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Design and Simulation of Planar Inverted F Antenna (PIFA) for Long Term Evolution Systems

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Abstract

In this paper, a new calculator form is designed to calculate fundamental parameters for Planar Inverted F Antenna (PIFA). The special algorithm is configured by MATLAB R2015a software (version 8.5) in the form of a GUIDE programming language to estimate the value of antenna length (La) and width (Wa) by professional software Computer simulation technology (CST) microwave studio (Version 2019) is used to design and study the effects of each parameter in the antenna performance. The designed model was used directly in manufacturing through this method without any optimization or improvement. This antenna fabricated on the FR4 substrate has relative permittivity of 4.3 with a volume of (120×60×1.5) mm^3 and the proposed antenna is fed by microstrip feeding structure. Simulation results of the (PIFA) show that the return loss, bandwidth, VSWR, and impedance are –52.100dB, 686 MHz, 1.0002 and 49.99 Ω respectively at resonant frequency 3.5 GHZ.

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1. Introduction

Wireless Communication is the fastest growing and most vibrant technological areas in the communication field. Wireless Communication is a method of transmitting information from one point to other, without using any connection like wires, cables, or any physical medium. Such type of medium is called Guided Medium. On the other hand, Wireless Communication does not require any physical medium but propagates the signal through space, etc., [1]. The Long Term Evolution is a broad band solution that offers various features with good flexibility in term of deployment options and potentials for mobile services [2].

The 5G (5th generation mobile networks or 5th generation wireless systems) is a term used in some research papers and projects to denote the next major phase of mobile telecommunications standards beyond the current 4G. 5G is considered as beyond 2020 mobile communications technologies [3]. This paper presents designs for PIFA antenna at 3.5 GHz, where 3.5GHz is one of the standard frequencies of the 5G communications. Speed is one of the key elements of the next-generation network. 5G is faster, smarter, as well as more energy-efficient than the 4G network. The 5G network's speed is 10 gigabits per second, which is 100 times faster than 4G [4]. The Planar Inverted-F Antenna (PIFA) is a very popular design in mobile communications [5,6]. PIFA antenna has been adopted in portable wireless units because of its low profile, light weight, and conformal structure. PIFA become one of the most popular antennas in recent years, bringing much attention to the research in this area, Applications where they have been used are: satellite/terrestrial communications, various cellular communications equipment such as handset terminals/base stations, GPS devices, biomedical transceivers and implantable applications, WLAN transceivers and Bluetooth devices, and MIMO systems, The number of applications of the PIFA and PIFA-derived antennas continues to grow rapidly [7]. Various programming languages with graphical user interfaces (GUI) has been used to design a calculator for solving antenna equations and designing planar inverted F antenna structure [8,9]. But, most of these calculators are specific to some parts of the antenna. Furthermore, some of them entered the field of analyzing results and examining the antenna. We will use MATLAB software for programming a new graphical user interface development environment (GUIDE) calculator to determine the dimensions of the proposed antenna with very high accuracy in our research paper.

2. Planar Inverted F Antenna (PIFA) Design

Design considerations for a PIFA include the resonant frequency, the impedance bandwidth, radiation patterns, gain and size [10]. Figure 1 shows the necessary measurements of the PIFA structure.

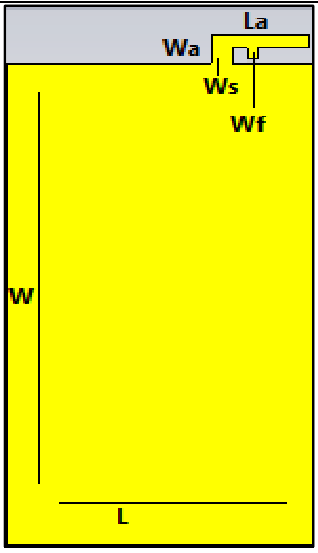

Figure 1. Structure of the PIFA.

PIFA has moderate (or) high gain in both horizontal and vertical polarization. Generally, most of the wireless systems use vertical polarization. Even if transmitter antenna polarization is not known, still the signal is received with good strength. When antenna orientation is not fixed, a signal with good gain (greater than 10 dB) is received and signal strength is calculated by summing up the horizontal and vertical components.

