A Frequency-Reconfigurable Monopole Antenna with Switchable Stubbed Ground Structure

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Abstract. *A frequency-reconfigurable coplanar-waveguide (CPW) fed monopole antenna using switchable stubbed ground structure is presented. Four PIN diodes are employed in the stubs stretching from the ground to make the antenna reconfigurable in three operating modes: a single-band mode (2.4-2.9 GHz), a dual-band mode (2.4 to 2.9 GHz/5.09-5.47 GHz) and a triple-band mode (3.7 to 4.26 GHz/5.3-6.3 GHz/8.0-8.8 GHz). The monopole antenna is resonating at 2.4 GHz, while the stubs produce other operating frequency bands covering a number of wireless communication systems, including WLAN, WiMAX, C-band, and ITU. Furthermore, an optimized biasing network has been integrated into this antenna, which has little influence on the performance of the antenna. This paper presents, compares and discusses the simulated and measured results.*

Keywords

Reconfigurable antenna, stubbed ground structure, bias network

1. Introduction

Reconfigurable antennas with characteristics-tunable capability have attracted extensive attention in modern wireless communication system due to their advantages of miniaturization and multifunction. As one type of these antennas, the frequency reconfigurable antenna, which provides chosen operating frequencies according to the varying radio environment, can make efficient use of spectrum without interference to other frequency bands, so it is an appropriate candidate for cognitive radio applications [1], [2]. Compared with using multiple transceivers that integrate with multiple antennas to serve several wireless systems, an individual frequency reconfigurable antenna which can operate in different resonant frequencies with a reduced size and an easier fabricated structure is a better choice.

Such kind of antennas can acquire different current distribution and achieve frequency-tunable capability by controlling switches to change the physical sizes or shapes of the radiation elements [3–5]. Various methods, such as using wire, patch, planer-inverted F antennas to achieve frequency agility have been reported in [6]. Recently, lots of frequency reconfigurable antennas with switchable ground structure have been reported [7], [8]. Monopole antennas with CPW filters in ground plane are proposed in [9]. Two p-i-n diodes or varactors are implemented in a square-ring resonator to make the antenna reconfigurable in different single-band modes. In [10–12], by locating the p-i-n diodes in the slotted ground to control the length, width or shape of the slots, the antenna can operate in different dual-band modes.

These antennas with switchable ground structure mentioned above are all only capable of switching between different single-band modes or dual-band modes. These papers have mainly introduced a method of slotting in the ground plane to achieve frequency reconfigurable capability, but haven't focused on the influence of stubbed ground structure. By adding switchable stubs in the ground plane [13], the antenna can be reconfigured as well and the design is more flexible. In addition, a reconfigurable antenna always needs a dc bias circuit to provide bias voltage for switches, while it may deteriorate the performance of the antenna. Therefore, it is a challenge to integrate an antenna with bias network, and it is significant to analyze the influence of the bias network in detail.

In this paper, we presented a novel frequency reconfigurable antenna with switchable stubbed ground structure. Four p-i-n diodes are implemented to control the length of the stubs stretching from the ground. By choosing the state of diodes, the antenna could operate in three modes: a single-band mode (2.4–2.9 GHz), a dual-band mode (2.4 to 2.9 GHz/5.09–5.47 GHz) and a triple-band mode (3.7 to 4.26 GHz/5.3–6.3 GHz/8.0–8.8 GHz). This reconfigurable antenna can work in five different frequency bands covering WIMAX band, WLAN band, C-band, and ITU band, which could satisfy the demands of the multi-band wireless communication systems well. Moreover, a biasing network is integrated into the antenna. The simulated reflection coefficients and radiation patterns show that the optimized bias network has a marginal effect on the performance of the antenna.

