Single-, Dual- and Triple-band Frequency Reconfigurable Antenna

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Abstract. *The paper presents a frequency reconfigurable slot dipole antenna. The antenna is capable of being switched between single-band, dual-band or triple-band operation. The antenna incorporates three pairs of pin-diodes which are located within the dipole arms. The antenna was designed to operate at 2.4 GHz, 3.5 GHz and 5.2 GHz using the aid of CST Microwave Studio. The average measured gains are 1.54, 2.92 and 1.89 dBi for low, mid and high band respectively. A prototype was then constructed in order to verify the performance of the device. A good level of agreement was observed between simulation and measurement.*

Keywords

Frequency reconfigurable antenna, slot antenna.

1. Introduction

The demands on communications systems have increased dramatically in recent years. Modern communications systems often incorporate numerous radio transceivers each operating at a different frequency. It is no longer practical to provide a dedicated antenna element for each individual radio. Fortunately a frequency reconfigurable antenna, based on using a single radiating element is able to cover a variety of different frequencies and beam-width as reported in [1], [2]. In comparison with fixed multiband antennas, reconfigurable antennas increase the flexibility of a radio system [3]. Some fixed multi-band antennas are reported in [4]-[6]. In terms of gain, the performance of the fixed multi-band antennas is better than that of their reconfigurable counterparts. This can be attributed to losses within the switches of a reconfigurable antenna. However fixed multiband antennas can only operate at certain frequencies as compared to reconfigurable antenna that can access a range of operating frequencies. This is important for cognitive radio and spectrum aggregation both of which will require antennas that can reconfigure their operating parameters. A fixed multiband antenna would not be adequate for use in these applications. Reconfigurable antenna is achieved through the use of microwave switches, such as MEMS or pin-diodes. The latter being the more popular choice. The reason for this is that MEMS switches are more expensive, afford lower reliability and require a higher bias voltage compared to pin-diodes [7]. Pin diodes, on the other hand, are based on more mature technology and are thus more readily available.

Broadly speaking the techniques for frequency reconfiguration can be divided into three main classes: 1) narrowband to another narrowband [8], 2) wideband to narrowband [9], and 3) multi-band to another multi-band [10]-[13]. An antenna that can be reconfigured from one narrowband to another narrowband is only capable of supporting one radio standard at a time. An antenna that can be reconfigured from wideband to narrowband, on the other hand, can support multiple radio standards at a time. However, the wideband operation inherently provides less interference rejection than narrowband operation. This limitation, is addressed by employing an antenna that can be reconfigured from one multi-band to another multi-band is preferred [10]-[13]. In [10], a varactor diode is used to tune the frequency location of the multi-band. In this way the antenna is able to cover a wide range of different frequencies. In [11], RF MEMS switches are used to achieve multiband reconfiguration in four different states. The antenna exhibits two dual-band states and two triple-band states. In this way the antenna is able to cover a wide frequency range from 0.8 GHz to 6 GHz. The antennas proposed in [12]-[13] can switch between single-band, dual-band, or multi-band operation.

The sickle-shaped slot antenna, reported in [12], incorporates six pin-diode switches. These switches are used to activate or deactivate certain slots. Consequently the antenna is able to provide seven different operating modes. The antenna proposed in [13] incorporates two switches. These switches enable it to provide three different operat-

