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Investigation of Varactor Diode for Frequency Selectivity in Wireless Communication

Siti Nabilah Rohim[1]**, Rahmat Sanudin**[1]*

[1]Faculty of Electrical and Electronics Engineering,
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Since the COVID-19 pandemic, began in the past two years, demand for mobile services has increased significantly across the world. Reconfigurable antennas are an indispensable component in wireless communication applications as they used varactor diodes as switching components to tune resonant frequency. In this paper, the varactor diode will be investigated as a part of tuning frequency agility in reconfigurable for Wireless Local Area Networks (WLAN). The electrical characteristics of the varactor diode that will be presented using MATLAB are capacitance-voltage (C-V) and frequency-voltage (F-V). Furthermore, two reconfigurable antennas which are microstrip patch and microstrip inset-fed are being investigated based on the reflection coefficient and elevation radiation pattern. Generally, the resonant frequency can be analysed based on the selective capacitance values where a small value of capacitance gives a wide range of resonant frequencies by varying the reverse bias varactor voltage. Simulation results show that both antennas are successfully addressed for investigating the antenna radiation pattern at the targeted frequency of 5GHz using the varactor diode as a feed element. Therefore, it is concluded that the varactor diode managed to aid in frequency tuning into the targeted frequency in the reconfigurable antennas.

Keywords: Varactor Diode, Reconfigurable Antenna, WLAN

1. Introduction

Research on reconfigurable antennas, counting patterns, frequency and polarization has expanded rapidly in current wireless communication systems [1], [2]. Antennas that can be configured rely on switching components because they could adjust the antenna's electric properties and radiation functions. The previous studies in [3] - [6] presented that the usage of switching components such as varactor diode is crucial to ensure the tuning functionality of reconfigurable antenna could be achieved since it offers a higher switching speed, better stability, and lower applied voltage. Besides, the varactor diode can be inserted in frequency modulators or through the resonant element in the generator, and the signal in the diode [7]. The characteristics of frequency dependent capacitance are presented in [8] where the structure of metal-semiconductor metal (MSM) varactor diode and the capacitance are dependent on the varactor on external voltage.

Corresponding author: rahmats@uthm.edu.my

In this paper, the varactor diode will be investigated through its electrical characteristics as a part of tuning frequency agility in reconfigurable antennas. The specification of varactor output parameters which are capacitance-voltage (C-V) and frequency-voltage (F-V) will be analysed using MATLAB software. On the other hand, the reconfigurable antennas are being designed to match the targeted operating frequency of 5GHz which is for WLAN application. The purpose of designing the antennas is to analyse their reflection coefficient and radiant pattern.

1.1 Varactor diode as tunning circuit

The varactor diode is a semiconductor, voltage-dependent, variable capacitor, also known as voltage-variable capacitance (VVC). The space charging of P and N region will increase with an increased reverse bias voltage and the transition capacitance, C_T will be decreased in turn. In addition, a varactor diode that parallels to the inductor provides a resonant tank circuit as shown in Figure 1, which may easily be modified by changing the reverse voltage of the diode's resonant frequency.

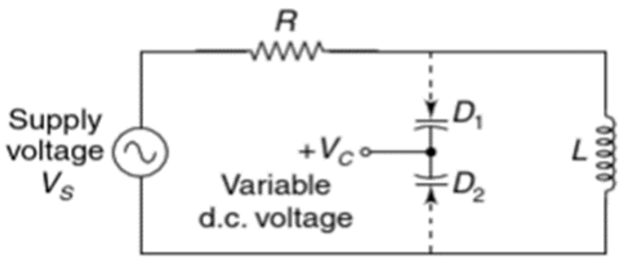

Figure 1: Tunning circuit with varactor diode [9]

2. Methodology

In this project, the electrical characteristics of the varactor diode in terms of its both C-V and F-V characteristics are simulated using MATLAB. A set of related formulas need to be manipulated to match the targeted frequency of 5GHz. Besides, two reconfigurable antennas are being designed to investigate the reflection coefficient and radiant pattern of antennas.

