

Design of Frequency Reconfigurable PIFA Antenna with Floating Ground Plane

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Abstract

Objectives: The rapid evolution of wireless communications systems open the field to frequency reconfigurable antenna. In this paper, we propose to study and design a PIFA antenna with frequency agility characteristic. **Methods/Analysis:** The reference antenna resonates at $F = 1000$ MHz. It consists of a PIFA design printed on the top side and the grounded PCB in the back one. To obtain a low profile and have a multiband behavior, a floating ground plane was printed in back side of the antenna coupled with the radiating PIFA element. A two resonances frequencies can be obtained. To electronically reconfigure the antenna in a determined band and acquiring a large tuning range, a varactor diode was embedded in the corner of the radiating element. **Findings:** When adding a floating ground plane, a two resonances frequencies can be obtained at 920 and 2800 MHz with better than -10 dB impedance match. To obtain three resonance frequencies with wide tuning ranges, we apply a reverse voltage V on the varactor diode. Frequencies can be shifted from 650 to 2457 MHz covering GSM850/1900/UMTS/LTE700/LTE2300 and ISM band. The reference and the active antennas were designed and described. Good agreement between simulations and measurement results. **Application/Improvements:** This work shows that tunable PIFA antennas are promising candidates for handheld portable.

Keywords: Floating Ground Plane, Frequency Agility, Large Tuning Range, PIFA, Reconfigurable Antenna, Varactor Diode

1. Introduction

The increase demand for portable devices with wireless connectivity across a broad frequency spectrum is the major challenge facing RF designers, because they have to manage the interconnection of both standards such as GSM, UMTS, WiMAX, Bluetooth, LTE, ... Covering several frequency bands simultaneously with a single antenna may be a very demanding task. To deal with this problem, frequency-reconfigurable antennas represent important research and development axes for introducing elasticity on the antenna characteristics^{1,2}. The advantage given by these kinds of antennas is to make the wireless telecommunication systems more flexible for several applications³⁻⁵.

The Planar Inverted F-antenna (PIFA) is very popular in the portable terminals industry because of its compactness, ease integration and their low manufacturing cost^{6,7}. However, it exhibits narrow bandwidth. Thereby, designing PIFA antenna with the ability to electrically control its resonance frequencies is strongly desired. Several researches have been conducted for this purpose. In⁸, the antenna occupies a size of 30×10 mm². The antenna uses only one PIN diode to cover GSM850/900/1800/1900/UMTS/LTE2300/LTE2500 mobile handset. In⁹, the reported antenna occupies a size of 27×10 mm². The antenna can be resonated both in the PIFA and loop mode by adjusting the ON/OFF state of the PIN diode. Nevertheless, the antenna can not cover the GSM 850

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band. M. N. M. Kehn and O. Q. Teruel proposed a reconfigurable microstrip patch antenna. The frequency agility was achieved using a varactor diode¹⁰. Based on the above discussion, we present a novel multiband tunable PIFA antenna covering GSM850/1900/UMTS/LTE700/LTE2300 and ISM band. A floating ground plane was printed under the radiating element in order to miniaturized and obtain a low profile antenna. To dynamically control the resonance frequencies, a varactor diode was inserted in the corner of the antenna. The designed antenna not only occupies a significantly smaller size $50 \times 13.5 \text{ mm}^2$ but also seems to be a simpler structure than the mobile handset antenna mentioned above.

2. Reference PIFA Antenna

2.1 Antenna Design

The dimensions of the proposed antenna is presented inure 1. The antenna is printed on $70 \times 150 \times 1.6 \text{ mm}^3$ FR4 substrate with $\epsilon_r = 4.4$. The radiating element is printed on the upper side and the grounded PCB in the

back side. The ground plane ($70 \times 132 \text{ mm}^2$) is considered to be longer than the radiating element with the aim to reflect the radiated power in the front direction ($\theta = 0^\circ$). A SMA connector use to feed the reference antenna and a shorting plate is used to short-circuit the top patch to ground plane.

2.2 Results and Discussion

The passive PIFA antenna was studied and simulated using the ANSYS ANSOFT HFSS.V15. The simulation reflexion coefficient S_{11} exhibits one resonant frequency $F_1 = 1 \text{ GHz}$ as it can be shown in Figures 1 and 2.

The 3D simulated radiation pattern for $F_1 = 1 \text{ GHz}$ is displayed in Figure 3. The antenna have a maximum radiation towards the positive Z-direction and a maximum gain of 3.07 dB. This result is due to the presence of the reflector plane which reduces the back radiation.

The surface current vectors distribution in the antenna at 1 GHz is illustrated in Figure 4. We can notice that these currents are especially localized in the close part to the feed line.