The following equations are used to find the resonant frequency of a PIFA for each of the listed study cases [11]:

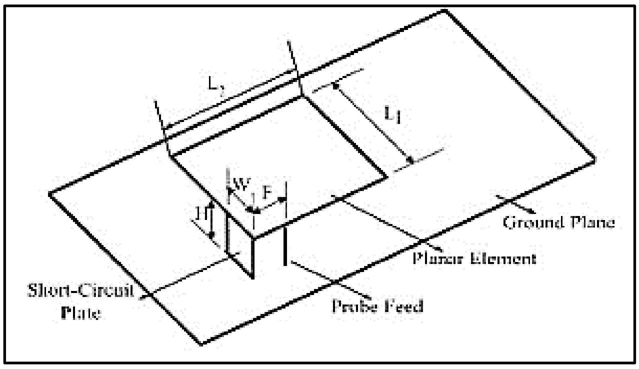

Figure 2. Planar inverted-*F* antenna [11].

Case 1: In Figure 2, when the width of the short circuit plate W is equal to the planar element length (L_1), i.e., ($W = L_1$), then a matching between this case and a short circuit microstrip antenna is obtained, which is a λ/4 antenna. The effective length of the microstrip antenna (L_2) is equal to a quarter wavelength (see equation (1)) where, L_2 is the length of the planar element.

$$L_2 = \frac{\lambda}{4} \qquad \ldots(1)$$

where λ is the desired wavelength, and the resonant frequency at this case will be:

$$f = \frac{c}{4(L_2)\sqrt{\varepsilon r}} \qquad \ldots(2)$$

Case 2: When the width of the shorting plate (*W*) is represented by a thin pin, i.e. ($W \approx 0$), then the effective length is ($L_1 + L_2$) which also equals to quarter-wavelength (see equation (3)). The resonant frequency in this case is expressed by equation (4).

$$L_1 + L_2 = \frac{\lambda}{4} \qquad \ldots(3)$$

$$f = \frac{c}{4(L_1+L_2)\sqrt{\varepsilon r}} \qquad \ldots(4)$$

Case 3: This case represents the general form of the design calculation of a PIFA antenna. When ($0 < W < L_1$), the resonant frequency depends on the sum of the patch lengths (L_1 and L_2), shorting pin width (*W*). The designed PIFA in this case resonates at a frequency given by equation (6).

$$L_1 + L_2 - W = \frac{\lambda}{4} \qquad \ldots(5)$$

$$f = \frac{c}{4(L_1+L_2-W)\sqrt{\varepsilon r}} \qquad \ldots(6)$$

All the previous equations were programmed by using MATLAB R2015a software (version 8.5) in the form of a GUIDE as shown in Figure 3. This PIFA calculator has two stages. First, the main measurements which calculated according to the input values. Second, the Length (*L*) measured based on a portion of the previous data. The required results for the design of the PIFA are included in Table 1.

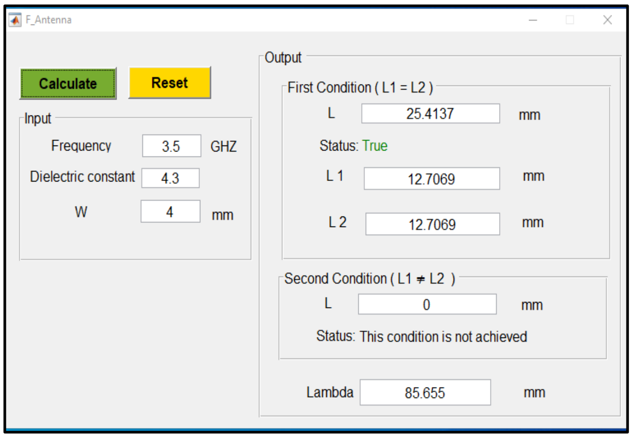

Figure 3. PIFA calculator.

Table 1. PIFA parameters and their values.

Parameters	Value (mm)
Length of ground (Lg)	60
Width of ground (Wg)	120
Thickness of substrate (h)	1.5
Width of cut (Wcut)	12
Length of shorting part (Ls)	3.5
Width of shorting part (Ws)	4
Width of feed part (Wf)	2.29
Feed gap (gf)	1
Length of antenna line (La)	18.52
Width of antenna line (Wa)	3

All results values are rounded to two digits because, on the practical side, it is hard to implement micro dimensions.