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2. Antenna Structure

As Fig. 1 shows, the basic proposed antenna is printed on a 40 × 43 mm^2 sized FR4 substrate (dielectric constant $\varepsilon_r = 4.6$, $\tan\delta = 0.02$ and thickness $h = 1.6$ mm) and fed by a CPW transmission line with the input impedance of 50 Ω.The antenna consists of two main parts: an arrow-shaped radiation element and a stubbed ground plane. The arrow-shaped radiation element is constituted by an equilateral triangle and a rectangle. Two P-shaped stubs are symmetrically added in the ground plane where four p-i-n diodes are used to control the length of the stubs as Fig. 2 shows. An optimized dc feed network with four bias lines is designed on the bottom of the antenna. Each bias line is connected by a 100 Ω SMD resistor and two 100 nH chip inductors to bias the p-i-n diodes through the vias. The p-i-n diode is MA4AGBLP912, which exhibits a resistance of 4 Ω in the ON state and a parallel circuit with a resistance of 2 kΩ and a capacitance of 0.025 pF in the OFF state.

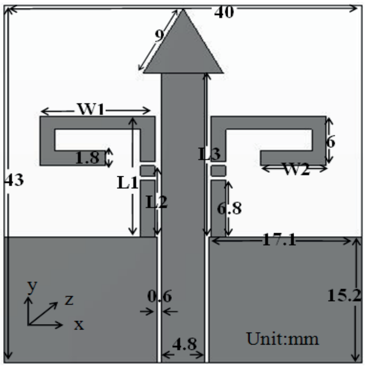
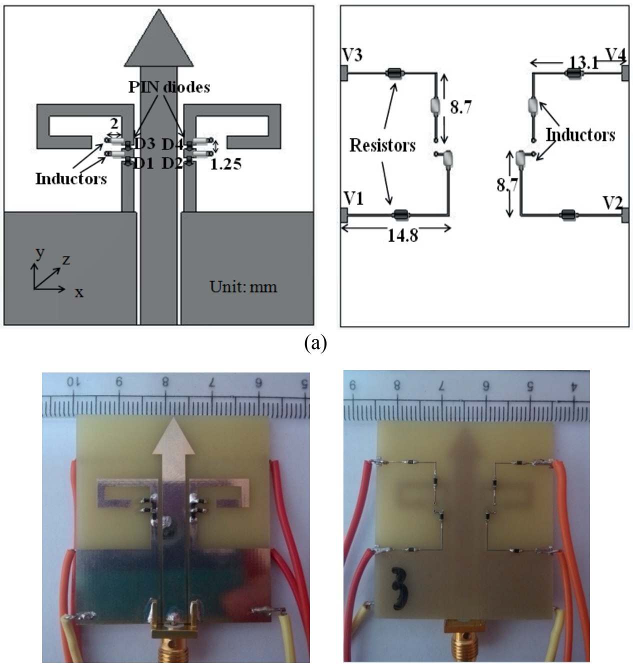


Fig. 1. Geometry of the proposed antenna (without biasing network) L1 = 12.9 mm, L2 = 8.5 mm, L3 = 19.6 mm, W1 = 12.5 mm, W2 = 7 mm.



(a)

(b)

Fig. 2. (a) The layout of the proposed antenna at top view and bottom view. (b)Photograph of the fabricated antenna.

3. Antenna Design

In the initiatory work, a quarter wavelength monopole is taken into account to acquire the resonant frequency at 2.4 GHz. Turning the top of the monopole into an arrow shape could vary the resonant frequency band conveniently. Actually, other shapes such as cone, circle and ring have the same effect. Each shape has a coupling coefficient, which is hard to calculate quantitatively. But we can have a qualitative analysis of it. The shape added in the monopole is equivalent to an inductance element and there are capacitances between the shape and stubs. Adjusting it and stubs to get appropriate inductance and capacitance, the antenna (the resonance circuit) can satisfactorily operate.

