A Novel Frequency Reconfigurable Monopole Antenna Using PIN Diode for WLAN/WiMax Applications

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***Abstract*—A frequency reconfigurable microstrip monopole antenna for WLAN/WiMax applications is proposed in this paper. The antenna uses three PIN diodes for the aim of achieving frequency reconfigurability. By switching the state of PIN diodes, the antenna is capable of operating at four different frequency bands with the center resonant frequencies of 2.4 Ghz, 3.3 GHz, 5.1 GHz and 5.6 GHz. The radiation pattern of the antenna is similar at all configurations. In different switching states, the antenna operates in single band mode. The dimension parameters of the antenna are calculated using some theoretical formula, simulated and optimized using CST software. The results in dimension parameter between calculating and simulating are relatively the same. The antenna is fabricated on FR4 substrate with a size of 40 × 30 mm, a thickness of 1.6 mm, and the relative permittivity of 4.4. A good agreement has been observed between the resonate frequency of measurement and simulation.**

***Index Terms*—Reconfigurable antenna, frequency reconfigurable antenna, monopole antenna, PIN diode, antenna for WLAN/WiMax.**

I. Introduction

With the rapid development of wireless communications, transceivers are now required to be lighter in weight, lower in price, smaller in dimension, and more diverse in their features. Further more, transceivers may be required to operate at different standards or for various applications. Frequency reconfigurable antennas are a superior choice over wideband or multiband antennas due to their capability to adjust the operating frequency band. In contrast, wideband [1]- [2] and multiband antennas [3]- [4] can serve multiple frequencies in one antenna but suffer from noise between neighboring bands. The reconfigurable antennas can switch dynamically between different frequency bands, so they can be used for pre-filtering which reduces the complexity of filter requirements in the transceivers [5].

So far, there have been many researches on frequency reconfigurable antenna with significant achievements such as [6]- [8]. In [6], a frequency reconfigurable figure 8 PIFA antenna has been proposed, which operates in two frequency bands from 2 GHz to 3 GHz and from 4 GHz to 7 GHz. Another reconfigurable antenna to be presented in [7] using 16 PIN diodes to obtain five states including one wideband mode and four narrowband modes, while the antenna structure is still complex. In [8] a bow-tie shaped frequency reconfigurable antenna using PIN diode with a simple bias circuit has been proposed for WLAN/WiMax/Bluetooth applications. This antenna can operate in three different states while using six PIN diodes. In [9], a reconfigurable patch antenna based on Complementary Split-Ring Resonators for WLAN applications was proposed.

Another structure which has attracted considerable research attention in reconfigurable antenna design is the monopole antenna due to its advantages such as a simple design, small dimensions, and ease of manufacture. A frequency reconfigurable monopole antenna in [10] was designed for WLAN/WiMax. However this antenna merely obtains two different frequencies. In [11]- [12], several frequency reconfigurable monopole antennas were also proposed for these applications. These antennas achieve different frequency states by adjusting the length of radiation elements using switches.

In this paper, a novel frequency reconfigurable antenna based on a microstrip monopole structure was proposed for WLAN/WiMax applications. The antenna uses PIN diodes for configurability, and different operating frequencies are obtained by not only adjusting the length of the radiation element but also by using matching impedance stubs. By using three PIN diodes, the antenna can operate at four ranges of bandwidth with resonant frequencies of 2.4 GHz, 3.3 GHz, 5.1 GHz and 5.6 GHz respectively. The proposed antenna has overall dimensions of $30 \times 40 \times 1.6\ mm$. The design process as well as an approach to calculating the dimensions of the various antenna elements are also presented here. To validate the antenna performance, a prototype has been fabricated and input reflect coefficient, S11 parameter, has been measured with the outcomes presented below.

The remainder of the paper is organized as follows: Section II describes the design process of the proposed antenna; Section III presents the results of the simulation and measurements with some discussion; and the conclusion of the paper is given in Section IV.