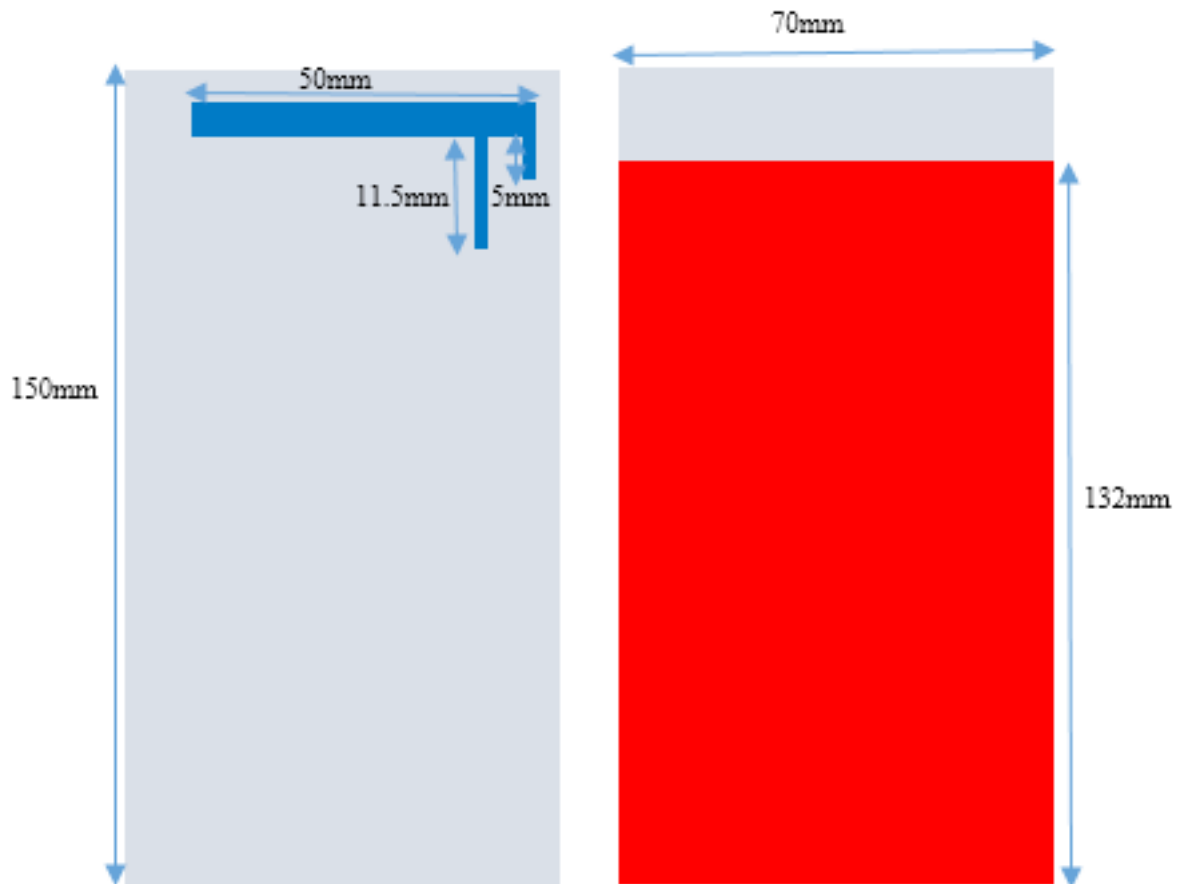


Figure 1. Reference antenna geometry: (a) front side and (b) back side views.

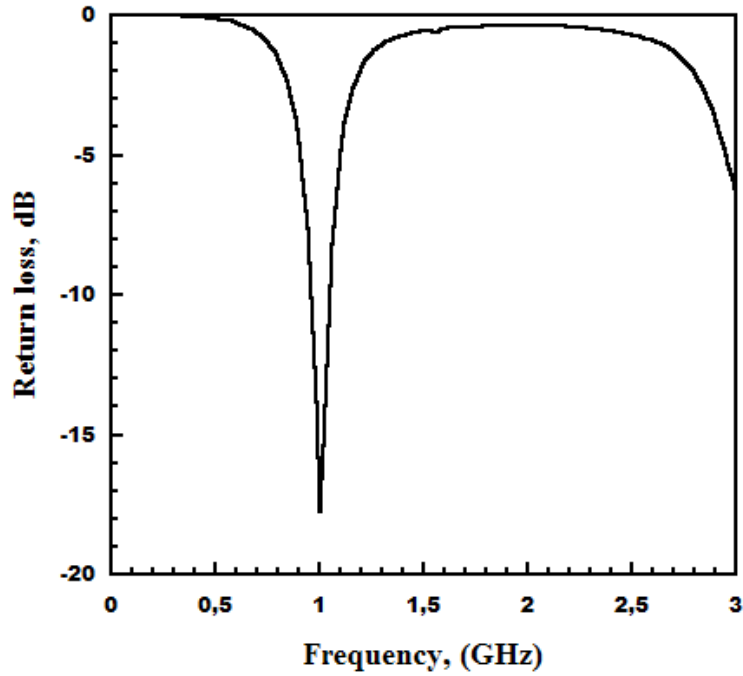


Figure 2. Simulated return loss S_{11} of the reference PIFA antenna.

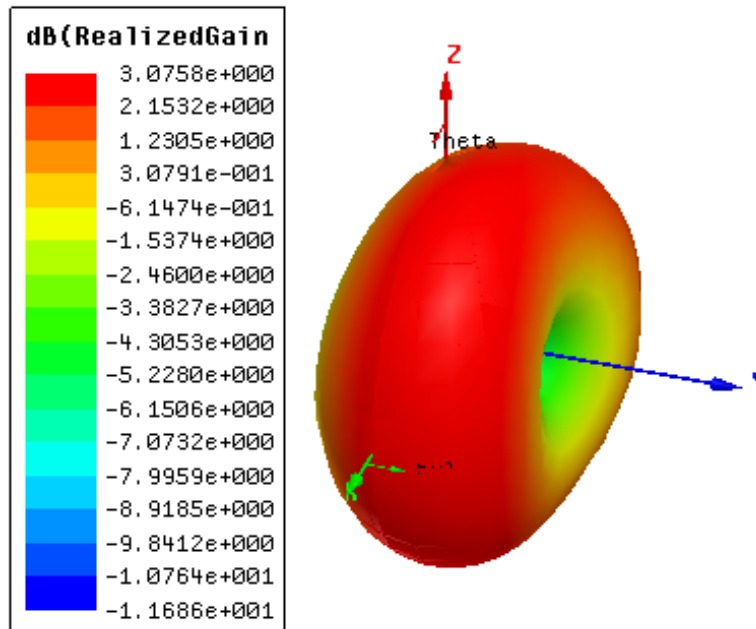


Figure 3. Simulated 3D radiation pattern at $F_1 = 1$ GHz.