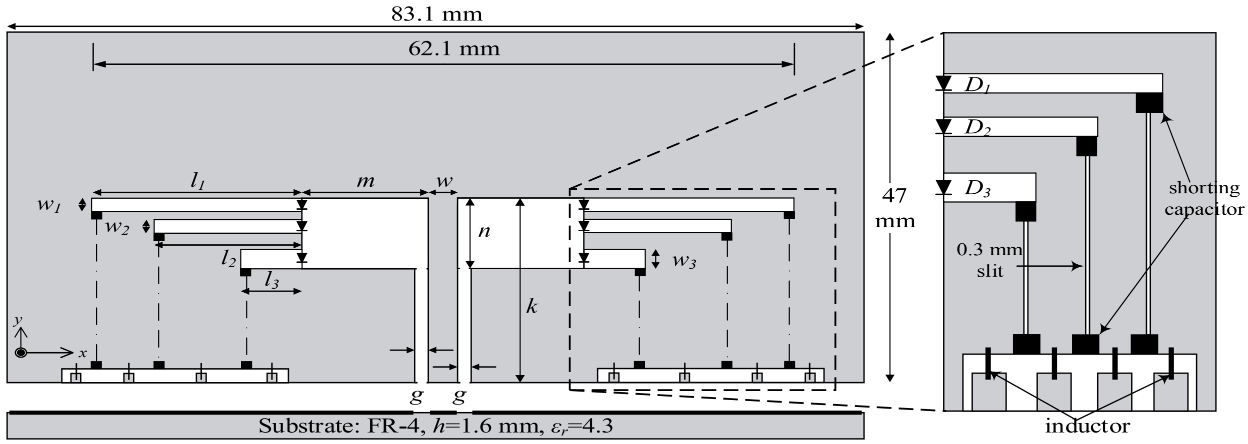


Fig. 1. The geometry of the proposed antenna.

ing states, namely: 2 dual-band and 1 triple-band mode. The antenna has applications in Bluetooth, WiMAX, and WLAN systems.

This paper proposes a new design for a frequency reconfigurable multi-band antenna based around a slot dipole. Three pairs of pin-diode switches are placed across, the dipole arms. It is possible to reconfigure the operating frequency of the antenna, by altering the states of the switches. In total, the proposed antenna is capable of operating in seven different states: three single-band, three dual-band, and one triple-band. The reminder of the paper is organized as follows: Section 2 describes the geometry of the antenna. Section 3 presents the simulation and measurement results. Finally Section 4 presents the conclusions.

2. Antenna Design

Fig. 1 describes the structure of the antenna along with the DC-bias circuitry used to control the microwave switches. The antenna is based on a design presented in [14] and consists of three pairs of slots, positioned in series. Then, the slots are merged into a rectangular box to have a stable and better impedance matching results. These slots are etched into the ground plane. The antenna is fed via a CPW transmission line.

It is fabricated on an FR-4 substrate having a relative permittivity (ε_r) of 4.3 and a thickness (h) of 1.6 mm. The size of the substrate is 83.1 mm × 47 mm. This size is chosen because it gives better S_{11} result after optimization was done. It is worth to note that the height of the substrate has a strong effect on the lowest resonance frequency. The geometrical parameters of the proposed antenna are given in Tab. 1. In comparison with a fixed multiband antenna, the proposed antenna can be reconfigured between a larger numbers of operating bands. The antenna also provides a degree of additional filtering, which would have the effect of reducing the level of interference at the receiver. These factors represent significant advantages in comparison with [14].

Each dipole arms is approximately half-a-wavelength long at the corresponding resonant frequency. For example, the uppermost arm has a length of 62.1 mm which is approximately half-a-wavelength long at 2.45 GHz. The middle and lower arms are 46.6 mm and 36.7 mm long, respectively. To obtain the best results, the values of all of the geometrical parameters have been optimized using a computer simulation tool. This is necessary to account for the specific path taken by the surface currents as well as the effect of fringing fields. Three pairs of pin-diode switches are inserted into the antenna, as mentioned earlier. An Infineon BAR50-02V pin-diode was employed in the prototype antenna [15]. Fig. 2 shows the equivalent circuit for pin-diode in the on-state. Fig. 3 and Fig. 4 show the equivalent circuit for pin-diode in the off-state. At frequencies below 4 GHz the value of capacitor is 0.15 pF. At frequencies above 4 GHz the capacitor value is 0.12 pF. The pin-diode pairs are denoted D_1, D_2 and D_3. These pairs of diodes are located on the upper, middle, and lower pairs of dipole arms, respectively. The electromagnetic computer simulations results reported in this paper were obtained using CST Microwave Studio® 2012 [16].