3. Simulation Results

The design of the proposed antenna is shown in Figure 4. It consists of substrate, ground plane, shorting plate and feeding post connected to the ground plane. The dimensions of PIFA are (120 mm × 60 mm × 1.5 mm). The FR4 has relative permittivity of 4.3, the PIFA is operated at resonant frequency of 3.5 GHz to cover the band of (42). The proposed antenna is fed by microstrip feeding structure. Computer simulation technology (CST) microwave studio (Version 2019) has been used to design this PIFA, as shown in Figure 4. The designed antenna without any optimization or improvement, and the results were immeasurable. Figure 5 shows that the minimum return loss is –52.100 dB with an impedance bandwidth of 686 MHz (3.23 GHz-3.92 GHz). The voltage standing wave ratio (VSWR) value is 1.0002, as shown in Figure 7.

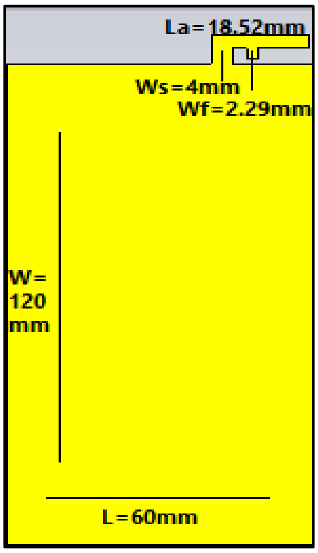

Figure 4. Structure of the proposed PIFA with all values of measured dimensions.

Table 2. Antenna description.

Frequency of operation	3.5 GHz
Dielectric constant of the substrate	4.3
Feeding method	Microstrip feeding
VSWR	1.00
Gain	5.844 dB

3.1 Return loss:

Figure 5 represents the line graph between the simulated return loss values and the frequency for each frequency located within the range (from 1 GHz to 5 GHz) automatically by a CST microwave software. All values of RL are negative because of logarithmic equation that converting the fractional numbers into negative real values. In the confined region between (1 GHz to 2.5 GHz), the RL values are close to zero, and this indicates that most of the incident power has reflected to the source. So, the antenna in this region does not work. After 2.5 GHz, the curve starts to decrease logarithmically arriving to 3.5 GHz. This indicates that the antenna is started to response gradually for these frequencies. After that, the values of RL begin to gradually rise until the possibility of the antenna of response disappears.

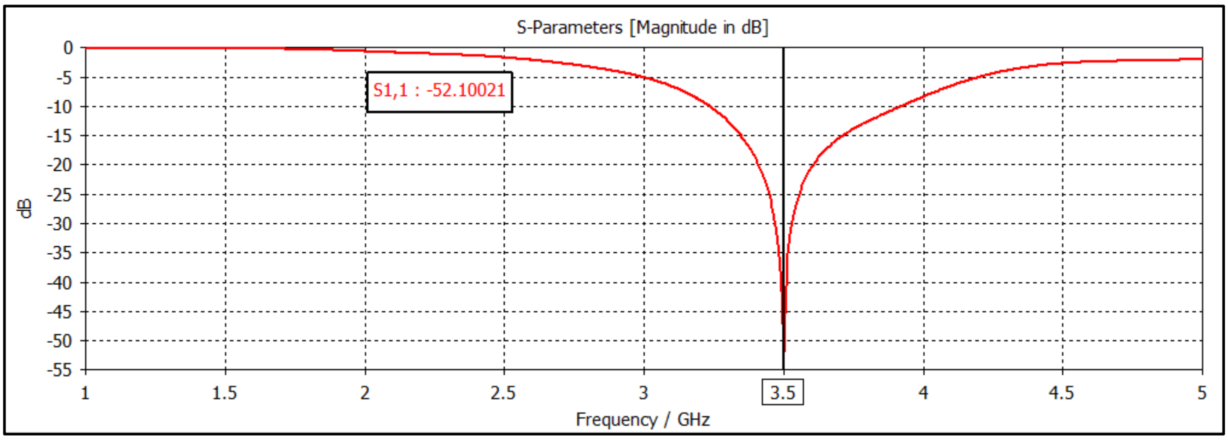

Figure 5. S-parameter of the PIFA.

The impedance bandwidth is 686 MHz (3.23-3.92) GHz at 3.5 GHz. The acquired bandwidth can sufficiently cover the bandwidth requirement for 5G applications.

3.2 Bandwidth:

Figure 6 represents the calculation process of the working zone bandwidth through the return loss graphed manually. Several extra lines have been placed to determine specific region. The horizontal solid line at –10 dB is placed to determine the antenna work area. The second horizontal solid line at –40 dB is neglected in this work, because of not within our work field. Also, the two vertical solid lines determine the frequency work space. The difference between a high frequency (3.9215 GHz) and a low frequency (3.2352 GHz) gives bandwidth which is equal to 0.686GHz or 686MHz.