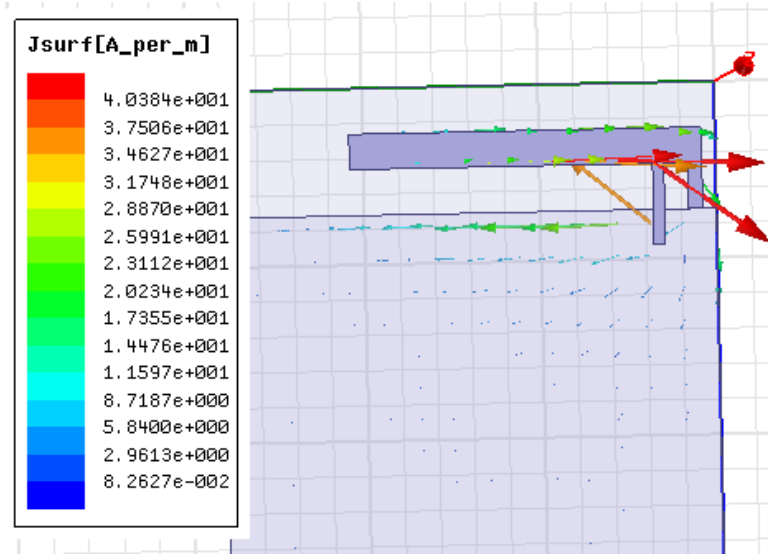


Figure 4. Surface current distribution at $F_1 = 1$ GHz.

3. PIFA Antenna with Floating Ground Plane

3.1 Antenna Design

To miniaturized and obtain a low profile antenna^[1], a floating ground plane was added on the back side below

the PIFA. It is able to changing the effective permittivity of the antenna and increase the electrical length of the radiating section. Thus, the overall size of the antenna is well reduced. The fabricated antenna is exhibited in Figure 5.

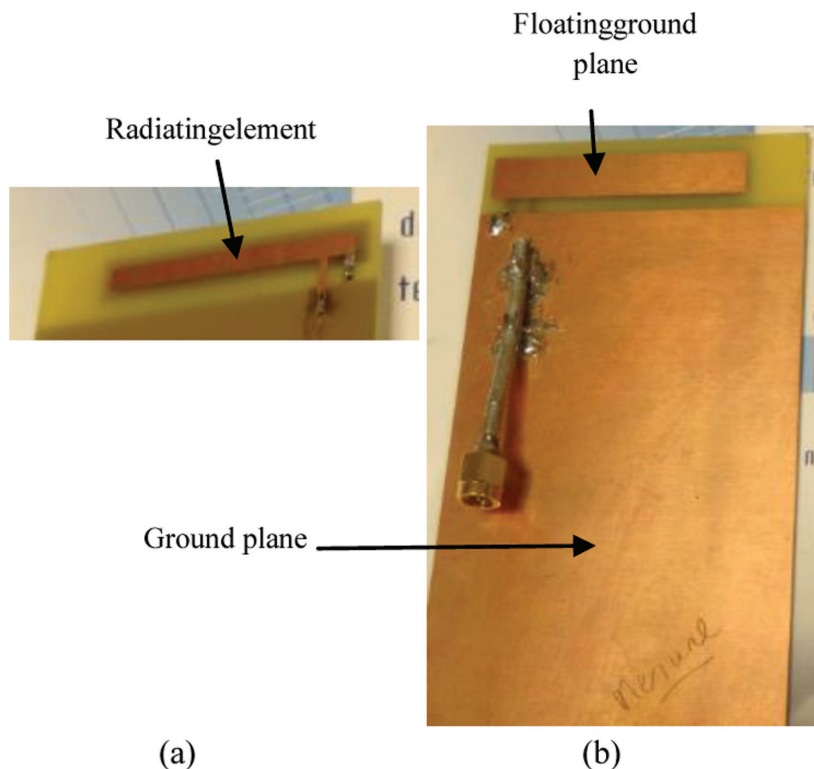


Figure 5. Photos of the realized prototype: (a) Top views, (b) Bottom views.

3.2 Results and Discussion

Figure 6 presents the return loss of the proposed bi-band PIFA antenna.

According to Figure 6, we can note that the PIFA antenna is characterized by a high simulated frequency at 2.8 GHz in addition to the resonance frequency, 0.92 GHz of reference PIFA antenna. The measured carried out show that the obtained antenna behaves as predicted. Indeed, measured resonances frequencies are 0.95 and 2.88 GHz. This result is due to the fact that the addition of floating ground plane under the radiating element in the aim to increase the coupling between them, generate a second resonance frequency.

To analyse the origin of these resonances frequencies, we have studied the current distribution for the prototype. Figure 7 illustrates simulated surface currents for the antennas at their resonance frequencies. The current is concentrated in the center of the radiating element and in the near zone of the supply line for the low frequency $F_1 = 0.92$ GHz. For the high frequency $F_2 = 2.8$ GHz, the current flow propagates at the end of the radiating element with a weak current at the center of the antenna. Which explains the importance role of adding a floating ground plane. The simulated and measured radiation patterns presented in Figures 8 and 9, respectively. They confirm the radiation behavior of the

structure described in Figure 7. Maximum simulated realized gain are 3.17 at 0.92 and 3.39 dBi at 2.8 GHz. Measured obtained gain are 2.28 at 0.95 and 2.44 dBi at 2.88 GHz.

4. Frequency Reconfigurable PIFA Antenna

4.1 Antenna Design

To dynamically control the resonance frequencies in a large tuning range, we considered integrated a varactor diode; BB833 from Infineon. It was loaded in the corner of the radiating element and the floating ground plane as it can be shown in Figure 10. The location of varactor diode is determined following a study of the surface currents distribution. In fact, we notice that the embedding of the diode at the zone where the concentrations of surface currents are high is irrelevant. In fact, in order to redirect the current flow, the diode must be placed in the region where the distribution of the surface currents is of low concentration. This location facilitates the establishment of new paths of the flux of surface currents. The agility characteristic was obtained by applying a variable reverse voltage V on the varactor diode. Hence, we change the capacitor values which affects the electric length of the PIFA leading to a continuous frequencies shift.