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
g	0.50	n	5.00
k	19.00	w	3.00
l_1	16.55	w_1	0.50
l_2	8.80	w_2	0.50
l_3	3.85	w_3	1.00
m	13.00		

Tab. 1. Parameter value of the antenna design.

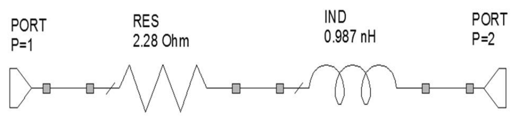


Fig. 2. Pin-diode on state equivalent circuit.

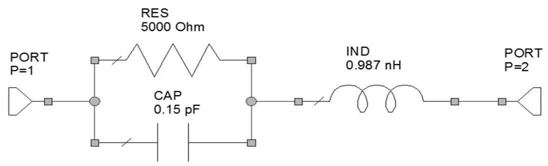


Fig. 3. Pin-diode off state equivalent circuit, frequency < 4 GHz.

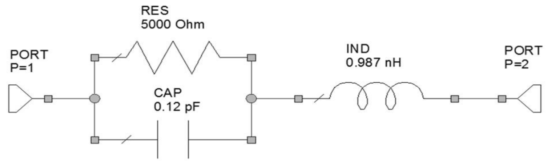


Fig. 4. Pin-diode off state equivalent circuit, frequency ≥ 4 GHz.

Tab. 2 describes the switch states required in order to obtain each of the seven different operating bands. States one, two, and three yield single-band operation. They are achieved by switching off only one pair of pin-diodes. The remaining pairs of diodes are switched on. To be specific, state one is achieved by switching off diode pair D_1. State two, on the other hand, is achieved by switching off diode pair D_2. In contrast, states four, five, and six are obtained by switching on only one pair of diodes. These states yield dual-band operation. To be specific, state five is achieved when only diode pair D_2 is switch on. Finally, if all of the pin-diodes are turned off, triple-band operation is achieved. This is referred to as state seven.

State	D_1	D_2	D_3	Bands
1	off	on	on	Single-band : (low)
2	on	off	on	Single-band : (mid)
3	on	on	off	Single-band : (high)
4	off	off	on	Dual-band : (low & mid)
5	off	on	off	Dual-band : (low & high)
6	on	off	off	Dual-band : (mid & high)
7	off	off	off	Triple-band : (low, mid & high)

Tab. 2. Switch configuration of the antenna design.

In the prototype, the biasing circuit comprises a number of 100 pF capacitor along with a 27 nH inductors. Each of the capacitors behaves as a DC block while each of the inductors serves as an RF choke. A series of 0.3 mm slits are introduced into the ground plane, as shown in the inset of Fig. 1. These slits serve as a means of isolating the bias voltages applied to the different switches from one another.

3. Results and Discussions

Fig. 5 shows a photograph of the fabricated antenna. Fig. 6 shows measured and simulated S_{11} curves corresponding to the seven operating bands. Inspection of these figures shows that there is generally a good level of agreement between measurement and simulation. The measured S_{11} for states one and two reveals resonances at 2.4 GHz and 3.5 GHz, respectively. For state one, a second passband also occurs around 5.8 GHz. This is also apparent on inspection of the gain plot, shown in Fig. 9(a). When configured to operate in state seven, the antenna exhibits resonances at 2.4 GHz, 3.5 GHz and 5.2 GHz. This would enable the antenna to support Bluetooth, WiMAX and WLAN systems, respectively.

