Triple Band PIN-Diode-Based Reconfigurable Antenna for the New Wi-Fi 6E Band and 5G Applications

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Abstract. In this work, a triple-band monopole antenna is designed and simulated using HFSS. The antenna design is suitable for Sub-6 GHz and the new unlicensed Wi-Fi band: 5.925−7.125 GHz applications. The proposed design is a planar micro-strip line-fed antenna based on a trapezoidal patch with two lateral strips connected to the patch via two PIN diodes to achieve antenna reconfigurability. The structure is printed on a 32×20 mm^2 FR4 dielectric substrate. Simulation results confirmed the reconfigurability of the proposed design with suitable radiation performances for the targeted frequency bands.

Keywords: Reconfigurable antenna, PIN-Diode, Wi-Fi 6E, 5G.

1 Introduction

The ever-growing demand for unlicensed frequency bands has prompted regulators to consider the exploration of bands up the 6 GHz for unlicensed spectrum. Like mobile network technologies, which have experienced major advances in recent years, wireless link technologies have also experienced rapid advances. Wi-Fi 6 technology is already supplanted today by a new standard: Wi-Fi 6E. Wi-Fi 6E (or Wi-Fi 6 Extended) is, today, the latest standard in wireless communication systems with commercially available products; it is available in Europe since March 2022 [1], [2], [3]. The improvements offered by Wi-Fi 6E are therefore essentially related to the extension of the spectrum on the 6 GHz band. Still unused so far, this latter is, moreover, twice as wide as the other lower frequency bands. Concretely, this makes it possible for higher data transmission speed (up to 10 Gb/s) and less suffering from traffic jams in the network [4], [5]. The 6E version introduces a new 6 GHz frequency band (5.925–7.125 GHz) in addition to 2.4 GHz and 5 GHz. The abundance of spectrum in this band creates new opportunities for the design of new systems that can support the emerging bandwidth-intensive and latency-sensitive applications [6] and releases the 2.4 GHz and 5 GHz bands that are regularly saturated in urban areas. The 5G New Radio Unlicensed (NR-U) is a new radio access system that is designed to operate in the 6 GHz bands alongside Wi-Fi [6], [7], [8]. In this context, there has been a great increase in the usage of multiband antennas to meet different

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applications in wireless communication such as Wi-Fi, WLAN, WiMAX, and 5G. Hence, there is a need for a multifunctional antenna that can operate on multiple frequencies. In addition, other wireless communications, such as 5G and Wi-Fi, can be integrated into a single terminal device. Reconfigurable antennas can serve as multifunctional electronic devices. Due to their intrinsic features such as reduced dimensions, lightweight and low cost compared with conventional antennas, reconfigurable planar microstrip antennas exhibit more advantages and better performances [9]. They have attracted much consideration because of their potential in wireless communication systems. Their radiation properties can be adjusted to achieve selectivity in frequency, bandwidth, polarization and gain. For interference rejection, frequency reconfigurable antennas can also be used [10]. Frequency interference can be suppressed by creating selected band notches in order to filter out the interfering frequencies from the antenna's operating frequency band. They can also be of great interest in overcoming the faced challenges in the advanced 5G and Internet of Things (IoT) technologies [10], [11], [12].

Reconfigurability in microstrip planar antenna designs is achieved using a variety of switches that change the current distribution in the radiating patch, helping to adjust the radiator's characteristics in terms of resonant frequency, radiation pattern or polarization [11], [13], [14]. Among them, PIN diode switches are the most popular in constituting reconfigurable antennas due to their efficiency, reliability and ease of integrating with microwave circuitry [9], [13], [15], [17].

In this work, a reconfigurable triple-band monopole antenna is designed and simulated using HFSS. The radiating structure operates in the two 5G bands: 3.5−4.5 GHz and 4.8−5 GHz in addition to the new unlicensed Wi-Fi band: 5.925−7.125 GHz. The proposed antenna is equipped with two PIN diodes operating in two states (ON and OFF) to enable full functionality in Wi-Fi 6E applications

2 Antenna design

The reconfigurable antenna structure proposed in this work is a triple-band monopole (Fig. 1).