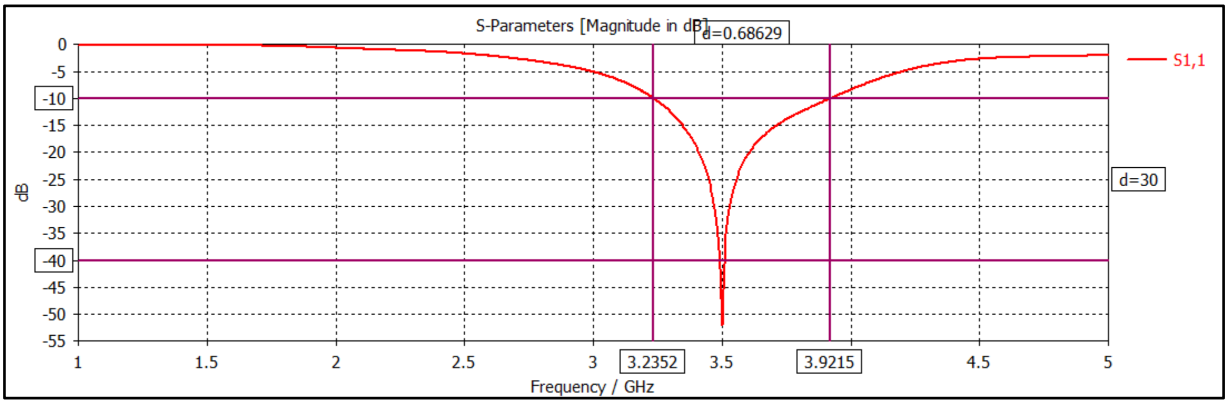

Figure 6. Simulated bandwidth.

3.3 VSWR:

The results of the VSWR parameter at the same frequency range of RL are demonstrated in Figure 7. The values of VSWR have been automatically calculated by CST microwave studio software**.** The minimum value of VSWR is 1.0002, which is located at the frequency of 3.5 GHz. In the left half of the line graph the VSWR values start to decrease from 300 to 1.0002, and that means the reflected voltage decline gradually. The values of the reflected voltage are increased in the right side of the graph from 1.0002 up to value 10 of VSWR. These two sides of high VSWR values indicate there are standing waves have been configured in undesirable frequencies. The matching between source and antenna impedances is almost ideal, because of the minimum value of VSWR is close to the one.

Voltage standing wave ratio (VSWR) should be 2:1 for good radiator. The gain of 5.844 dB with VSWR value of 1.0002 indicating a good impedance matching (perfect matching VSWR = 1) which implies that almost all input power could be transmitted as shown in Figure 7.

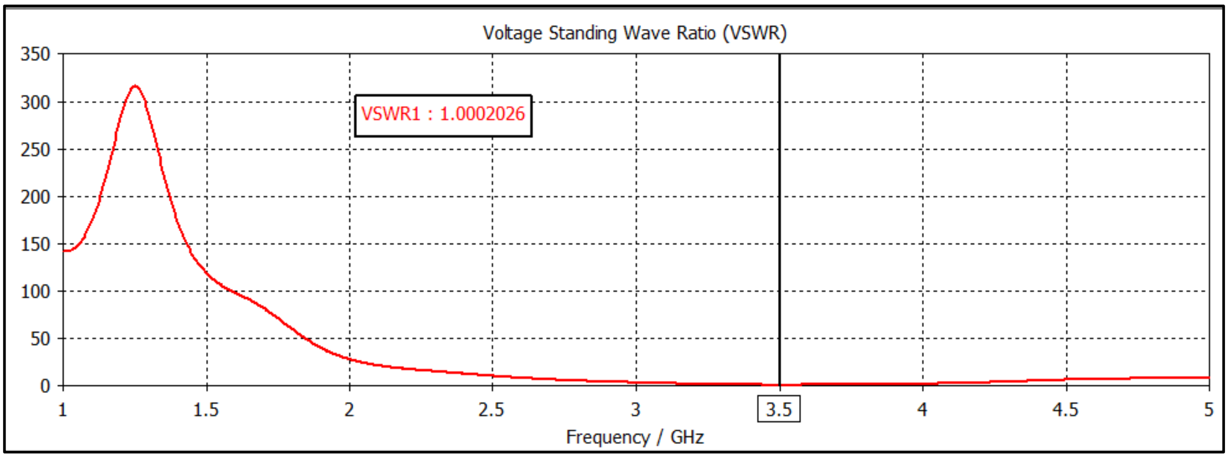

Figure 7. VSWR of the PIFA.