II. Antenna Design

The structure of the proposed frequency reconfigurable antenna is shown in Fig. 1. The antenna is designed on FR4 substrate with dimensions of $40 \times 30\ mm^2$. The thickness of the substrate is $h = 1.6\ mm$, the relative permittivity is $\varepsilon_r = 4.4$ and the loss tangent is 0.002. The length of the ground is $L_g = 20\ mm$. The antenna includes two elements and two stubs (shown in Fig. 1a). Three PIN diodes are used in order to connect or disconnect between the elements or between the element and the stubs. Inductors are used to isolate AC current from the DC bias line system which is in turn used to control PIN diodes. Dimensions and positions of the elements and stubs are given in Fig. 2c by denotations. Three SMP1345 PIN diodes are used to obtain four operating states. These PIN diodes can operate within a frequency range from 10 MHz to 6 GHz and have equivalent circuit depicted in Fig. 2 [14]. The operation of the PIN diodes in four states are given in Tab. I.

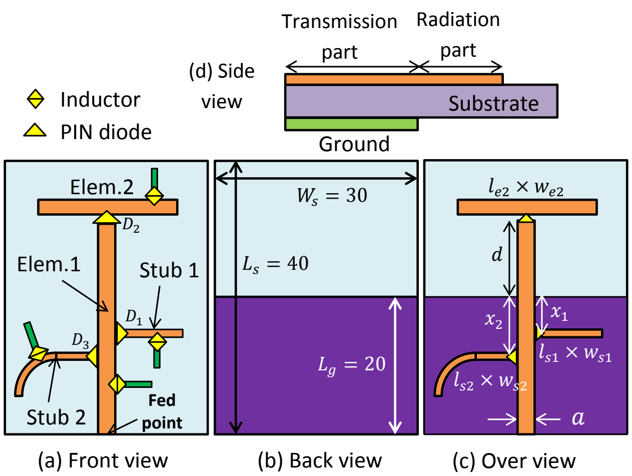


Fig. 1. Antenna structure (the sizes are given in mm)

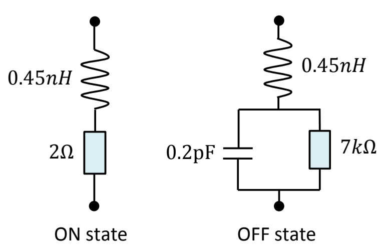


Fig. 2. Equivalent circuit of PIN diode SMP1345

The antenna is divided into two parts, one for transmission and one for radiation. The transmission part is backed by the ground plane and conversely the radiation part has no ground (shown in Fig. 1d). In this study, the different operating frequencies of the antenna are obtained by changing the electric length of the radiation part and by using matching stubs in transmission part. By switching the PIN diodes to ON or OFF, the antenna can operate at four resonant frequencies.

TABLE I
Operation of PIN diodes at the states

State	D1	D2	D3
S1	OFF	OFF	OFF
S2	ON	OFF	OFF
S3	OFF	ON	OFF
S4	OFF	ON	ON

The electrically equivalent shapes of the antenna at different configurations are given in Fig. 3.

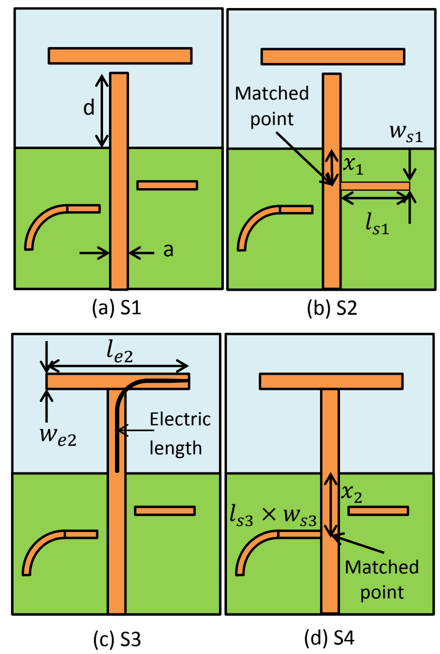


Fig. 3. Equivalent shapes of the antenna at different states

In state S1, all PIN diodes are off, and the antenna only includes the element 1 which is actually a microstrip transmission line lengthened over the ground. The width, a, is selected to achieve matched condition for 50Ω- impedance systems, and the radiation length, d, is calculated to obtain the operating frequency of 5.1 GHz.

