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A Pattern Reconfigurable Antenna for WLAN and WiMAX Systems

Santasri Koley, Lakhindar Murmu, and Biswajit Pal

Abstract—A novel tri-band pattern reconfigurable planar antenna is proposed. Tri-band is achieved by inserting a bandstop filter at the feed line of a wideband monopole antenna with complementary split ring resonator (CSRR) on a circular patch. Two parasitic arc-shaped stubs are in the back side of the radiator that works as a reflector. The antenna radiation pattern is switched from omnidirectional to one of two different directional modes by activating one of the stubs. Three different radiation modes are controlled by four ideal switches. Radiation pattern reconfigurability makes it suitable for the use of flexible cognitive radio front-end system. The proposed antenna is suitable for WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz applications. Good agreement between simulated and measured results validates its possible application.

1. INTRODUCTION

Two different air interface standards for wireless access to telecommunication core network have recently become very popular. The first standard is for wireless LAN (WLAN) that certifies network devices to comply with the IEEE 802.11 standard. The second standard is for wireless MAN (WMAN), called Worldwide Interoperability for Microwave Access (WiMAX) that promotes conformance and interoperability of the IEEE 802.16 standard. Recently, many multiband antennas have been reported, which cover WiMAX and WLAN bands [1–4].

However, efficient utilization of such bands is very crucial as it rapidly becomes more crowded. It can be solved by pattern reconfigurable antennas which can increase spectrum utilization by dynamically adopting their parameters to the system requirements and surrounding environment. In reconfigurable antennas, radiation pattern can be shaped to concentrate the main beam to the desired direction and minimize the unwanted beam in other directions. Therefore, multipath propagation fading can be mitigated, and directional gain will increase [5].

Many pattern reconfigurable antennas have been reported in literature [5–16], such as a corner reflector antenna for single band [6], dual-band [7, 8] and compact structures that can provide different directional radiation patterns using electronic switches for single band [9–12], wideband characteristics [13, 14]. A pattern reconfigurable antenna that has multiband characteristic in WLAN and WiMAX bands can improve the whole system performance. However, few published designs have discussed pattern reconfiguration of multiband antennas in the dense unlicensed WLAN 2.4/5.2/5.8 and WiMAX 3.5/5.5 bands. In [7, 8], pattern diversity antennas are designed in WLAN and WiMAX systems. However, the antennas are fairly complex as they have many corner reflectors and make them impractical to be used in modern devices. ultra-wideband (UWB) pattern reconfigurable antennas [13, 14] can cover all WLAN and WiMAX bands, but frequency interference cannot be avoided. In [15], a dielectric resonator antenna is designed for only two frequencies of 3.5 and 5.2 GHz. However, no such pattern reconfigurable antennas [5–16] have been implemented, which cover all the WLAN and WiMAX bands.

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* Corresponding author: Santasri Koley (santasrikoley27@gmail.com).
The authors are with the Department of Electronics Engineering, Indian School of Mines, Dhanbad 826004, India.

In this paper, a simple novel tri-band pattern reconfigurable planar antenna is presented for all WLAN and WiMAX bands. Multiband is achieved by notching the undesired frequency bands of a circular disk UWB monopole antenna which operates from 2.5 to 7.28 GHz. Quarter-wavelength open stubs were introduced to the feed line of the antenna to stop wide undesired frequency from 4 to 5 GHz. By introducing a slot-type ring resonator on the radiating patch, some frequency band is notched at 3 GHz, and finally a tri-band antenna is realized. The proposed antenna radiation pattern is switched from omnidirectional to one of two different directional modes by using arc-shaped stub reflectors, as in [13]. The antenna is simulated and optimized using time domain solver of CST Microwave StudioTM. The proposed antenna is designed on a 40 40 mm^2 low-cost FR4 substrate with thickness of 1.6 mm, dielectric constant of 4.4 and loss tangent of 0.02. The designed antenna is suitable for WLAN 2.4 (2.4–2.484 GHz), 5.2 (5.15–5.35 GHz), 5.8 (5.725–5.825 GHz), and WiMAX 3.5 (3.3–3.69 GHz), 5.5 (5.25–5.85 GHz) band applications. The simulated results of impedance bandwidth, radiation pattern and realized gain of the designed antenna are validated experimentally.