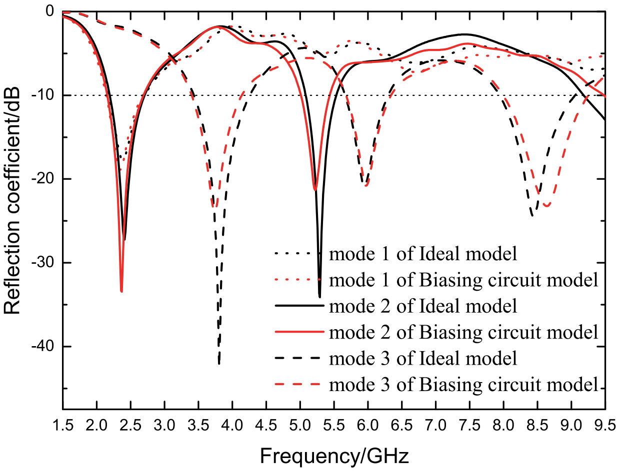


Fig. 3. Influence of the biasing circuit on the reflection coefficient of antenna.

Since the p-i-n diodes are used in the actual situation, the dc feed network with four bias lines is added in the antenna. As the p-i-n diodes are located in ground plane, so capacitors are not required. Each bias line with a resistor and an inductor in the back of the substrate biases each diode through a via and the other inductor beside the diode. A current limiting resistor is used in each bias line to provide the rated current for each p-i-n diode. Even though the bias network is designed on the backside of the substrate, the coupling between the bias lines and the monopole still produce the radiation we are not interested in and it will worsen the antenna performance. Therefore, we optimized the route of bias wires to minimize the coupling, and added an inductor to separate the bias line into several short metal wires which may radiate at high frequencies beyond the frequencies of interest. Moreover, when the vias for the diodes are in the stubs, much current that should have distributed on the stubs will flow to the vias, and the current distribution changes, the radiation frequency band shifts. However, if we drill a hole beside the stubs, and connect the vias with the stubs by an inductor, the influence of the bias circuit will be smaller.

In order to study the influence of the bias network and the p-i-n diodes, we use the CST Microwave Studio to analyze the performance of different models. Ideal model uses ideal switches (the ON and OFF state of the ideal switches are replaced by the connected metal and the disconnected metal). Biasing circuit model, containing the components model of via holes, resistors and inductors, is based on Ideal model but has a bias network; while the proposed antenna model included all models of inductors, via holes, resistors and p-i-n diodes. Table 1 summarized simulated performance of three models operating in different modes. The simulated reflection coefficients results of first two models are compared in Fig. 3. It is observed that the resonating frequencies of biasing circuit model just shift slightly compared to these of the ideal model. We also make a comparison between the simulated radiation patterns of these two models. Although the results are not shown in this paper, they demonstrate that the bias network has a marginal effect on the antenna radiation patterns. In conclusion, the bias network has a small influence on the antenna. As for the impact of p-i-n diodes, it can be seen in Tab. 1, simulated frequency bands of the third model broaden or narrow slightly at the operating modes when compared with the first two models, which is attributed to the non-ideal on and off state of p-i-n diodes. Other results of the proposed antenna will be given in Sec. 4.

Case	Diodes state	Frequency band (GHz)		
		Ideal model	Basing circuit model	The proposed antenna model
Mode 1	D1,D2,D3, D4 OFF	2.16-2.70	2.16-2.70	2.16-2.70
Mode 2	D1,D2 ON, D3,D4 OFF	2.14-2.72 5.08-5.52	2.14-2.72 4.99-5.42	2.14-2.67 4.90-5.40
Mode 3	D1,D2,D3, D4 ON	3.38-4.28 5.65-6.32 7.9-9.0	3.38-4.16 5.65-6.35 7.98-9.25	3.36-4.20 5.70-6.49 7.67-9.11

Tab. 1. Simulated performance of three models in operating modes.

4. Result and Discussion

The current distribution reaches the densest on the arrow-shaped monopole when the proposed antenna operates at about 2.4 GHz. Fig. 4 illustrates the surface current distributions of the antenna at other four resonant frequencies. As it can be seen, the current distributions reach the densest on different positions of the stubs when the antenna works at other four resonant frequencies. During simulation, though the frequency at 2.4 GHz is decided by the length of the arrow-shaped radiation element, the stubs will slightly affect it as shown in Fig. 5(a). In mode 2, the value of L2 is about a quarter wavelength in the corresponding frequency at 5.27 GHz. This resonant frequency will fade away when inappropriate values are chosen as displayed in Fig. 5(b). In mode 3, the operating frequency at 3.87 GHz can be independently acquired by adjusting the value of W1, and L1 is the main parameter to decide the radiation at 8.3 GHz.

