Numerical Investigations of a Reconfigurable Patch Antenna using a Pin Diode and a Varactor Diode for Wireless Communication Systems

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Abstract - In this work, a design and a numerical study of a reconfigurable patch antenna, using a PIN diode and a varactor diode, are proposed. This antenna has been printed on FR-4 substrate material of a relative permittivity ε_r=4.4. The reconfigurability of the proposed antenna was achieved by using a PIN diode and a varactor diode in order to change the electrical length of the patch, which leads to a change in the resonant frequency. The software CST microwave studio is used to simulate the proposed antenna. The obtained results show that a frequency bandwidth spreading from 4.60 GHz to 5.29 GHz is achieved.

Keywords - Patch antenna, diodes PIN, varactor diode, reconfigurable antenna, resonance frequency.

I. INTRODUCTION

Antenna is one of the most important elements in modern telecommunication systems (radar, satellite and mobile phone). Furthermore, most of these systems require more than one antenna. This latter, which can operate at different frequencies and polarizations, are generally installed at positions on wireless systems such as a radar station, a satellite base station or a mobile phone, for better reception quality. Indeed, the use of multiple antennas is certainly very undesirable because it can increase the size of the system and material costs. In addition, multiple antennas can introduce electromagnetic interference, which can threaten the normal operation of electronic circuits. It is obvious that a possible way to reduce the number of antennas is to have one that can be reconfigured to offer multiple functions and can also operate at different frequencies and change field polarizations. Such reconfigurable antenna: the new multifunction antenna configuration [1].

In the literature, reconfigurable antennas can achieve from various mechanisms. Among existing methods: a technique based on used of smart materials such as ferrites [2-4]. Another technique of reconfigurable antennas (electrically reconfigurable antennas) is based on integration of switching components as PIN diodes (Positive Intrinsic Negative diode) [5-8] or varactors diodes [9-10].

The PIN diode, which can easily be converted to a simple switch, has been widely used for the designing various reconfigurable antennas due to a number of advantages, including good reliability, high switching speed, compact size and low resistance [1].

In this work, a design and a numerical study of a new and simple reconfigurable patch antenna using a PIN diode and a varactor diode are proposed. By switching the PIN diode and using a varactor diode, the electrical length of the patch will be changed which leads to a change in the resonance frequency.

The remained of this paper is organized as follows. Methodology of the proposed antenna design is presented in Section 2. Geometry of the antenna is described in Section 3. PIN diode and varactor diode used is presented in Section 4. In Section 5, we present results. Finally, to conclude, remarks are presented in Section 6.

II. DESIGN METHODOLOGY

The principle of reconfigurable frequency antennas using localized elements (PIN diodes and / or varicaps diodes) is based on exploiting the variation of the electrical length of the radiating element (in our case is the patch). The general methodology for the design of our antenna is described by the flowchart in Figure 1.

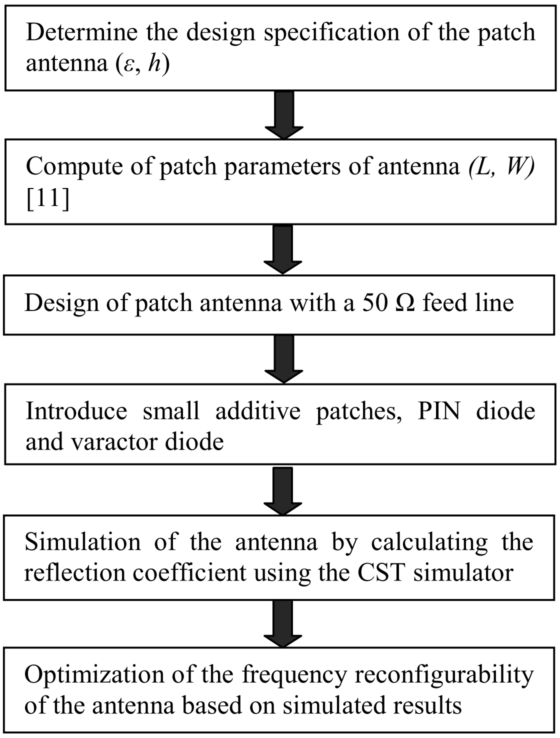


Fig. 1. Flowchart of the general design methodology for reconfigurable antennas using a PIN diode and a varactor diode.

III. GEOMETRIC PARAMETERS OF THE ANTENNA

This section explains briefly the structure of the antenna. The geometry of the antenna studied is illustrated in figure 2. This antenna is designed with a rectangular patch, two small rectangular patches and a PIN diode and a varactor diode (to ensure the reconfigurability of the antenna) on a FR-4 substrate with a thickness $h = 1.58\ mm$, relative permittivity $\varepsilon_r=4.3$ and tangential loss of 0.025.