From [13], a is given by:

$$\frac{a}{h} = \begin{cases} \dfrac{8e^A}{e^{2A}-1} & , \frac{a}{h} \leq 2 \\ \dfrac{2}{\pi}\left(\begin{array}{c} B - ln(2B+1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \\ \times \left(lnB + 0.39 - \frac{0.61}{\varepsilon_r} \right) \end{array} \right) & , \frac{a}{h} > 2 \end{cases} \tag{1}$$

where $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$, $B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} - 1$, Z_0 is impedance of the transmission line.

d is calculated by:

$$d = \frac{\lambda_r'}{4} \tag{2}$$

where $\lambda_r' = \frac{c_0}{f_r\sqrt{\varepsilon_e}}$ is the effective wavelength of the resonant frequency f_r, and ε_e is effective permittivity of transmission line given by:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + \frac{12h}{a}) \tag{3}$$

The results of the calculation is $a = 3.1\ mm$ and $d = 8.1\ mm$. In the state S2, the PIN diode D1 is ON, the stub 1 is connected to the element 1 in order to match impedance for the other frequency. The dimensions and the position of the matching stub, $l_{s1} \times w_{s1}$ and x_1 respectively, are calculated to obtain matched condition for a frequency of 5.6 GHz. After adding the stub, the impedance at matched point (presented in Fig. 3b) at desired frequency $f_d = 5.6$ GHz seen toward the radiation part must be 50 Ω, which equals the line impedance of the antenna for the matched condition. This means that:

$$\frac{1}{50} = \frac{1}{Z_s(f_d)} + \frac{1}{Z_b(f_d)} \tag{4}$$

where Z_s is the impedance of the stub at matched point seen into the stub, Z_b is the impedance of the antenna at matched point seen toward the radiation part before adding the matching stub. Because the stub is an open circuited transmission line, Z_s has only an imaginary part, i.e $Z_s(f_d) = jX$. Let Γ_1, Γ_2 denote the voltage reflection coefficients of the antenna at matched point and fed point before adding the stub, respectively. They can be written as:

$$\Gamma_1(f_d) = \frac{Z_b(f_d) - 50}{Z_b(f_d) + 50} \tag{5}$$

$$\Gamma_2(f_d) = \frac{Z_{in}(f_d) - 50}{Z_{in}(f_d) + 50} \tag{6}$$

where Z_{in} is the impedance of the antenna at fed point seen into the radiation part before adding the stub (i.e in state S1). The Z_{in} value can be acquired from the simulation software. In addition, Γ_2 can also be calculated by:

$$\Gamma_2(f_d) = \Gamma_1(f_d) e^{-j\frac{4\pi(L_g - x_1)}{\lambda'_d}} \tag{7}$$

where $\lambda'_d = \frac{c_0}{f_d\sqrt{\varepsilon_e}}$ is the effective wavelength of the desired frequency f_d before adding the stub. From equations (4)-(7), it can be seen that X and x_1 as[1]:

$$X = 25\sqrt{\left|\frac{Z_{in}(f_d) + 50}{Z_{in}(f_d) - 50}\right|^2 - 1} \tag{8}$$

$$x_1 = L_g + \frac{\lambda'_d}{2}\left(\frac{arg\left\{\frac{Z_{in}(f_d) - 50}{Z_{in}(f_d) + 50}.\frac{2jX - 50}{50}\right\}}{2\pi} + k\right) \tag{9}$$

where k is a certain integer which is chosen following the criteria of minimum value x_1. Finally, the length of the stub is calculated from the equation (10) after selecting the appropriate width of the stub, w_1 which is a free parameter.