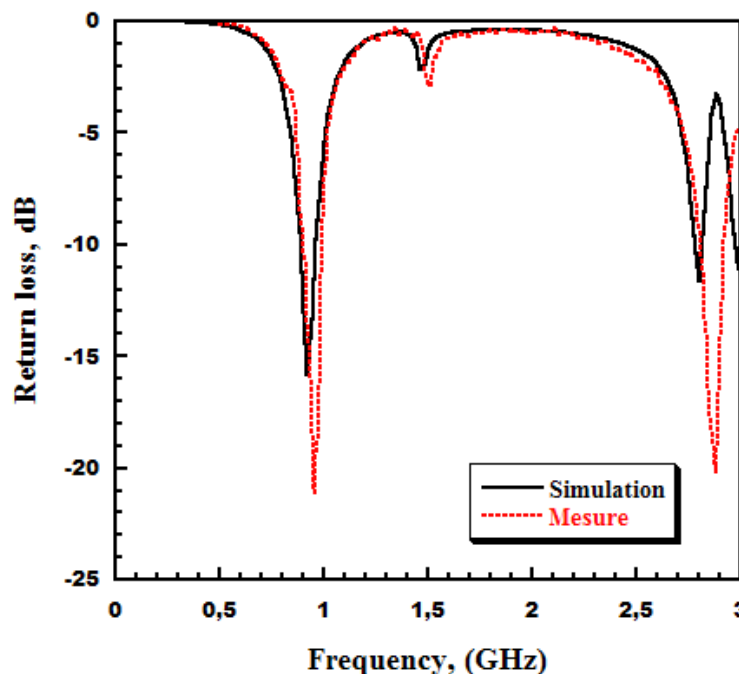


Figure 6. Measured and simulated return loss S_{11} of the proposed PIFA antenna.

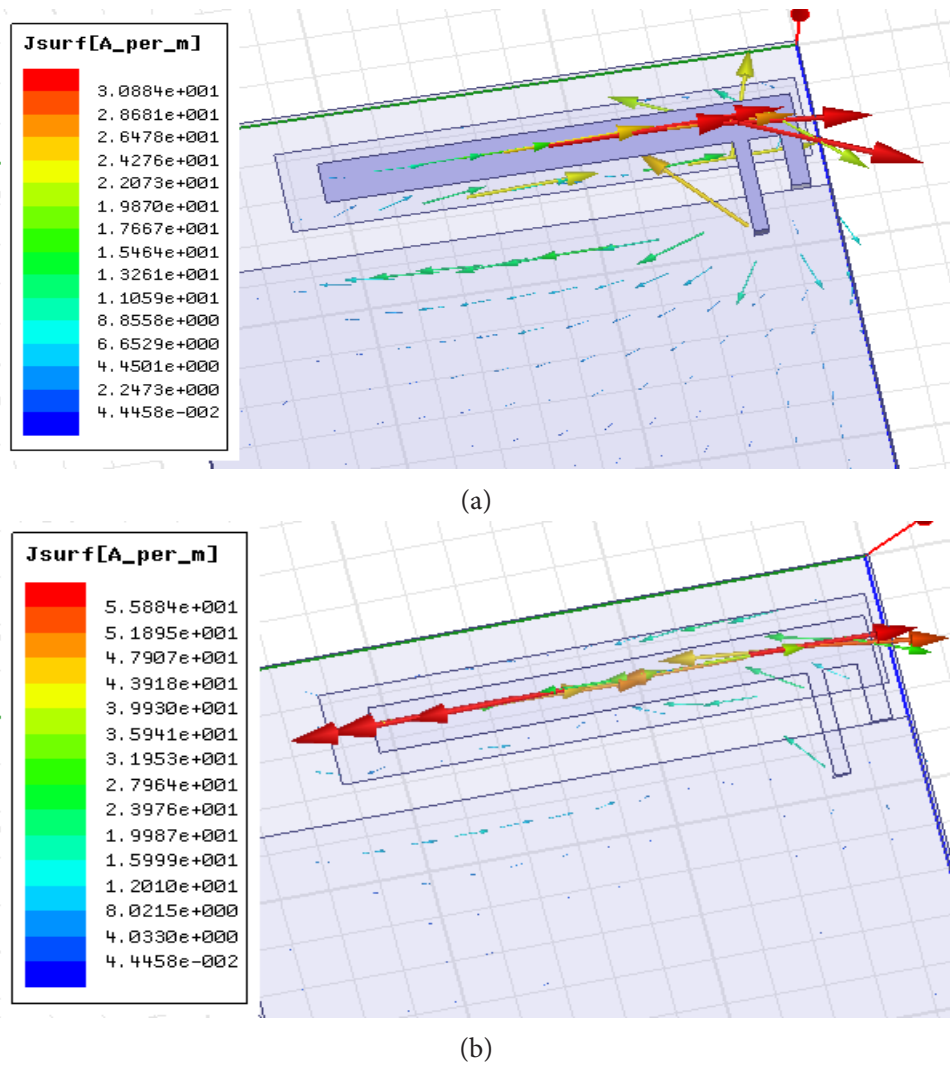


Figure 7. Simulated surface current distribution of the proposed antenna at: (a) 0.92 GHz and (b) 2.8 GHz.