3.4 Input Impedance:

The theoretical results of the input impedance of the first antenna used with CST microwave studio software is represented in Figure 8. The value of Z_{in} is 49.991 Ω at the 3.5 GHz for operating frequency. This value is so close to the reference impedance value (50 Ω).

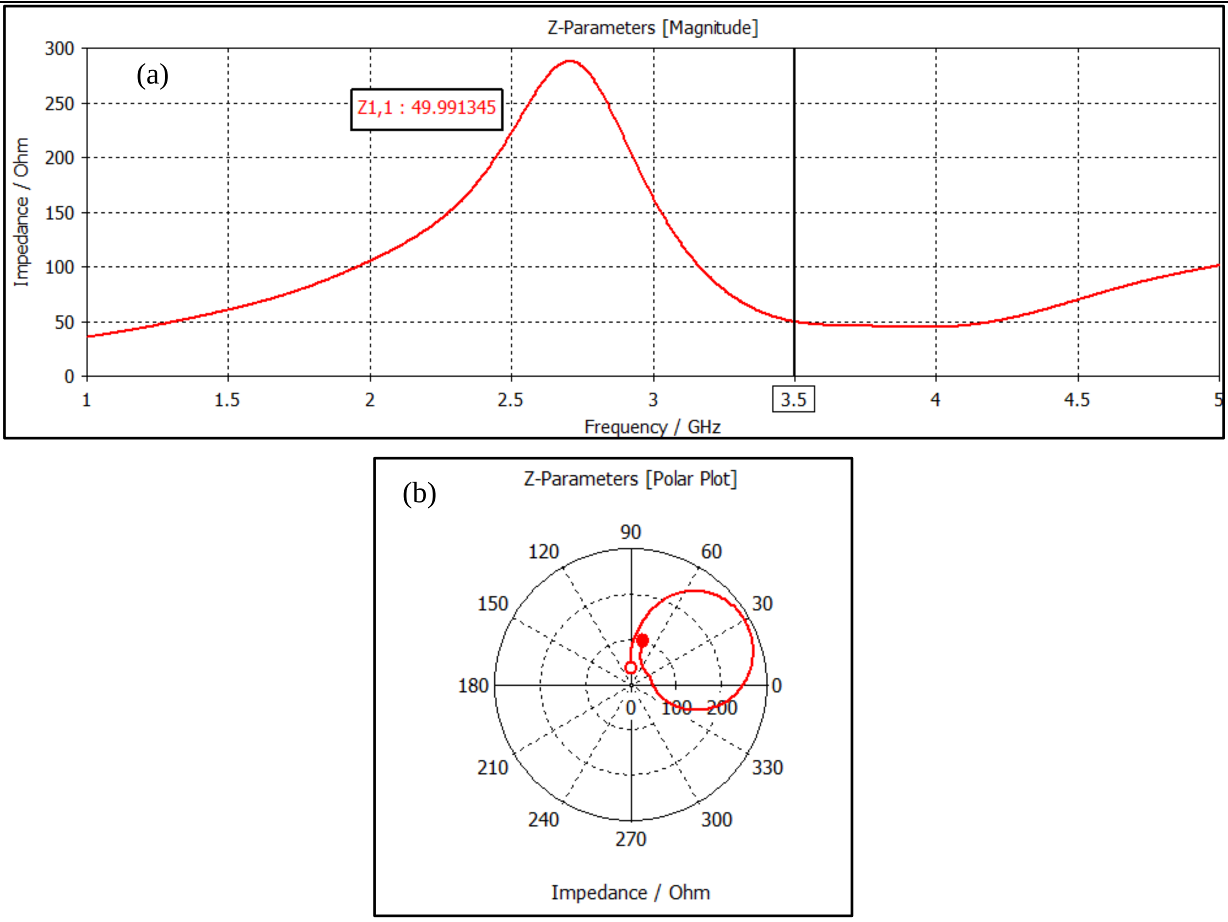

Figure 8. (a) Simulation value of the input impedance of PIFA using linear graph (b) Simulation value of the input impedance of PIFA using smith chart.