2.1 Electrical characteristics of varactor diode

For the characteristics of C-V, the exact magnitude of connection capacitance for a varactor diode is determined for zero-bias (C_D) capacitance, the forward voltage used to remove the entire depletion layer, and the real reverse voltage (V_R), which is applied across the junction [9]. It is given in Eq. 1:

$$C_D = \frac{C_0}{(1+2|V_R|)^{\frac{1}{2}}} \qquad Eq. 1$$

where C_0 is capacitance at zero bias $80\text{x}10^{-12}F$. The value of reverse bias voltage (V_R) should be below the breakdown voltage, above which the value of capacitance C_D equals zero because of the breakdown of the depletion region.

For the characteristics of F-V, the equivalent diode circuit is designed with C_J (V) and a R_S (V) series resistance, dependent upon the voltage, associated with the ohmic contact and finite epitaxial layer thickness. The series resonant frequency can be obtained from the tunning circuit and is given as in Eq. 2.

$$f_r = \frac{1}{2\pi\sqrt{L_S C_D}} \quad Eq. 2$$

where $L_S = 100H$ is a package inductance in equivalent circuit and C_D is a capacitance in zero bias. Both Eq. 1 and Eq. 2 are used in the simulation to produce the F-V curve of the varactor diode to see the correlation between capacitance and voltage of the varactor diode.

2.2 Reconfigurable antenna design with varactor diode

This paper focuses on designing and simulating a reconfigurable antenna that utilizes a varactor diode to adjust the frequencies so that it could operate 5GHz. Two types of planar antennas designed in this work are microstrip patch antennas (Figure 2)and microstrip inset-fed antennas (Figure 3). The basic microstrip antenna is studied in [10] and a single-feed method can be used to generate circular polarisation in patch antennas. Both antennas are simulated using air as the substrate of the patch antenna with the value of dielectric constant or relative permittivity ε_r and loss tangent δ are 1 and 0 respectively.

In addition, the dimension of the notch as shown in Figure 3 is simulated using the standard structure of a microstrip inset-fed antenna which optimizes for the impedance of 30-Ω at the feed network. A varactor diode is placed at the edge of the notch patch in a microstrip inset-fed antenna, while the slot in the microstrip patch antenna can be replaced by a varactor diode. The height of the antenna will determine the different dimensions of a ground plane and patch for both antennas. The reason for using these two antennas is to compare the reflection coefficient of magnitude (dB) over the targeted frequency (Hz). The antenna's dimensions were estimated using the formulas in [11] and the values for each antenna parameter are listed in Table 1 and Table 2 respectively.

Table 1: Dimensions of the Microstrip Patch Antenna at 5 GHz

Parameter	Value (mm)	Parameter	Value (mm)
W_g	0.44969	L	0.44969
L_g	0.02878	D_f	0.007195
W	0.44969	h	0.000599

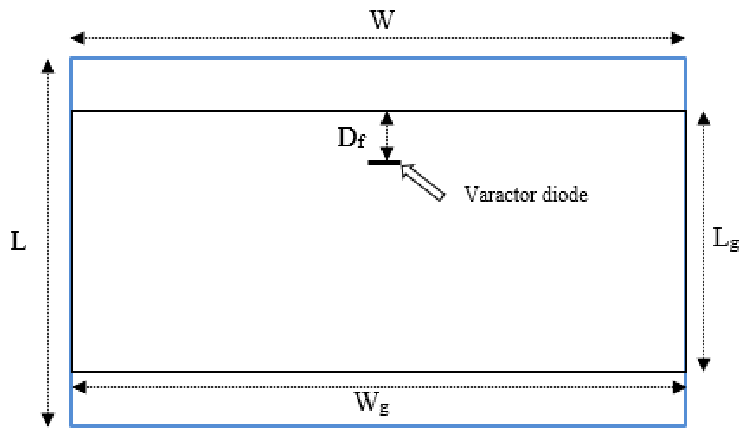

Figure 2: Structure of Microstrip Patch Antenna

Table 2: Dimension of the Microstrip Inset-Fed Antenna at 5 GHz

Parameter	Value (mm)	Parameter	Value (mm)
W_g	0.026981	W_f	0.001713
L_g	0.026981	G	0.002998
L	0.059958	F	0.003997
W	0.059958	h	0.001499