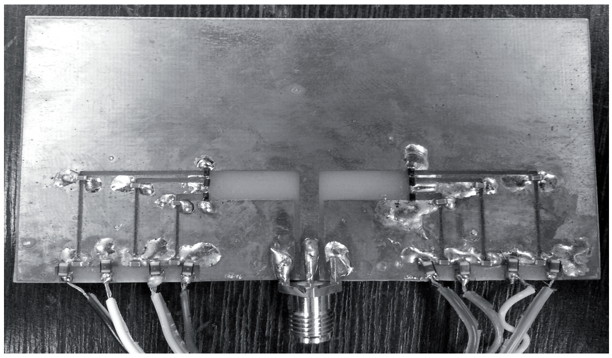
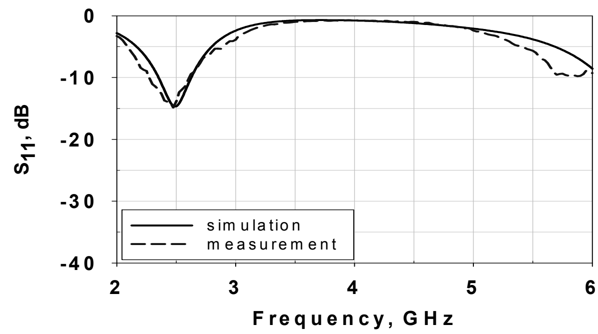


Fig. 5. Photograph of the proposed antenna.



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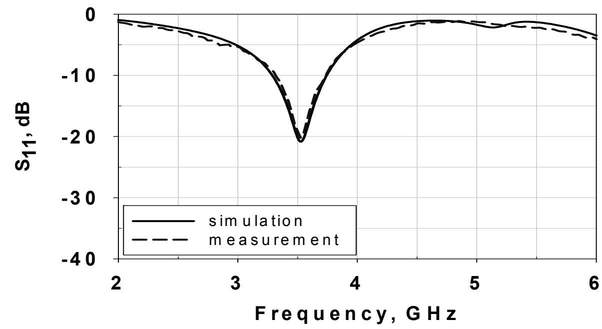

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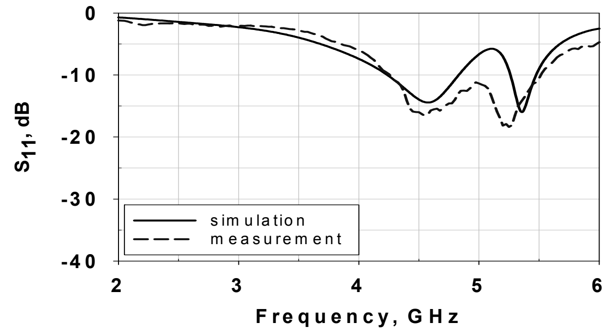

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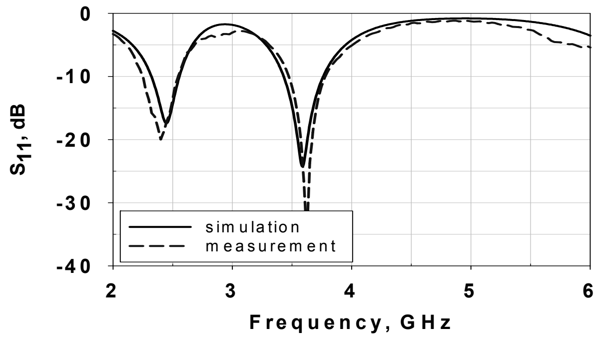

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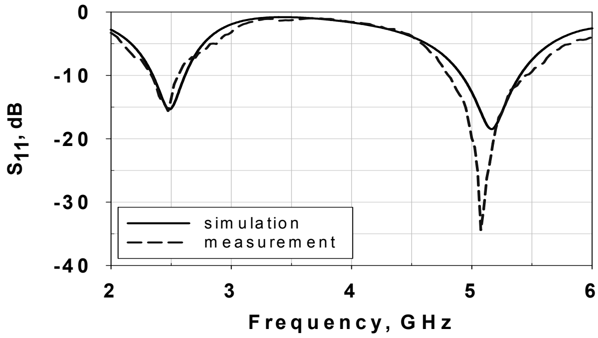

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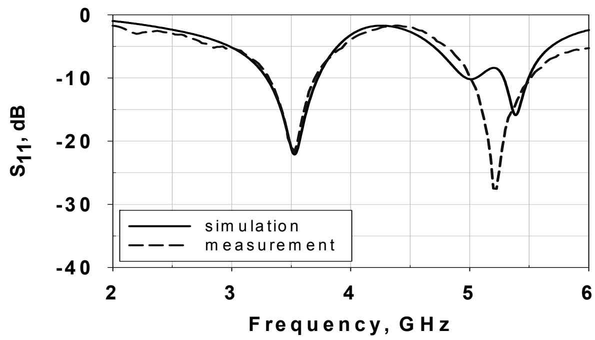