$$l_{s1} = \frac{\bar{\lambda}_d}{2\pi}\left(arctan(-\frac{Z_0}{X}) + \pi\right) \tag{10}$$

[1]In this paper, $|.|$, $arg\{.\}$ denote absolute and argument value of a complex number, respectively.

where $\bar{\lambda}_d = \frac{\lambda_d}{\sqrt{\bar{\varepsilon}_e}}$ is the effective wavelength, and $\bar{\varepsilon}_e$ is the effective permittivity of the stub line, which can be obtained by applying (3) to the stub line (i.e exchange a by w_{s1}). Z_0 is the impedance of the stub line, given by [13]:

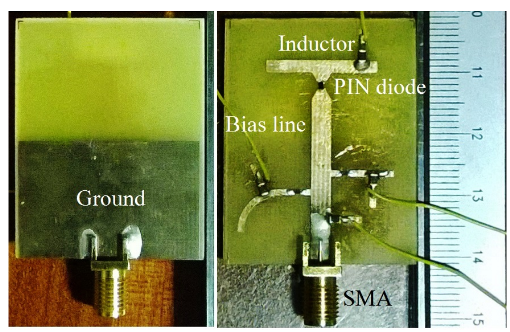
$$Z_0 = \begin{cases} \frac{60}{\sqrt{\bar{\varepsilon}_e}} ln\left(\frac{8h}{w_{s1}} + \frac{w_{s1}}{4h}\right) & , \frac{w_{s1}}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\bar{\varepsilon}_e}\left[\frac{w_{s1}}{h} + 1.393 + \frac{2}{3}ln\left(\frac{w_{s1}}{h} + \frac{13}{9}\right)\right]} & , \frac{w_{s1}}{h} > 1 \end{cases} \tag{11}$$

After obtaining the simulation result of state S1, $Z_{in}(5.6GHz) = 34.84 - 11.05j$ (Ω), and applying these aforementioned calculations, the parameter x_1, l_{s1} is found to be $4.0\ mm$ and $12.0\ mm$ respectively where the value of the width was selected as $w_{s1} = 1\ mm$.

In the state S3, only PIN diode D2 is on, element 2 is connected to element 1. It will lengthen the radiation part to achieve resonating frequency at 2.4 GHz. In order to calculate the length of the second element, l_{e2}, we can apply the equation (2), but in this case, the electric radiation length should be $d + \frac{l_{e2}}{2} = \frac{\lambda'_r}{4}$. From this point, one can extrapolate $l_{e2} = 18.0\ mm$.

TABLE II
THE SIZES OF THE ANTENNA

State	Parameter	Calculated (mm)	Simulated (mm)
S1	d	8.1	9
	a	3.1	3.2
S2	x_1	4.0	4.5
	w_1	Chosen (1)	1
	l_1	12	11.8
S3	w_2	Chosen (1)	1
	l_2	18	18
S4	x_3	8.6	8.5
	W_3	Chosen (2)	2
	l_3	16.1	16.7



(a) Back view (b) Front view

Fig. 4. Prototype of the proposed antenna

In the state S4, both diodes D3 and D2 are switched on, whereas diode D1 is switched off, then the stub 2 is connected to the element 1. The antenna obtains matched impedance condition for the frequency of 3.3 GHz. The calculations for the dimensions and the position of stub 2 is similar to stub 1 in state S2. In state S3, the simulation impedance of the antenna at fed point read from Smith chart is $Z_{in}(3.3GHz) = 35.71 + 58.08j$ (Ω). The calculated results are $x_2 = 8.6\ mm$, $l_{s2} = 16.1\ mm$ with the width of stub 2 is chosen as $w_{s2} = 1\ mm$.

