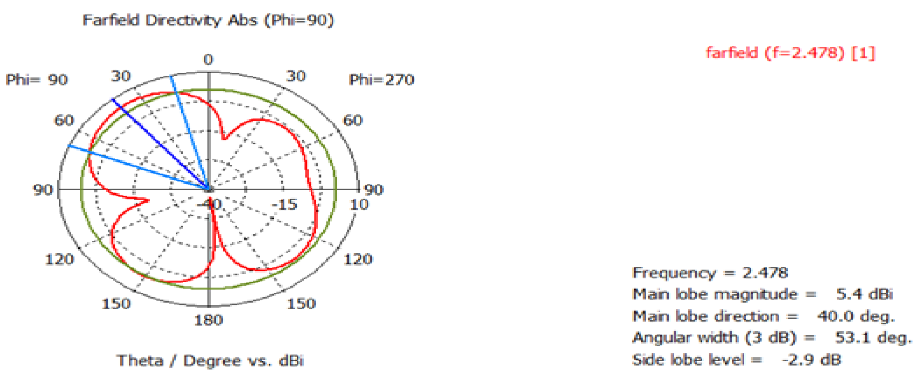

Fig. 9. Simulated radiation patterns in dB ($\varphi = 90$, y-z plane) at fr=2.478 GHz

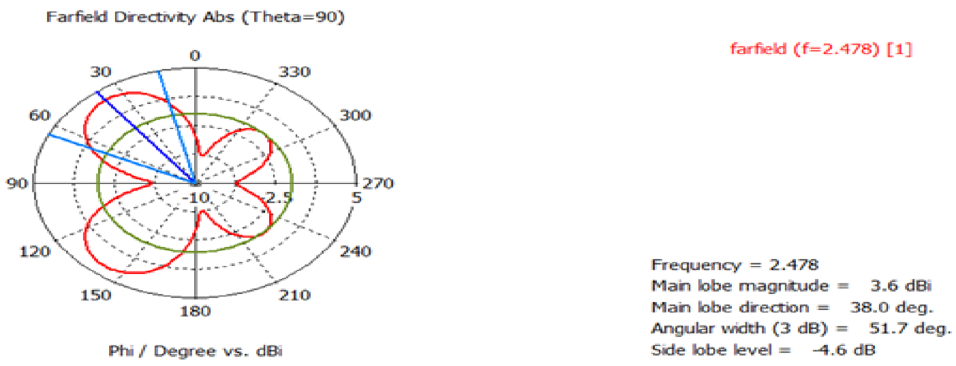

Fig. 10. Simulated radiation patterns in dB ($\theta = 90$, x-y plane) at fr=2.478 GHz

In Figure 11 it is shown the simulated maximum gain is above 2.9 dB. Both parameters are very acceptable for a mobile phone antenna and validate an adequate radiation performance besides the large bandwidth.

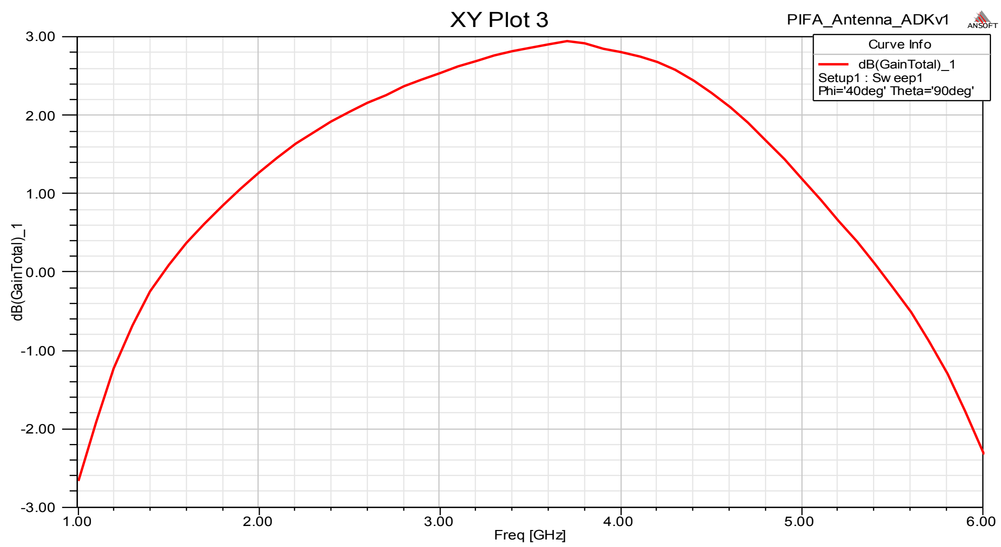

Fig. 11. Simulated gain at fr=2.478 GHz

4 Conclusion

The new design PIFA proposed in this article can cover the frequency range from 2.31 GHz to 2.71 GHz (400 MHz), therefore, it includes applications: Wi-Fi (2.4GHz), Bluetooth (2.4 GHz) and the two LTE bands (2.3GHz, 2.5GHz). The Changes of the length of the top radiating plate (Lp), the width of the top radiating plate, the height between the top radiating plate and the substrate (ha) and the feed position (x) changes the frequency of resonance and bandwidth and don't have significant effect on the radiation pattern.

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