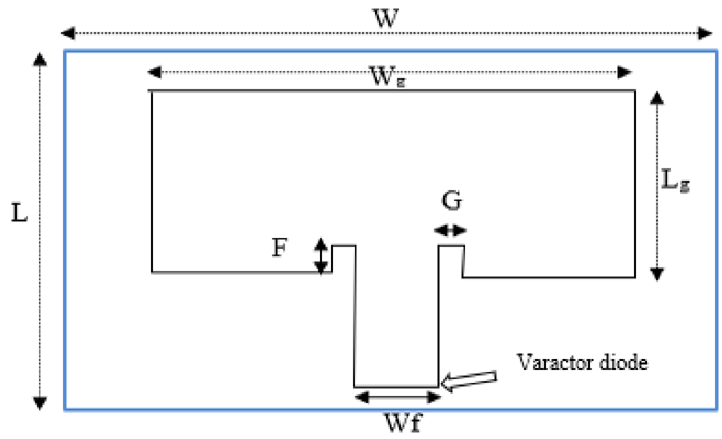

Figure 3: Structure of Microstrip Inset-Fed Antenna

3. Results and Discussion

3.1 Capacitance-Voltage Curve

Figure 4 shows the C-V curve of the varactor diode. The varactor diode has a nonlinear capacitance curve, which is inversely proportional to the square root of the voltage. This means that lower reverse voltage produces greater capacitance change than those at higher reverse voltages. In this paper, a set of selected capacitance values is set at zero bias C_0. At the point of reverse bias voltage -14 V, the value of capacitance is 14.86pF as shown in Figure. 4. In [9], the same point of reverse bias voltage -14 V gives a quite similar range of capacitance 13pF, hence the pattern of capacitance decrement over voltage increment has been verified.

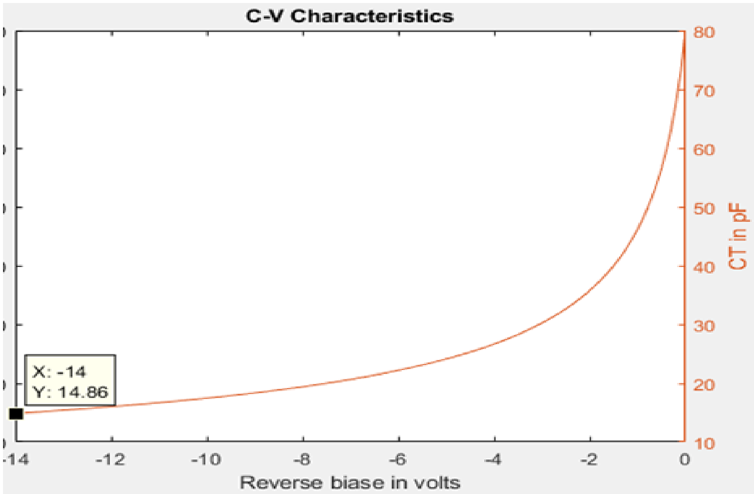

Figure 4: C-V curve of varactor diode

3.2 Resonant Frequency Versus Reverse Bias Voltage

The resonant frequency depends on the reverse voltage of the varactor when capacitance is replaced with a varactor whose interconnection capacitances depend on the voltage. Two values of capacitance, 65 pF and 100 pF are used to compare the resonant frequency of the varactor diode. The capacitance of 65 pF produces a resonant frequency of 5 GHz, compared to 4 GHz produced by capacitance of 100 pF as shown in Figure 5. The result shows that a small change in capacitance generates a significant difference in resonant frequency in the same range of reverse voltage.