Based on the calculation results, the dimensions of the antenna are optimized again by CST simulation software. The optimized results are shown in table II in comparison with the calculation results. It can clearly be seen that the simulated results are in close agreement with the calculated values. Fig. 4 shows a photograph of the fabricated antenna.

III. Results and discussion

In this section, the simulated and measured results of S11 parameter as well as simulated radiation pattern are presented. Simulated results of S11 parameter are shown in Fig. 5 which are in good agreement with our desired goals. It can be seen clearly that each configuration produces a single resonance. The four configurations have center operating frequencies of 2.4 GHz, 3.3 GHz, 5.1 GHz and 5.6 GHz with bandwidths of 470 MHz (from 2.28 GHz to 2.75 GHz), 420 MHz (from 3.12 GHz to 3.54 GHz), 1.42 GHz (from 4.47 GHz to 5.89 GHz) and 1.36 GHz (from 4.93 GHz to 6.29 GHz) which are presented in percentage of resonate frequency of approximately 20%, 13%, 28% and 25% respectively. These bandwidths are suitable for WLAN/WiMax applications.

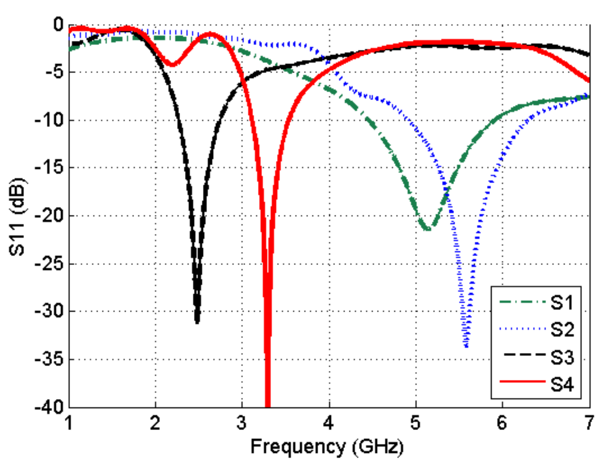


Fig. 5. Simulated results of S11 for the proposed antenna

Fig. 6 shows the comparison between the simulated and measured S11 parameter results of the proposed reconfigurable antenna for each configuration. There is a close agreement between the simulated and measured results of the resonant frequency. However, these resulting bandwidths are slightly different due to fabrication and the substrate quality.

The simulated radiation patterns of the antenna with different configurations are plotted in Fig. 7. It can be seen that the radiation patterns are nearly omnidirectional and they are similar for all the frequency bands. The antenna peak gains are about 1.5 dB for 2.4 GHz, 1.4 dB for 3.3 GHz, 2.8 dB for 5.1 GHz and 2.2 dB for 5.6 GHz. Table III summarizes