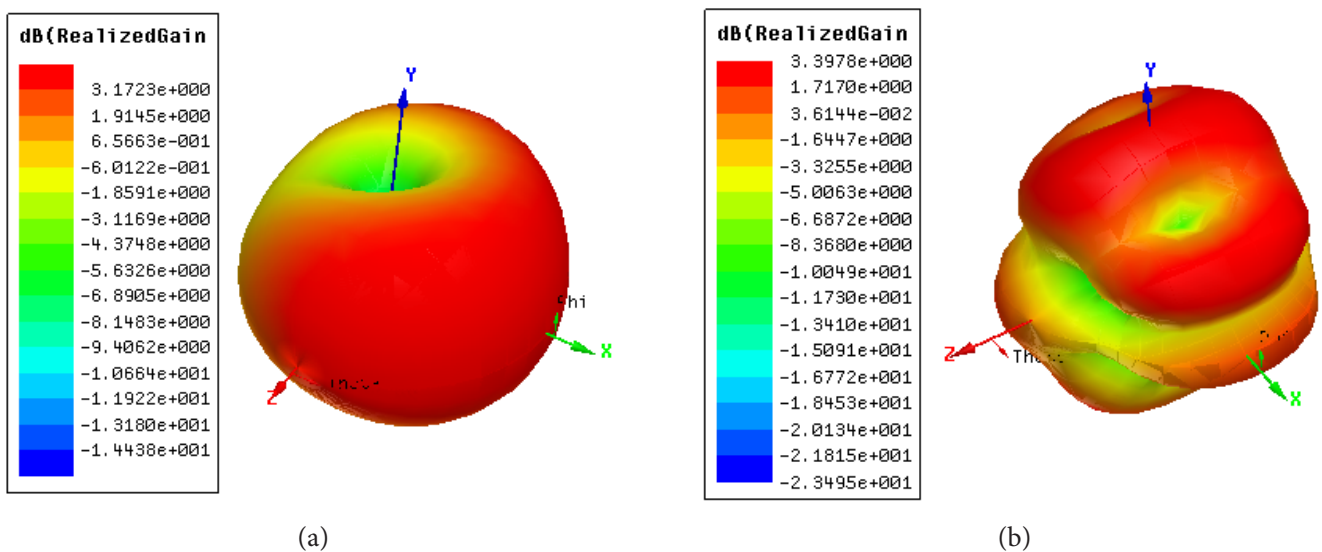


Figure 8. Simulated 3D radiation pattern at: (a) 0.92 GHz and (b) 2.8 GHz.

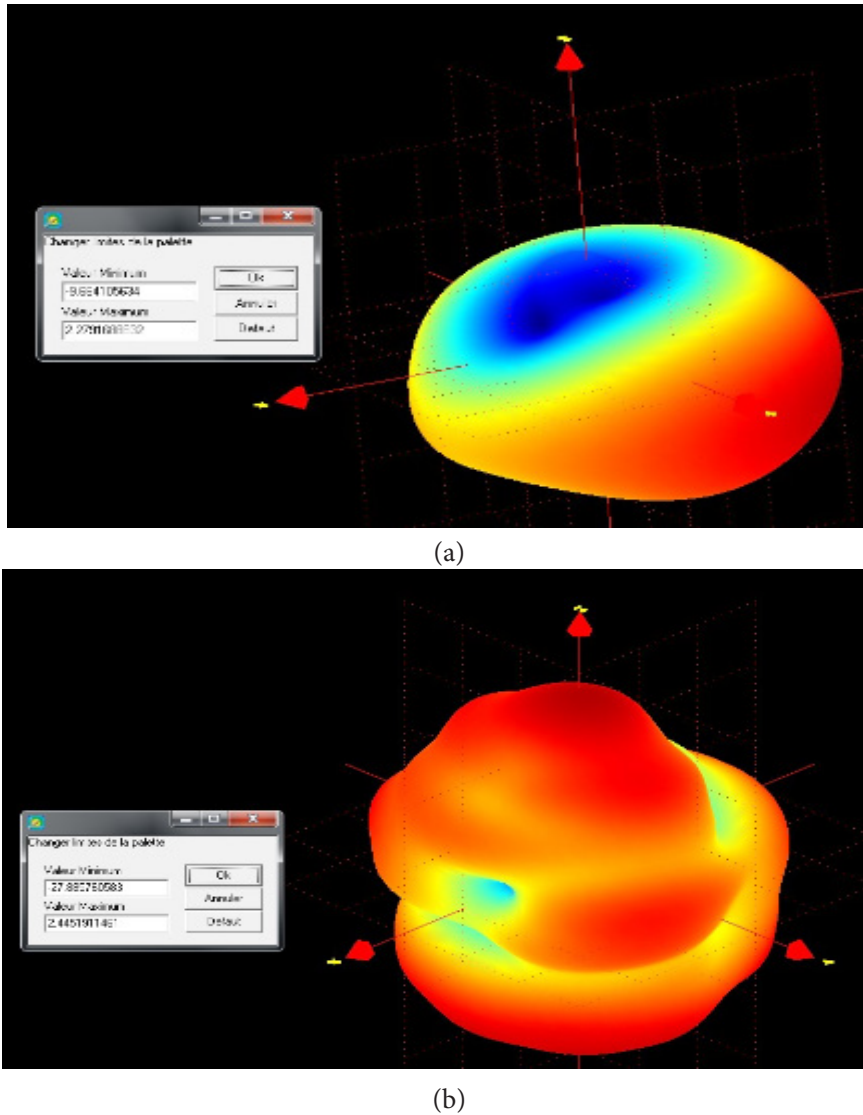


Figure 9. Measured 3D radiation pattern at: (a) 0.95 GHz and (b) 2.88 GHz.