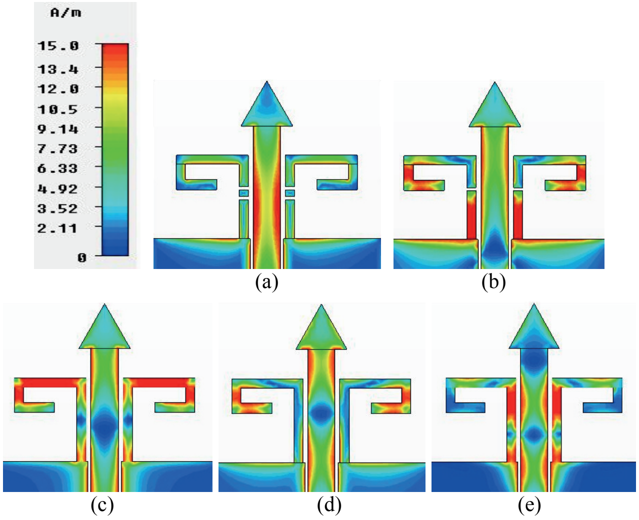


Fig. 4. Simulated surface current distributions of the antenna: (a) 2.4 GHz in mode 1 and 2; (b) 5.27 GHz in mode 2; (c) 3.87 GHz, (d) 5.9 GHz and (e) 8.3 GHz in mode 3.

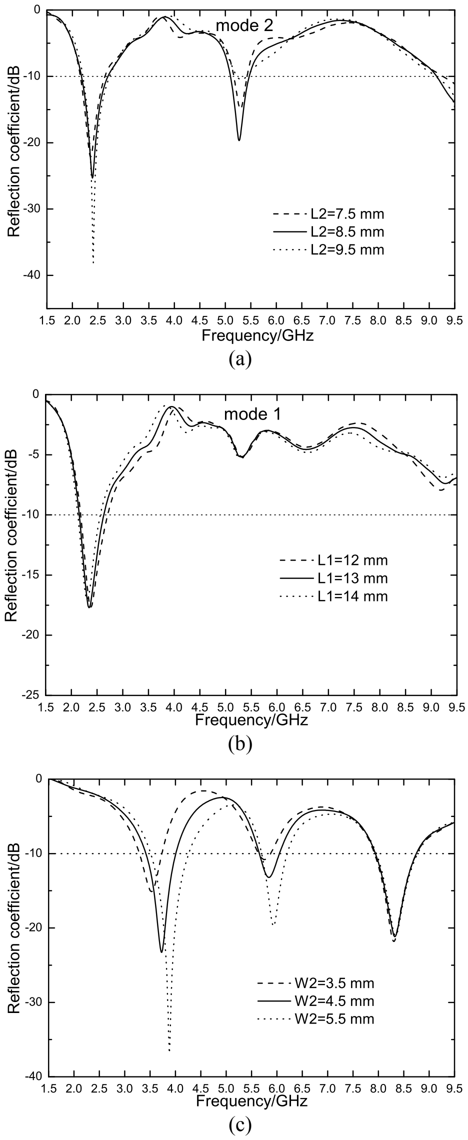


Fig. 5. Simulated reflection coefficient of the proposed antenna with different value of (a) L1, (b) L2, (c) W2.

When optimizing the parameters of W1 and W2, desirable coupling between the stubs and the arrow-shaped monopole can be acquired at 3.87 GHz and 5.9 GHz. It can be seen that the resonant frequencies at 3.87 GHz and 5.9 GHz move down when decreasing W2. Fig. 5 shows the simulated reflection coefficient of the proposed antenna with different values of some parameters.