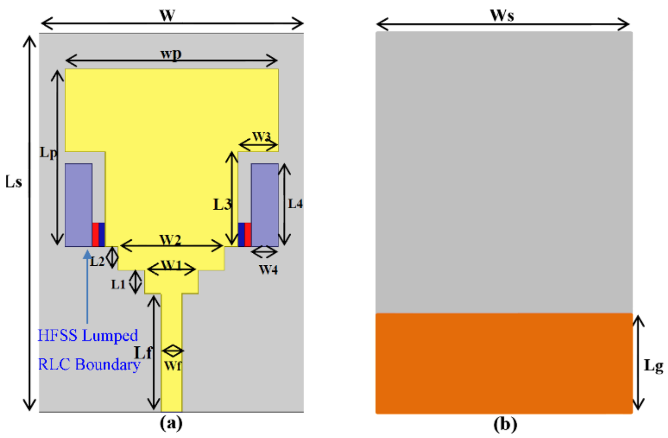

Fig. 1. Proposed antenna. (a) top and (b) bottom view

A trapezoidal patch is printed on a low loss FR4 type dielectric substrate of dimensions 32×20 mm^2 with ε_r = 4.4, tanδ=0.02 and thickness h = 1.6 mm. Two inverted L-shaped open slots are grooved on the radiating trapezoidal patch, resulting in two parasitic strips of dimensions L4×W4. To ensure the option of configurability of the antenna, the two strips are connected to the patch via two SMP1320-079LF type PIN diodes of dimensions 2×0.5 mm^2. The radiating element is fed by a micro-strip line with a characteristic impedance of 50Ω of dimensions 10×1.6 mm^2. The design's geometrical dimensions are illustrated in Table 1. The antenna is designed and simulated using HFSS v15.

Table 1. Design parameters of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
Ws	20	**W2**	8
Ls	32	**L2**	2
Wp	16	**W3**	3
Lp	15	**L3**	8
Wf	1.6	**W4**	2
Lf	10	**L4**	7
W1	4	**h**	1.6
L1	2	**Lg**	9

As shown in Figure 2, two SMP1320-079LF type PIN diodes are chosen in this conducted study. The PIN circuitry parameters are given by: C = 0.3 pF; RL=0.9Ω (ON state); Rh = 20 KΩ (OFF state) and L = 0.7 nH, the parasitic inductance resulting from the conditioning and the value of Rh are assumed to be greater than the reactance of C, so they are neglected from the equivalent model. The equivalent circuits of the PIN diode RF switch in ON and OFF states can be modeled in HFSS by assigning "Lumped RLC boundary" to the 2D structure (Fig.2). When the PIN diode is ON (conducting) the values of the RLC circuit are R1=R2=0.9 Ω, C1=C2=0.3 pF and L1=L2=0.4 nH. In OFF state, the resistors become R1=R2=20 KΩ.

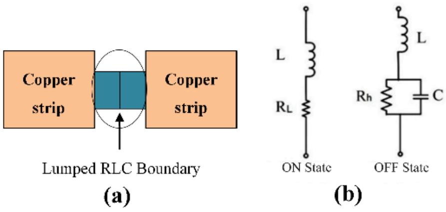

Fig. 2. (a) PIN diode model in HFSS and (b) ON and OFF equivalent circuits.

3 Simulation results

The PIN switch based reconfigurable antenna is designed, simulated and analyzed using the numerical software HFSS. Results are presented, analyzed and commented (Figs 3 and 4). Three working modes are considered to analyze the frequency and pattern tunability according to the switching (ON/OFF) states of the two PIN diodes (OFF-OFF, ON-OFF and ON-ON).

The evaluated parameters are the S_{11} parameter and the 2D radiation patterns for different states of the PIN diodes. Table 2 represents the performance analysis for the triple band reconfigurable design.

According to Fig. 3, it can be noticed that the proposed antenna operates at three frequency bands depending on the states of the PIN diodes. First, in the ON-OFF mode, three frequency bands are observed: 3.4−3.8 GHz, 4.1−4.9 GHz, allocated to 5G sub-6 GHz applications, and 5.9−7.1 GHz, corresponding to the new Wi-Fi 6E frequency band. Peak S_{11} responses of −16.7 dB, −29.9 dB and −23.3 dB at the resonance of 3.6 GHz, 4.4 GHz and 6.1 GHz with bandwidths of 400 MHz, 800 MHz and 1200 MHz, respectively. Second, by switching on the two diodes (ON-ON mode), the upper band is suppressed and only the first two lower bands are preserved: 3.4−4.1 GHz and 4.7−5.5 GHz corresponding to the 5G sub-6 GHz bands. These bands are achieved at −17.7 dB and −18.5 dB at the resonance of 3.7 GHz and 5 GHz with bandwidths of 700 MHz at 3.7 GHz and 800 MHz at 5 GHz, respectively.

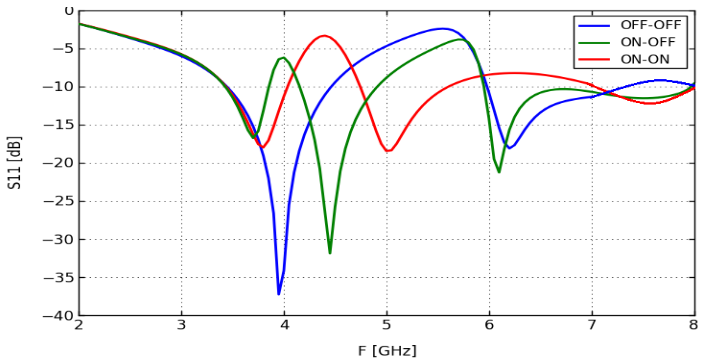

Fig. 3. Simulated S11 parameter for different diode states.