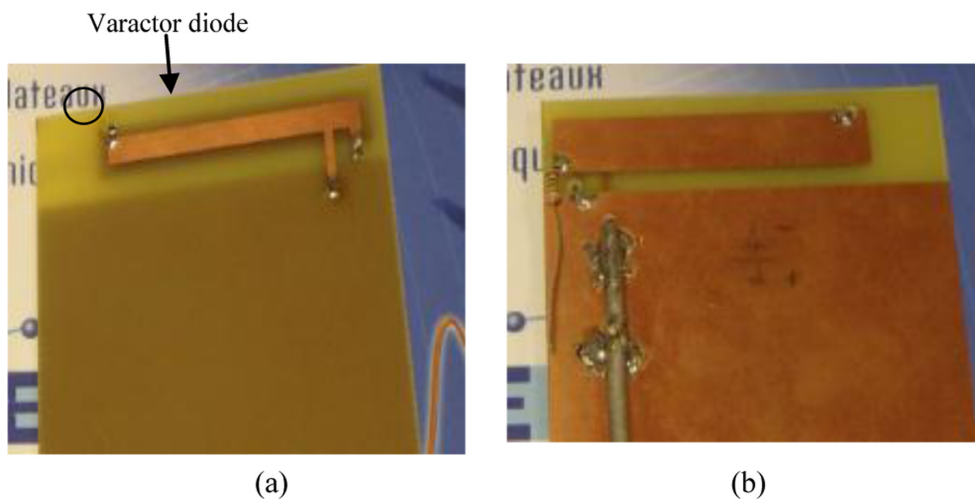


Figure 10. Photos of the prototype: (a) Top view and (b) bottom views.

4.2 Results and Discussion

Figure 11 presents the S-parameter measurements when the bias diode is changed (0-17 V). In fact, the loading of the varactor diode generates a new frequency F_2 , in the center of the existing resonances frequencies, that shift to lower frequencies when decreasing the reverse bias voltage (increase of the capacitor values). The first frequency F_1 is the reference antenna resonance frequency. By controlling the bias voltage V , F_1 can be moved from 896 to 650 MHz. The third frequency F_3 (reference antenna resonance frequency), shifted to lower frequencies. A wide tuning frequencies range of 2457 to 1502 MHz was obtained. For F_2 , a tuning range of 1379 to 954 MHz was achieved. Table 1 summarized the measured resonant frequencies of the proposed antenna. For reason of clarity, we presented the measured and simulated reflection coefficient for reverse bias $V = 4$ v ($C = 4$ pF) in Figure 12. A good agreement can be noticed between

both simulated and measurement results. The differences between simulated and measured in the higher frequencies can be explained by the fact that we only consider the varactor diode model like a capacitor without taking into account the losses of the diode.

The surface current vectors distribution in the antenna at 0.82 and 1.18 GHz are illustrated in Figure 13 respectively. As it can be shown, at the frequency 0.82 GHz the path of the surface current is alike that of the unloaded antenna for the first frequency. At the second frequency (1.18 GHz), the streams are redirected to the diode with a maximum current located in the corner.

The simulated and measured 3D radiation pattern for $V = 4$ V are plotted in Figures 14 and 15 respectively. The proposed antenna presents stable radiation properties and they confirm the radiation behavior of the structure described in Figure 13 with maximum simulation gain 3.54 at 820 and 0.58 dBi at 1180 MHz. The obtained measured gain are -1.49 at 820 and -0.58 dBi at 1150 MHz.

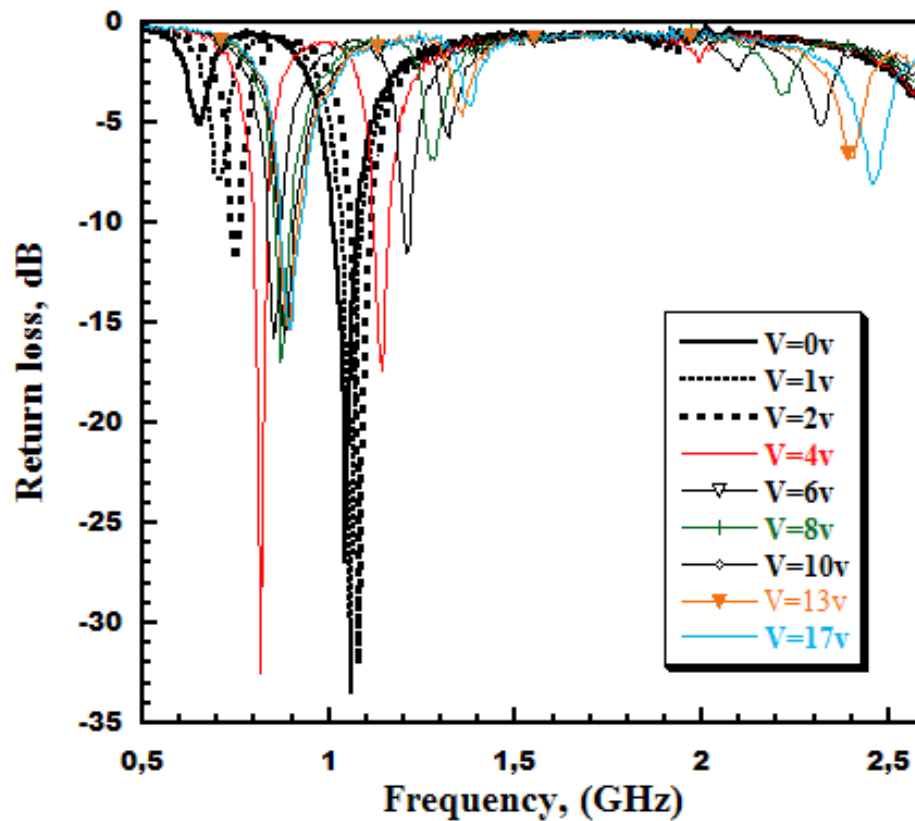


Figure 11. Measured return loss S_{11} of the proposed antenna.