The dimensions of the initial design are determined on the basis of a published study [11]. However, this model is based on the estimation when the calculating of patch dimensions. In order to achieve an antenna operating at the desired frequency (in our case is *4.60 GHz*), the patch dimensions are adjusted. The different parameters of the antenna are shown in Table 1. The simulations were performed using the Computer Simulation Technology (CST) simulator.

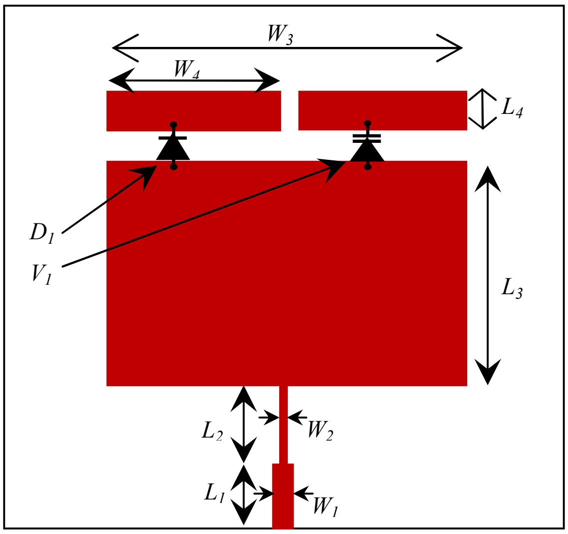


Fig. 2. Geometry of the studied antenna.

Table 1. Different parameters of the antenna.

Antenna dimensions	W_1	L_1	W_2	L_2	W_3	L_3	W_4	L_4
Values *(mm)*	2.36	0.2	15.5	7.0	3.8	8.4	11.5	0.7

IV. PIN DIODE AND VARACTOR DIODE USED IN SIMULATION

A) PIN Diode

Over the last decade, PIN diodes have been used for the design of various frequency reconfigurable antennas [5-7]. The operation of a PIN diode requires the biasing of a direct current where its equivalent circuit, for ON (forward bias) and OFF (reverse bias), is shown in Figure 3 [1]. When the diode is forward biased (ON mode), it can be represented by an R_S resistor (typically, ~ 0.1 Ω at 1 mA) and an inductance L (~ 0.1 nH). In the case where the diode is reverse biased (OFF mode), it is represented by a very high inverse resistance R_P and a capacitance. To simplify circuit analysis, the ON and OFF states of a diode are simply treated as ideal switches, as shown in Figure 4 [1].

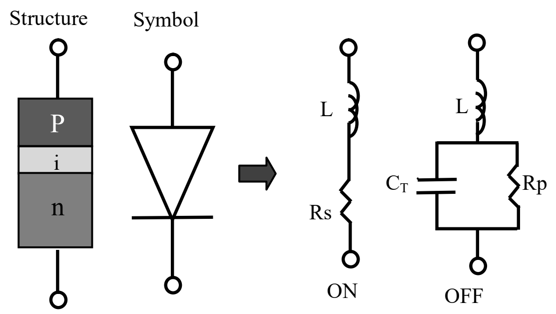


Fig. 3. PIN diode: Equivalent circuits for ON and OFF states.

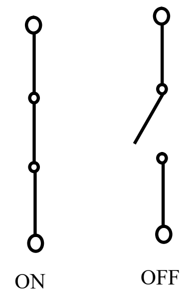


Fig. 4. PIN diode: Ideal equivalent circuits for ON and OFF states.

In this proposed reconfigurable antenna design, we used in the simulation a PIN diode type HPND-4005 because of its advantages in opened and closed states. The previous figure (Fig. 4) shows the equivalent circuit RLC of the PIN diode used. Different values of the equivalent RLC model are calculated by Agilent Advanced Design System (ADS). Table 2 shows equivalent localized elements (RLC model), which models the PIN diode, in the ON and the OFF states [12].

Table 2. Value of PIN diode for ON and Of states.

PIN diode mode	*Resistor* (Ω)	*Inductor* (nH)	*Capacitor* (pF)
ON	3.5	0.45	0
Off	3000	0.45	0.08

B) Varactor Diode

A varactor diode is a diode which has the characteristics of a capacitor whose capacitance value can be adjusted using reverse bias of the voltage. This variable capacitance is used in reconfigurable devices such as filters [13-14] and antennas [7-8]. In this study, we will use a varactor diode to ensure the tunability of our antenna without modifying its basic geometry.