Finally, in the OFF-OFF state, we notice that the second band is rejected, so only the two extreme bands are preserved: 3.4−4.4 GHz and 5.95−7.1 GHz corresponding to 5G applications and the new Wi-Fi 6E standard. Peak S_{11} responses of −37.1 dB and −17.8 dB at the resonances of 3.9 GHz and 6.2 GHz with bandwidths of 1000 MHz and 1150 MHz, respectively. Table 2 summarizes the peak reflection response, impedance bandwidth and maximum gain at different frequency bands with resonant frequencies. We notice a stable and satisfactory gain fluctuating between 2.37 and 3.03 dBi. These results confirm well the reconfigurability option of the proposed antenna.

Table 2. Design parameters of the proposed antenna.

Parameter	Diode State	Values
S_{11} Parameter	ON-ON	-17.7 dB @ 3.7 GHz -18.5 dB @ 5 GHz
	ON-OFF	-16.7 dB @ 3.6 GHz -29.9 dB @ 4.4 GHz -23.3 dB @ 6.1 GHz
	OFF-OFF	-37.1 dB @ 3.9 GHz -17.8 dB @ 6.2 GHz
Impedance Bandwidth	ON-ON	700 MHz @ 3.7 GHz 800 MHz @ 5 GHz
	ON-OFF	400 MHz @ 3.6 GHz 800 MHz @ 4.4 GHz 1200 MHz @ 6.1 GHz
	OFF-OFF	1000 MHz @ 3.9 GHz 1150 MHz @ 6.2 GHz

Max gain	ON-ON	2.42 dBi @ 3.7 GHz 2.50 dBi @ 5 GHz
	ON-OFF	2.37 dBi @ 3.6 GHz 2.59 dBi @ 4.4 GHz 2.88 dBi @ 6.1 GHz
	OFF-OFF	2.60 dBi @ 3.9GHz 3.03 dBi @ 6.2 GHz

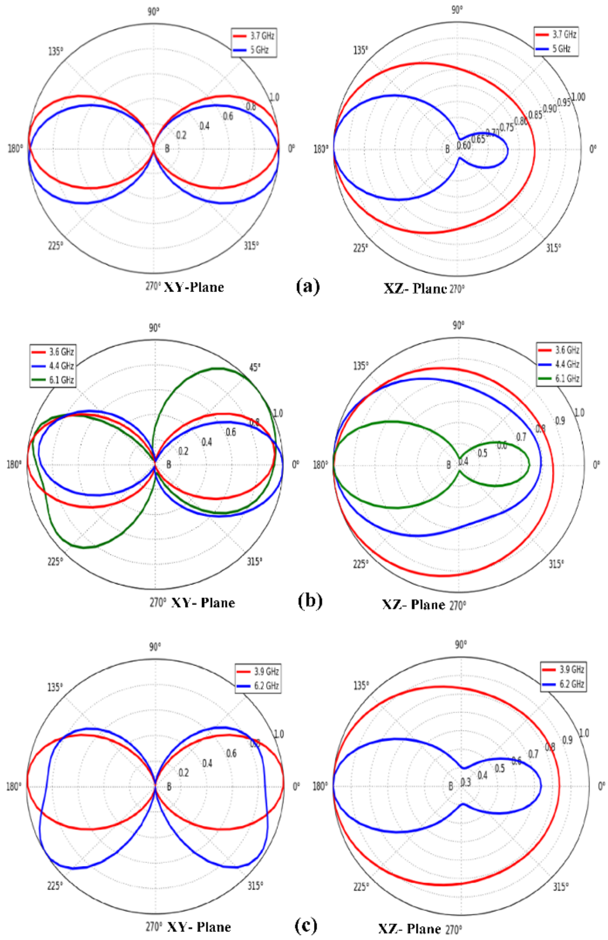

Fig. 4. (a) ON-ON, (b) ON-OFF and (c) OFF-OFF state for the corresponding resonant frequencies.

Figures 4 (a, b and c) illustrate the 2D radiation patterns in the vertical XZ plane and the horizontal XY plane for the resonant frequencies of the different operating bands of the proposed antenna. A quite omnidirectional radiating characteristic of the designed monopole antenna antenna is noticed.

4 Conclusion

In this work, a PIN-diode-based reconfigurable monopole antenna is presented. The antenna possesses a triple band characteristic. It operates in three frequency bands: the two 5G bands: 3.5−4.5 GHz and 4.8-5 GHz in addition to the new Wi-Fi band: 5.925−7.125 GHz.

Good results are obtained in terms of reflection coefficient S11, impedance bandwidth and gain, meeting the requirements of the targeted wireless communication systems. The proposed antenna has the advantages of low profile, simple structure and high radiation performance. It can be applied for 5G applications and the new Wi-Fi band 6E.

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