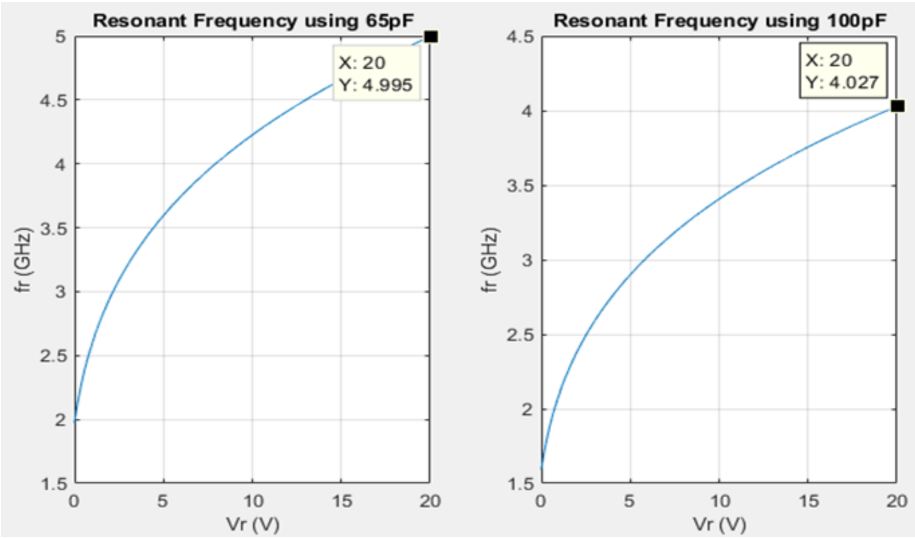

Figure 5: Resonant frequency with different values of capacitance

3.3 Reflection Coefficient for Both Antennas

The reflection coefficient is a measurement of how much of an electromagnetic wave is reflected by a transmission medium impedance discontinuity. The reflection coefficient is greatest far from the antenna's frequency range and decreases to zero at the antenna's resonance frequency. If the antenna is reflecting a lot of electromagnetic waves, it will radiate less, hence affecting the performance of an antenna. In this paper, two antennas are designed and each is coupled with a varactor and a proper biasing network. The reflection coefficient is simulated using MATLAB based on the structure of the microstrip patch antenna.

Figure 6 shows the reflection coefficient of the microstrip patch antenna at 5 GHz is -23.31 dB, which is good for reconfigurable antenna properties [12]. For the microstrip inset-fed antenna, the reflection coefficient is -15.26 dB which is lower than the microstrip patch antenna as shown in Figure 7. Therefore, the microstrip patch antenna shows a reasonable improvement as compared to the microstrip inset-fed antenna where the location of the varactor diode plays a major role in tunning the resonant frequency. Furthermore, the dimension of this microstrip patch antenna plays a major role in determining the magnitude (dB) of the targeted frequency. A direct comparison in [13] shows the reflection coefficient for 5.37 GHz for WLAN bands is -21.179 dB, which is slightly lower than the reflection coefficient for microstrip Patch antenna.