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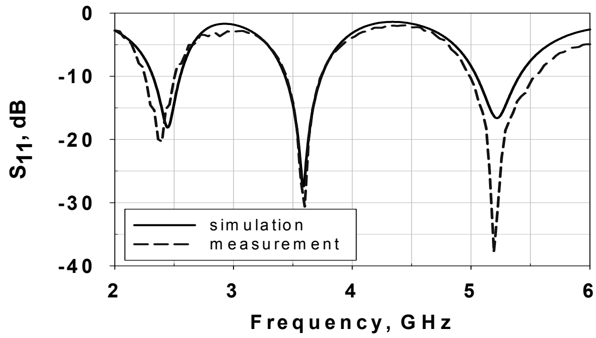
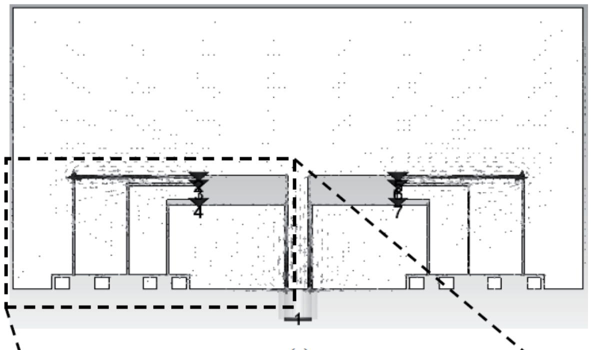


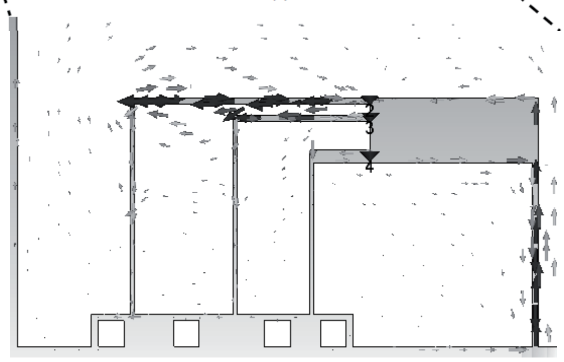
(g)

Fig. 6. Measured and simulated S_{11} of the antenna: (a) state one, (b) state two, (c) state three, (d) state four, (e) state five, (f) state six, (g) state seven.

Fig. 7 shows simulated current distributions associated with the proposed antenna. The figure illustrated the current distributions at three different frequencies. Fig. 7(b) indicates that the current flows mainly along the longest arm at low frequency. At the middle range frequency; the current flows predominantly along the middle arm as shown in Fig. 7(c) whilst the high frequency current is concentrated along the shortest arm and shown in Fig. 7(d).



(a)



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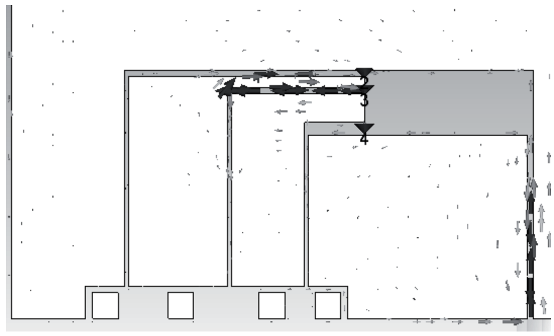

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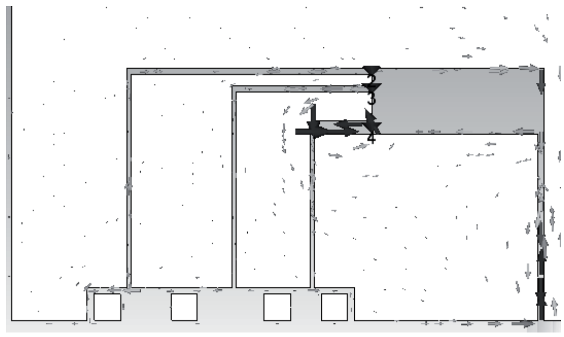

(d)

Fig. 7. Simulated current distribution for state seven (a) overall view at 2.4 GHz; zoom in view (b) at 2.4 GHz, (c) at 3.5 GHz and (d) at 5.2 GHz.