Fig. 6 shows the simulated and measured reflection coefficient of the proposed antenna in three modes. A p-i-n diode is driven by 3 V dc voltage from a dc power supply when it is in ON state. The reflection coefficient was measured by Rohde & Schwarz ZVB20 Vector Network Analyzer. The operating frequency band measured for the single-band mode 1 is 2.4–2.9 GHz, which can apply to WLAN 2.4 GHz and WIMAX 2.5 GHz. In the dual-band mode 2, the measured frequency bands are 2.4–2.9 GHz/ 5.09–5.47 GHz, which can cover the WLAN 2.4/5.2 GHz and WIMAX 2.5 GHz. For the triple-band mode 3, the operating frequency bands are 3.7–4.26 GHz/ 5.3 to 6.34 GHz /8.08–8.8 GHz, which can serve the multi-band

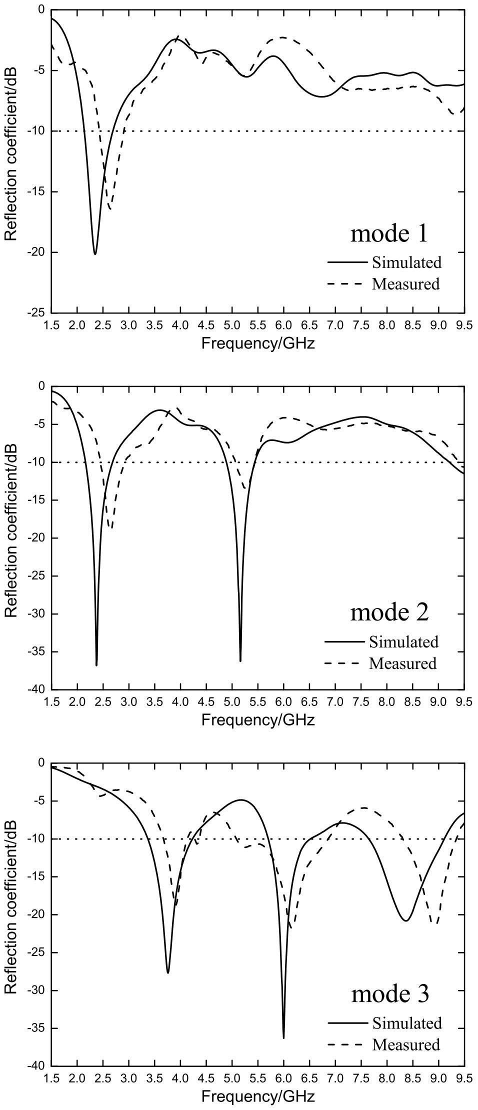


Fig. 6. Simulated and measured reflection coefficient of the antenna in three modes.