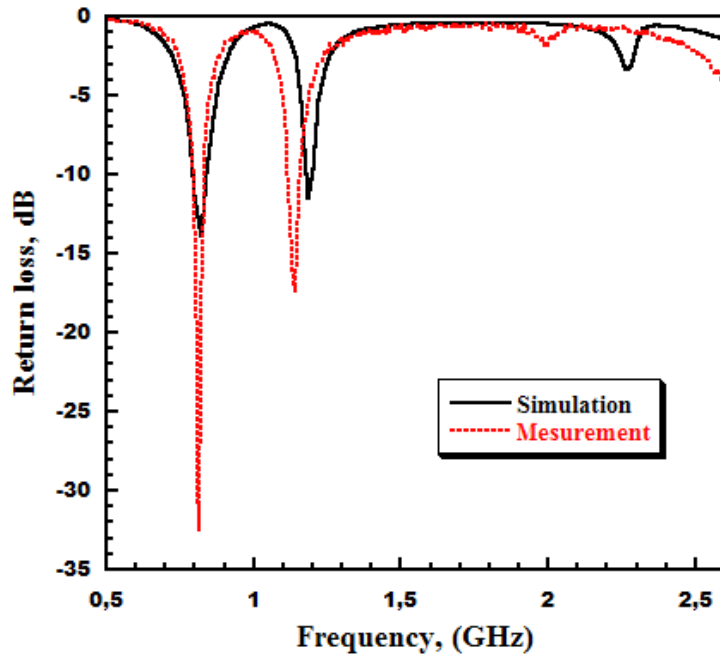


Figure 12. Simulated and measured return loss S_{11} for $V = 4$ V ($C = 4$ pF).

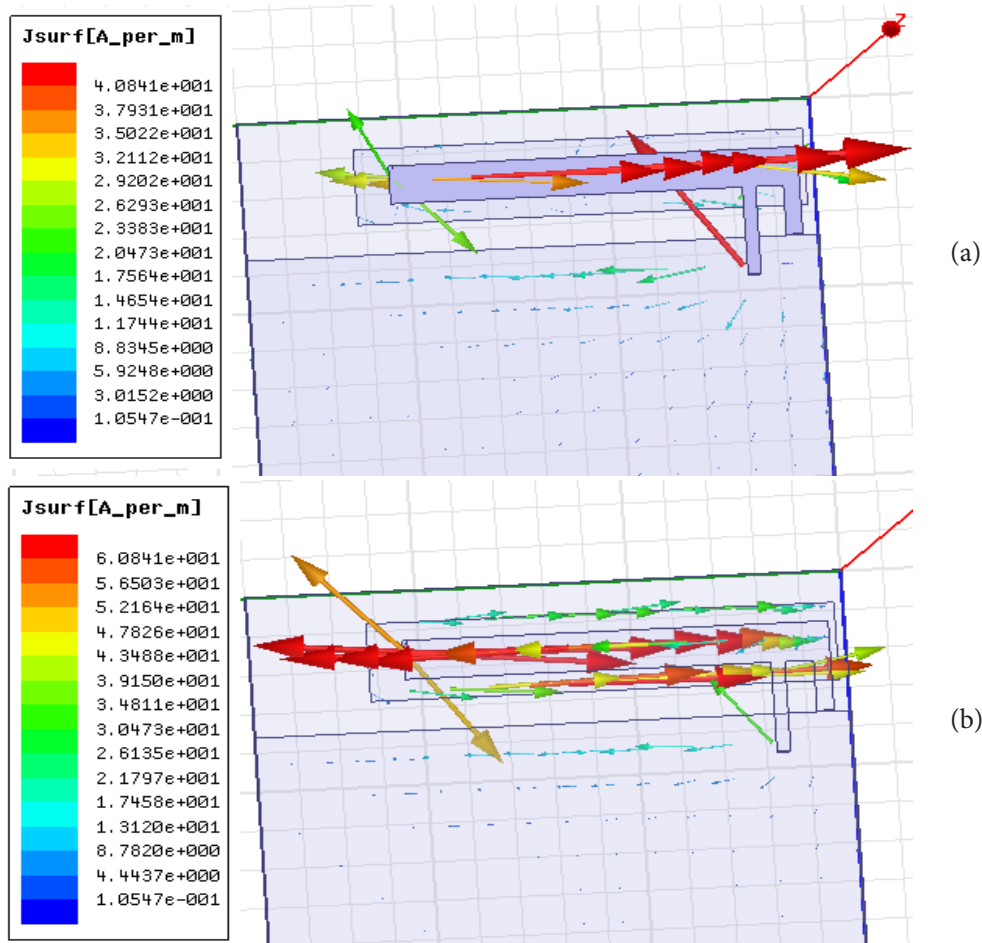


Figure 13. Simulated surface current of the PIFA antenna for $V = 4$ V at: (a) 0.82 GHz and (b) 1.18 GHz.