Fig. 8 shows the measured radiation patterns corresponding to the single-band and triple-band of operations. Fig. 8(a), Fig. 8(c) and Fig. 8(e) shows the x-z plane radiation patterns, while Fig. 8(b), Fig. 8(d) and Fig. 8(f) shows the y-z plane radiation patterns. The patterns were obtained at 2.4 GHz, 3.5 GHz, and 5.2 GHz. These results indicate that radiation patterns corresponding to different states but the same frequency are quite similar in terms of their shape. It is worth noting that the flexible wires, attached to the edge of the board, affected the radiation pattern especially at high frequency if they are scattered.

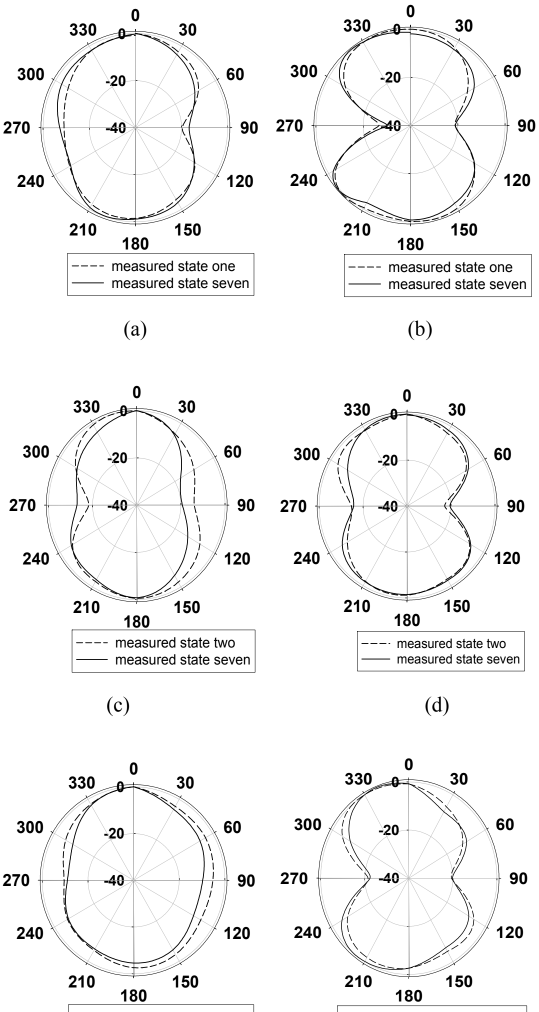

Fig. 8. Measured radiation pattern of the antenna: state one and seven at 2.4 GHz: (a) x-z plane, (b) y-z plane, state two and seven at 3.5 GHz: (c) x-z plane, (d) y-z plane, and state three and seven at 5.2 GHz: (e) x-z plane, (f) y-z plane.

Fig. 9 shows the measured gain, as a function of frequency, for states: one, two (single-band), five (dual-band), and seven (triple-band). The gain was measured in the 0° direction of x-z plane. From the graph, the passband gains for single and dual-band operation are seen to be comparable with those for triple-band operation. The measured passband gain for state one is 1.58 dBi while that for state two is 3.00 dBi. The curve for state five is shown in Fig. 9(c). The measured gains are seen to be 1.52 dBi and 2.00 dBi at the centers of the low and high frequency passbands, respectively. For state seven, the measured gains are 1.53 dBi, 2.83 dBi and 1.78 dBi at the centers of the low, middle and high frequency passbands, respectively.