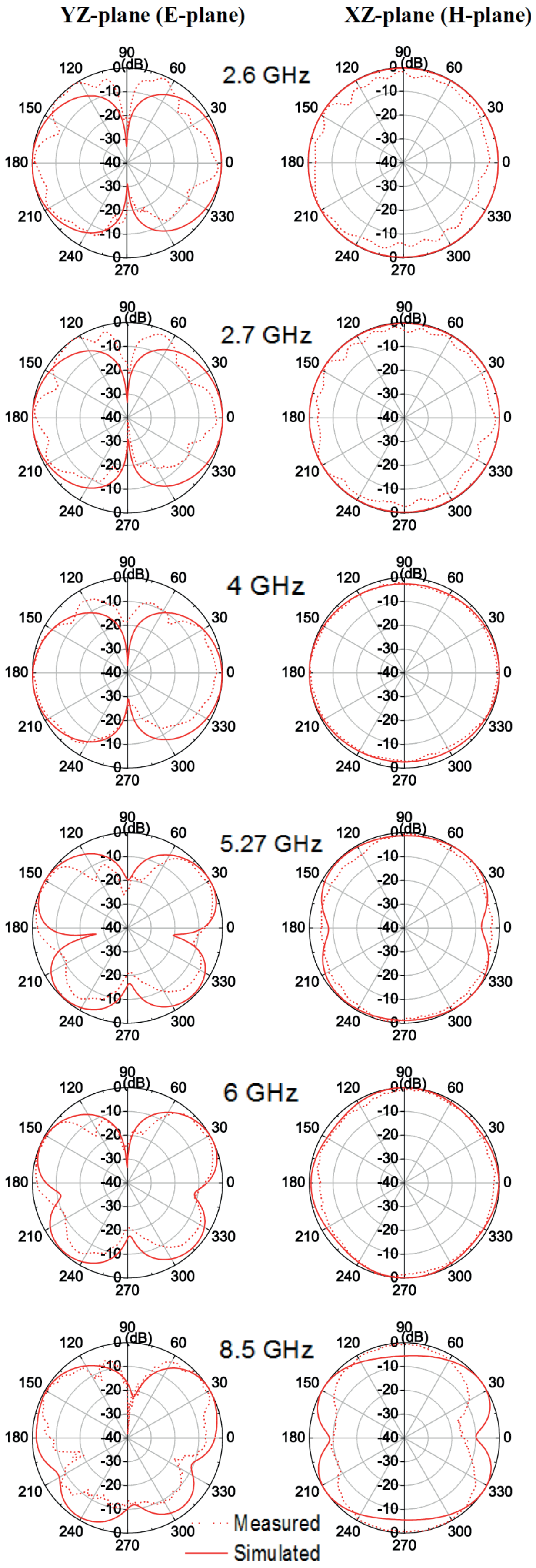


Fig. 7. Simulated and measured normalized radiation patterns.

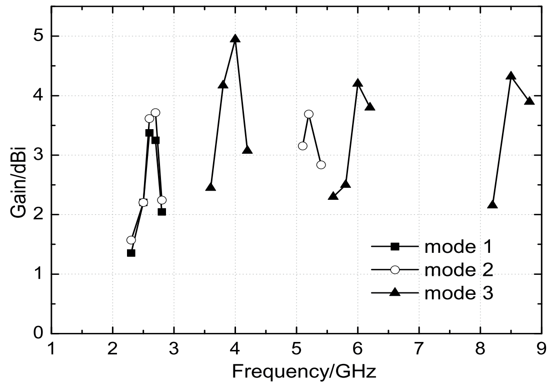


Fig. 8. Measured peak gain of the proposed antenna.

wireless communication systems including WLAN 5.8 GHz, C-band (3.7–4.2 GHz), and ITU (8–8.4 GHz). The measurements match well with the simulated results except that there is a shift at some resonant frequencies. The main reasons are listed as follows: firstly, there are tolerances in the exact value of the substrate's dielectric constant (±6% error specified by manufacturer) and the dimensions of the antenna. Secondly, the components in bias network such as inductors, resistors and p-i-n diodes are non-ideal, which indicates the equivalent parameters in simulation are not available in measurement. Finally, parasitic parameters may be introduced during welding process.

Comparisons between the simulated and measured normalized radiation patterns for three operating modes are demonstrated in Fig. 7. The proposed antenna was measured in an anechoic chamber, and two dc power supplies covered with absorbers were used to control the states of p-i-n diodes. According to the results, it is the obvious to see the *xz*-plane radiation patterns are almost omnidirectional, and the antenna has a dipole-shape radiation pattern in the *yz*-plane. Fig. 8 shows measured gain of the proposed antenna. The measured peak gain of mode 1 is about 3.38 dBi at 2.6 GHz, and mode 2 is approximately 3.61 dBi at 2.7 GHz. The two gain curves of mode 1 and mode 2 at around 2.6 GHz are consistent. Other values of the measured peak gain are 3.69 dBi at 5.27 GHz, 4.95 dBi at 4 GHz, 4.2 dBi at 6 GHz, and 4.32 dBi at 8.5 GHz, respectively. The results coincide with the measured reflection coefficient of the antenna.

5. Conclusion

In this paper, a novel frequency-reconfigurable monopole antenna with stubbed ground structure is introduced for multi-band wireless communication systems including WLAN, WIMAX, C-band, and ITU. It has a different structure from the traditional monopole antenna, which shows an antenna could acquire frequency reconfigurable capability as the slotting ground structure does by adding switchable stubs in the ground plane. The simple structure makes the antenna easy to be fabricated. Moreover, the design of a bias network that has little influence on antenna performance is a reference for integrating an antenna and a bias network together in future.

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