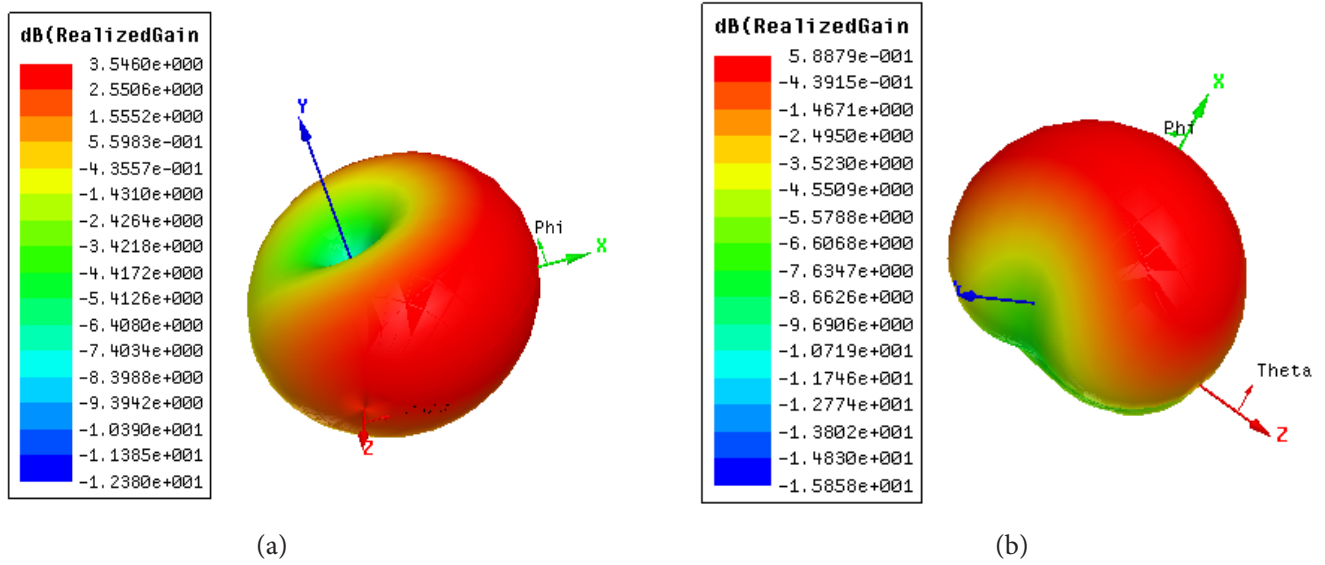


Figure 14. Simulated 3D radiation pattern at: (a) 0.82 GHz and (b) 1.18 GHz.

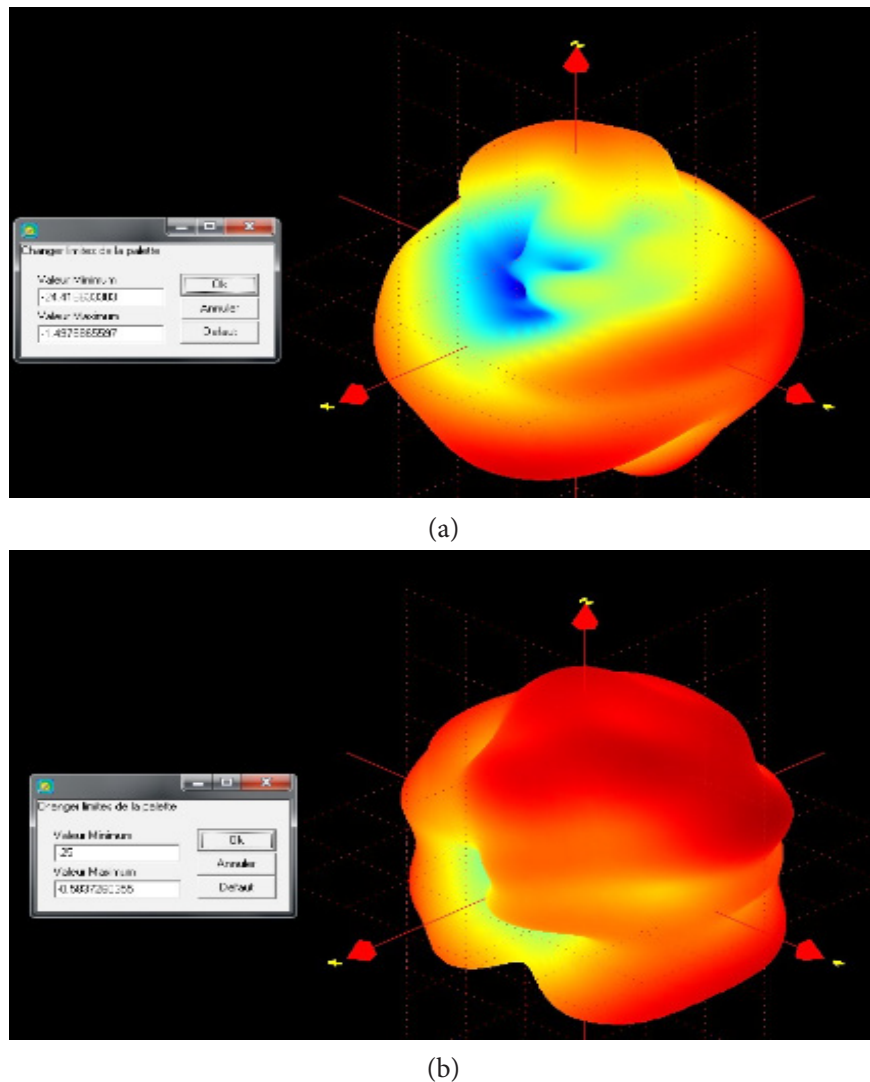


Figure 15. Measured 3D radiation pattern at: (a) 0.82 GHz and (b) 1.15 GHz.

Table 1. Measured resonant frequencies

Voltage (V)	Capacitor value (pF)	F ₁	F ₂	F ₃
Unloaded antenna	--	954	--	2880
17	0.9	896	1379	2457
13	1	890	1356	2400
10	1.4	880	1318	2313
8	1.8	870	1275	2217
6	2.8	840	1204	2091
4	4	820	1150	1989
2	7	740	1079	--
1	9.8	700	1060	--
0	≈20	650	1039	--

5. Conclusion

A tunable PIFA antenna covering 650-2457 MHz bands has been demonstrated. The antenna reference with size $70 \times 132 \times 1.6 \text{ mm}^3$ resonate at 1000 MHz. A floating ground plane was added coupled with radiating element in order to miniaturized and obtain a low profile antenna. A two resonances frequencies was obtained at 920 and 2800 MHz. To sweep the resonances frequencies in a desired bands, one varactor diode was integrated between the radiating patch and adding floating ground plane. A large tuning frequencies range of 650-896, 1039-1379, 1989-2457 MHz was achieved. Good agreement between simulations and measurements. The goal of this work is to show that tunable PIFA antenna are promising candidate for handheld portable. A lot of additional research are planned to enhance the antenna performance to cover additional bands.

6. References

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