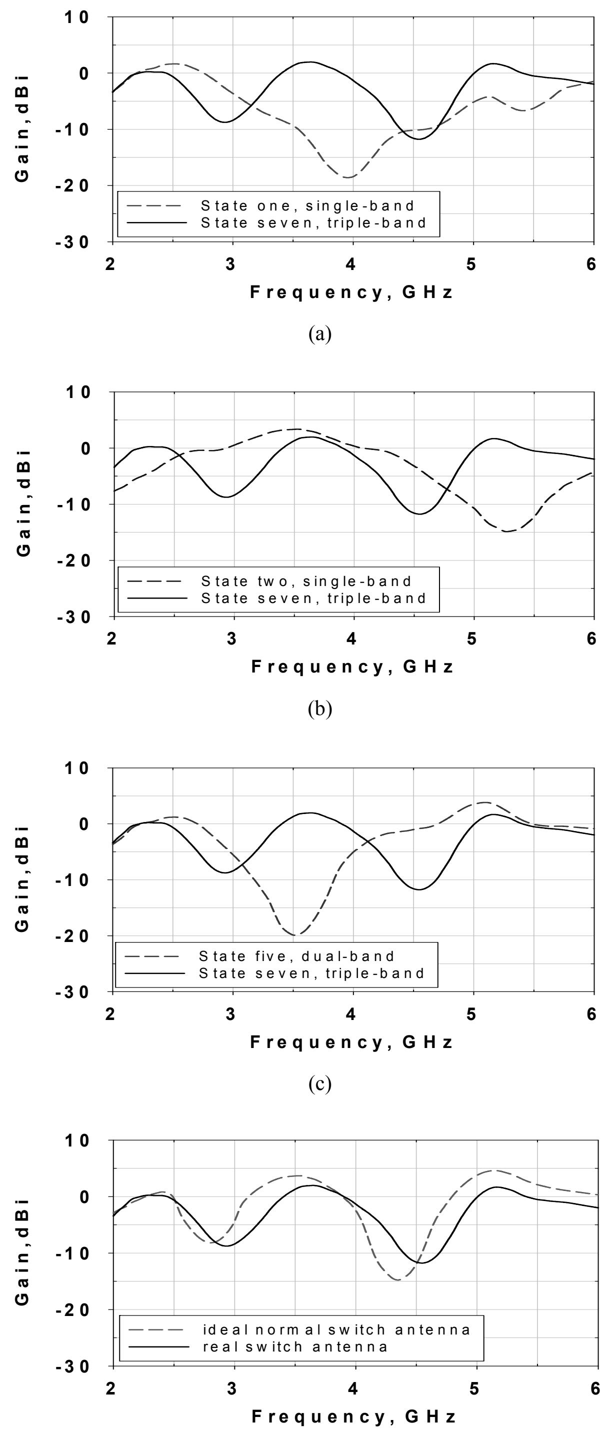

Fig. 9. Measured gain of the antenna: (a) state one and state seven, (b) state two and state seven, and (c) state five and state seven, (d) ideal and real switch.

Tab. 3 provides a summary of the gain measurement data. The effects of the pin-diode switches can be analyzed by comparing the gain performance of the proposed antenna with that of an antenna incorporating hardwired switches (i.e. idealized switches) as shown in Fig. 9(d). It is observed that the use of pin-diodes degrades the gain slightly, as one would expect.

State	Measured gain, dBi		
	Low band	Mid band	High band
1 (pin-diode)	1.58	-	-
2 (pin-diode)	-	3.00	-
5 (pin-diode)	1.52	-	2.00
7 (pin-diode)	1.53	2.83	1.78
Ideal switch	2.87	3.24	4.11

Tab. 3. Summary of gain measurement result.

4. Conclusion

This paper presents a design for novel frequency reconfigurable antenna. It is shown that frequency reconfigurability can be achieved by switching in and out selected pairs of dipole arms within the antenna. A prototype of the antenna was fabricated. This prototype incorporates pin-diode switches. The design was validated by comparing simulated and measured results. The flexibility to have different operating frequencies makes the proposed antenna suitable for use in electronic devices which must operate within multiple frequency bands.

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