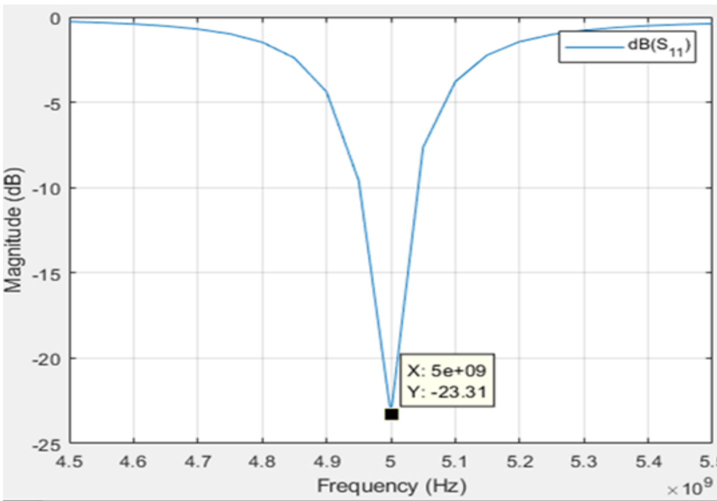

Figure 6: Reflection coefficient of Microstrip Patch Antenna at 5GHz

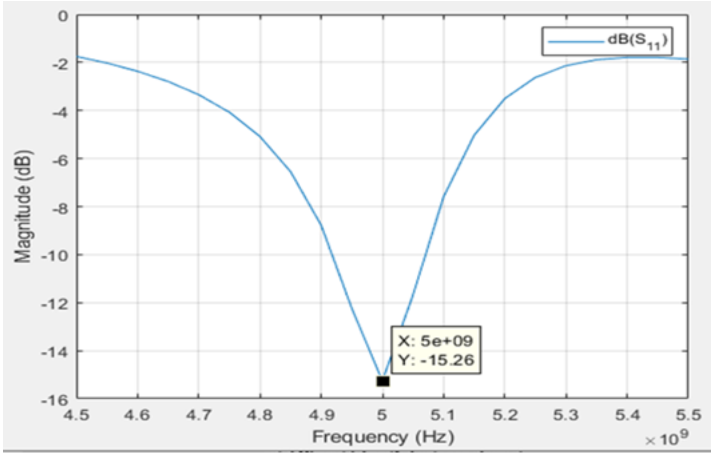

Figure 7: Reflection coefficient of Microstrip Inset-Fed Antenna at 5GHz

3.4 Radiant Pattern of Antennas

This project focuses on designing and simulating a reconfigurable antenna that utilizes a varactor diode to adjust the frequencies to operate in the wireless frequency ranges. Both antennas are compared based on the gain peak at beamwidth of 90 degrees and the number of nulls. Figure 8 shows the elevation radiation pattern of a microstrip inset-fed antenna at 5 GHz where the gain peak is 9.59 dBi with a beamwidth of 90 degrees. The beamwidth of 180 degrees is behind the peak of the main lobe, establishing the front-to-back ratio at about -17.35 dBi with a low number of null. On the other hand, the elevation radiation pattern for the microstrip patch antenna has a gain peak of 9.805 at 90 degrees as shown in Figure 9, which is higher than the microstrip inset-fed antenna. Therefore, the microstrip patch antenna has a higher gain that implies better signal propagation and an optimized antenna. The 180-degree beamwidth results in a front-to-back ratio of approximately -25.42 dBi, where the number of nulls is high due to high gain [14].

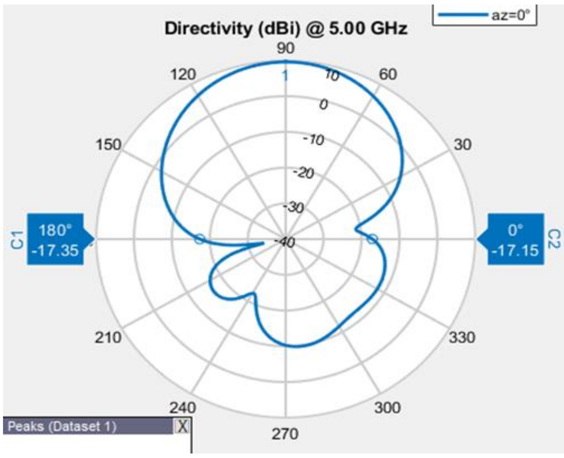

Figure 8: Elevation Radiation pattern of Microstrip Inset-Fed Antenna

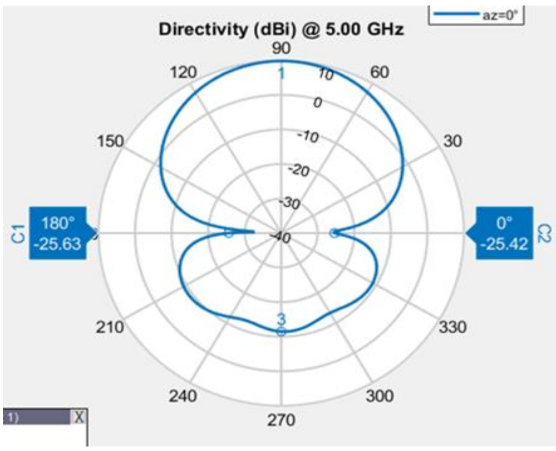

Figure 9: Elevation radiation pattern of Microstrip Patch Antenna

4. Conclusion

Simulation results show that the nonlinear capacitances curve is inversely proportional to the reverse bias of varactor diode voltage. On top of that, the resonant frequency can be analysed based on the selective capacitance values where a small change in capacitance reflects a significant change of resonant frequency by varying the reverse voltage of the varactor diode. In terms of reflection coefficient, the microstrip patch antenna shows a reasonable improvement and optimize as compared to the microstrip inset-fed antenna. Furthermore, using a varactor diode as a feed, it can be verified that both antennas managed to operate in the targeted frequency of 5 GHz based on their antenna radiation pattern. Therefore, it is concluded that the varactor diode plays an important role in the frequency tuning in the reconfigurable antenna.

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