3.5 Gain:

The values of gain in polar form are presented in Figure 9. The red loop is a cross-section of the gain lobe from top view. The blue line represents the highest gain value which has an angular displacement about 126.0 degrees from the center of radiation. The effective area of gain is determined by two orange lines separated with 109.4 degrees. As a result, the main lobe magnitude was equal to 5.74 dBi.

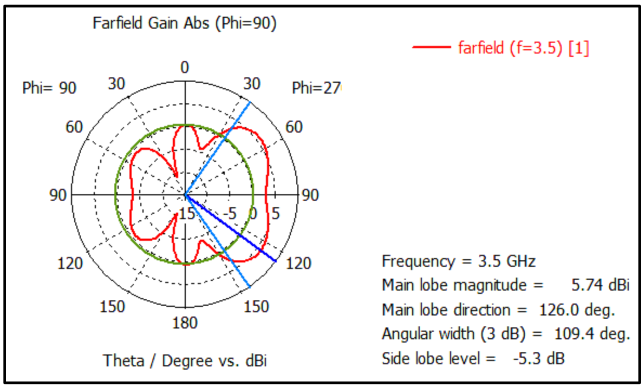

Figure 9. Farfield of the PIFA.

Figure 10 shows the far-field radiation patterns of the antenna. From this, it can be seen that the gain is about 5.844 dBi.

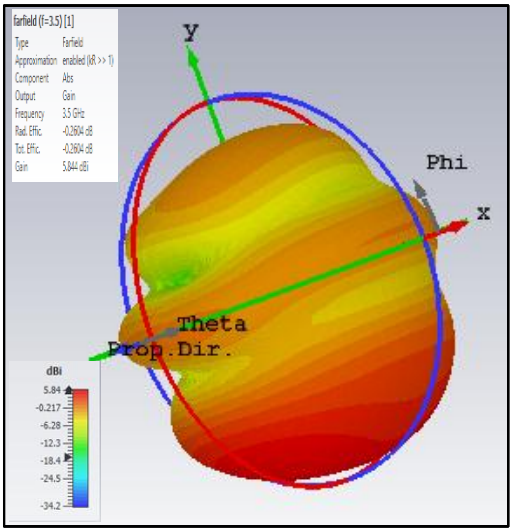

Figure 10. A 3-D model of the gain for simulation radiation pattern.

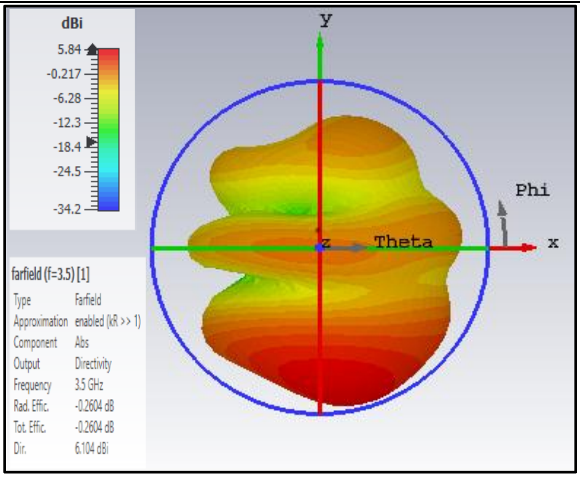

Figure 11. Directivity of the PIFA.

3.6 Directivity

Maximum gain in a given direction is called directivity. Figure 11 represents the simulated pattern in 3-D model form of the PIFA. The major lobe of this model shows that the intensity of radiation is mainly on the x-axis. This direction indicates the front side of the used antenna**.** The color ramp is demonstrating the distribution of intensity for the directivity from –33.9 to 6.1 Decibels Per Isotropic (dBi).

Table 3. Comparison between experimental results of proposed MPA and other studies.

Studies	RL (dB)	B.W.
[13]	–42	755
[14]	–43	350
This work	–52.100	685

4. Conclusions

The purely theoretical method has been reached for designing the simplest types of PIFA without any optimization. Simulation results of the (PIFA) show that the return loss, bandwidth, VSWR, and impedance are –52.100dB, 686 MHz, 1.0002 and 49.99 Ω respectively at resonant frequency 3.5 GHZ. The antenna operates at 3.5 GHz, which has a good performance in the satellite/terrestrial communications, and 5G applications. We suggest adopting this designed antenna as a basis for adding the improvements or performing various experiments on it. The antenna can be used in mobile phones and tablet computers.

Acknowledgments

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