In this study of the proposed reconfigurable antenna, we used in the simulation a varactor diode of type SMV1232-079LF [15]. Figure 5 shows the equivalent circuit of a varactor diode [15-16]. Where $C_j(V)$ is the variable capacitance of the diode, which can be varied from 4.15 pF to 0.72 pF, with a reverse voltage between 0V and 15 V, Rs(V) is the variable serie resistance of the diode, Lp is the parasitic inductance and Cp is the parasitic capacitance arising from the installation of the packaging material. The Cp was neglected in the equivalent circuit of the simulation. The values of Rs and Lp are 1.5 Ω and 0.7 nH respectively [13-14].

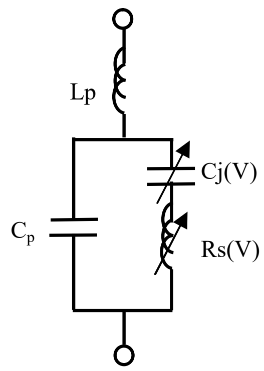
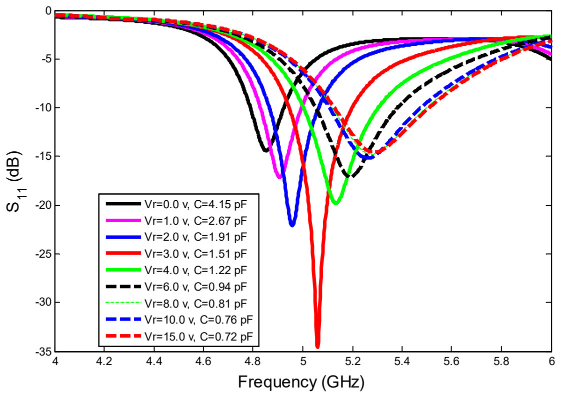


Fig. 5. Equivalent circuit of a varactor diode.

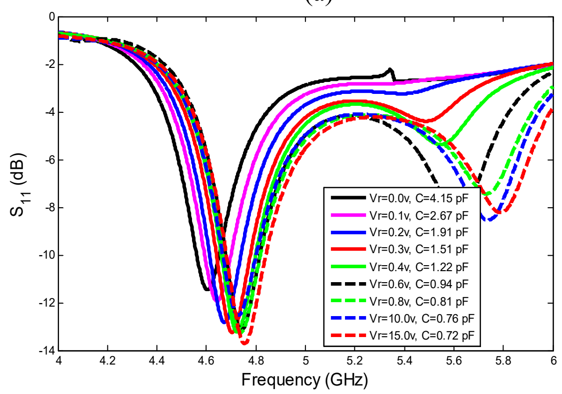
V. RESULTS AND DISCUSSION

In this work, the results are obtained by using the CST simulator. Values of the antenna dimensions are indicated in Table 1.

In order to test the agility of the proposed antenna, we applied different values of the voltages across the varactor diode. Figure 6 shows the simulated reflection coefficients of the antenna for different values of the voltages applied across the varactor diode (in Figure 6.a, the PIN diode is in the OFF state (OFF mode) and in Figure 6.b the PIN diode is in the On state (On mode)). We can see that the simulated reflection coefficients (S_{11}), at least in one of diode mode, are less than -10 dB at all resonance frequencies. Indeed, the resonance frequency changes with the change in the intensity of the voltages applied across the varactor diode. For example, in the case where the PIN diode is in the blocking state, the resonance frequency for $V_r = 0$ V ($C = 4.15$ pF) is 4.856 GHz. It is shifted to 5.060 GHz when $V_r = 3.0$ ($C = 1.51$ pF). This variation is due to the variation of the electrical length of the radiating element (patch). These results are in good agreement with the results obtained in [12, 16].



(a)



(b)

Fig. 6. Simulated reflection coefficients of the proposed microstrip patch antenna for different capacitance values of the varactor diode. (a) PIN diode in the OFF state. (b) PIN diode in the ON state.

VI. CONCLUSION

The work presented in this study is a numerical study of a frequency reconfigurable microstrip patch antenna. The reconfigurability of the proposed antenna was achieved by using two localized elements (a varacator diode and a PIN diode), in ordered to changing the effective electrical length of the microstrip patch which leads to a change in the resonance frequency. The results obtained are in good agreement with those obtained in the literature. These results show that a frequency bandwidth spreading from 4.60 GHz to 5.29 GHz is achieved. In this work, the numerical study of a reconfigurable patch antenna was focuced on reflection coefficients. Future study will be expected for other antenna performance such as bandwidth and gain.

VII. REFERENCES

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