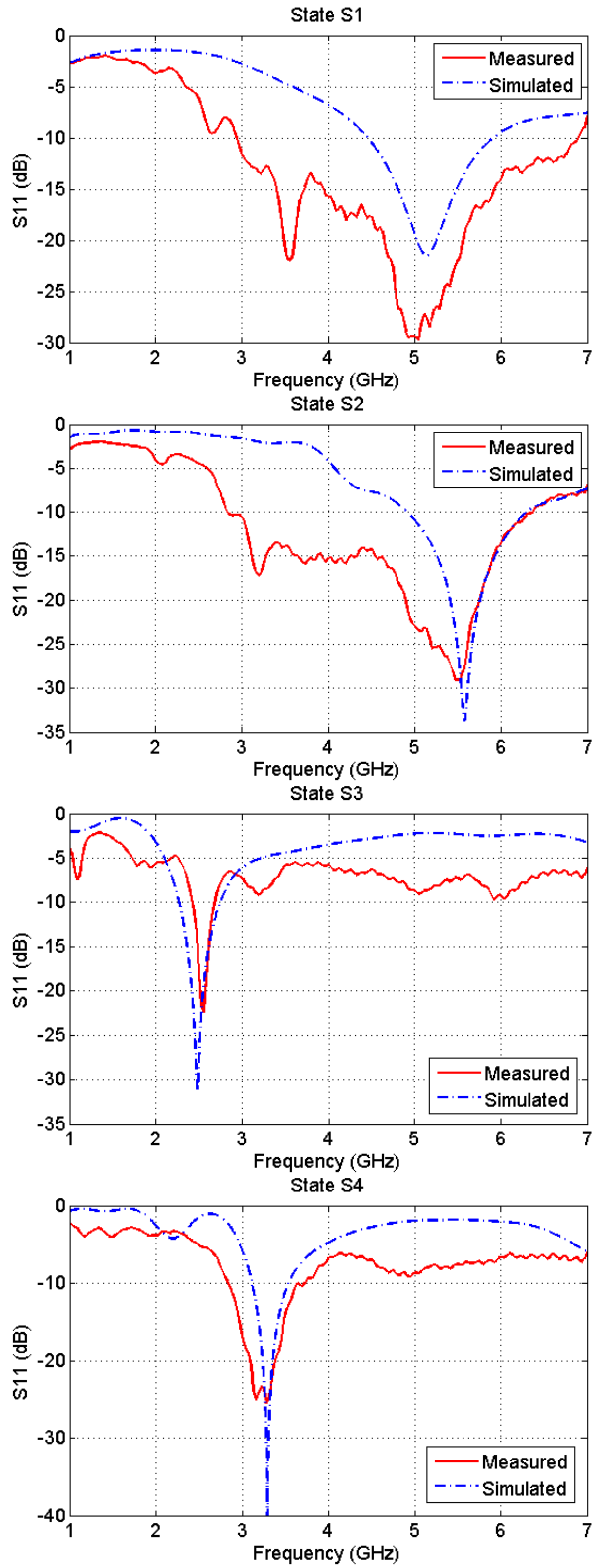


Fig. 6. Simulated and measured results of S11

all the results for center frequency, bandwidth, peak gain and radiation efficiency in the four states of the proposed antenna.

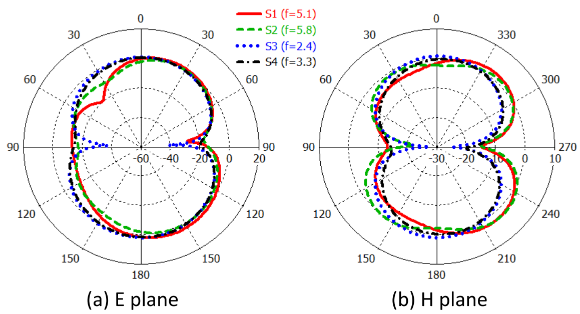


Fig. 7. 2D radiation patterns of four states at H plane and E plane.

TABLE III
SUMMARY OF RESULTS IN ALL STATES OF THE PROPOSED ANTENNA

State	Observed Frequency (GHz)	Bandwidth (%)	Peak gain (dB)	Total efficient (%)
S1	5.1	28	2.8	78
S2	5.8	25	2.2	70
S3	2.4	20	1.5	79
S4	3.3	13	1.4	69

IV. CONCLUSION

This paper presents a new design of frequency reconfigurable monopole antenna using PIN diode for WLAN/WiMax applications. By using three diodes, the antenna obtains four different configurations with the center resonant frequencies of 2.4 GHz, 3.3 GHz, 5.1 GHz and 5.6 GHz while the radiation patterns are almost unchanged. It also presents an approach to calculating dimension parameters in order to archive the desired frequency reconfigurable antenna. The prototype of the proposed antenna is fabricated on FR4 and the antenna performance is verified through simulation as well as measurement.

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