The paper is organization as follows. In Section 2, antenna design principle is described, and Section 3 discusses the experimental results. The paper is concluded in Section 4.

2. ANTENNA DESIGN PRINCIPLE

The topology of an open stub bandstop filter is shown in Figure 1. A quarter-wavelength resonator is tapped into 50 Ω microstrip line. A bandstop filter with transmission zero at 4.5 GHz is achieved for the single open stub, depicted as type 1 in Figure 2. By mounting two open stubs onto a microstrip, a wider rejection bandwidth with transmission poles is achieved, as shown in Figure 2 (type 2). The length and the separation between the two stubs are a quarter of the wavelength at the resonant frequency. To enhance the selectivity of the bandstop filter, a modified bandstop filter is used, indicated as type 3 in Figure 1. It will result in the moving of transmission poles towards transmission zero thus sharps the selectivity.

A UWB microstrip antenna consisting of a circular monopole patch of 10 mm, with a 10 dB return

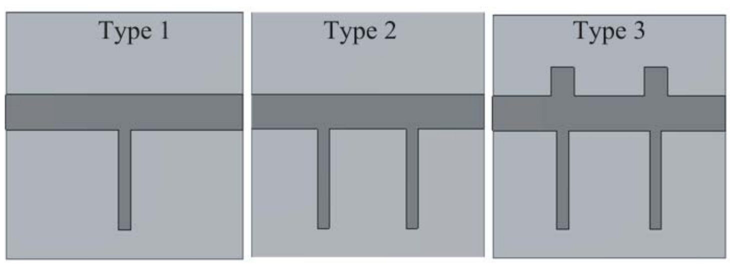


Figure 1. Topology of open-stub bandstop filter.

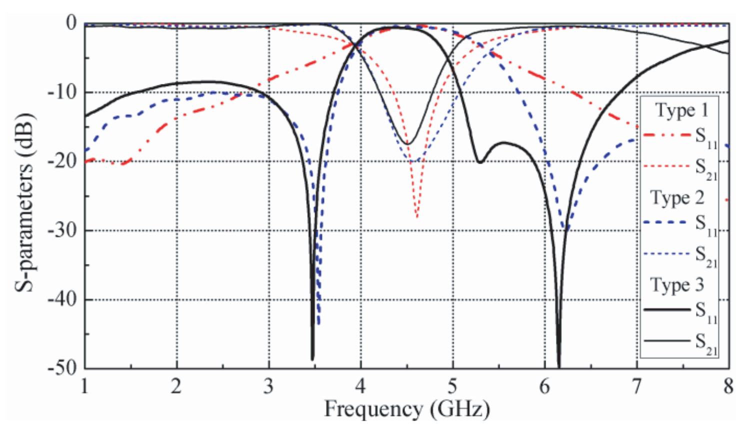


Figure 2. Simulated S-parameters of open-stub bandstop filters.

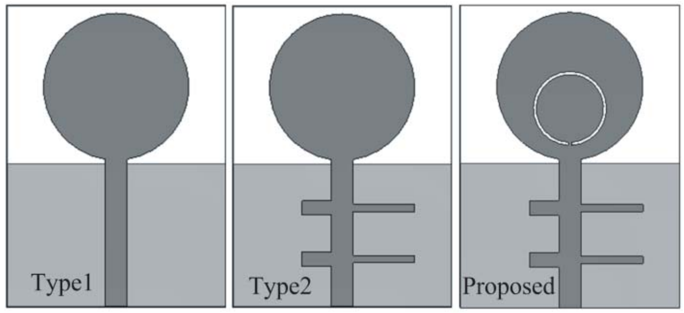


Figure 3. Step-wise evolution of the proposed antenna.

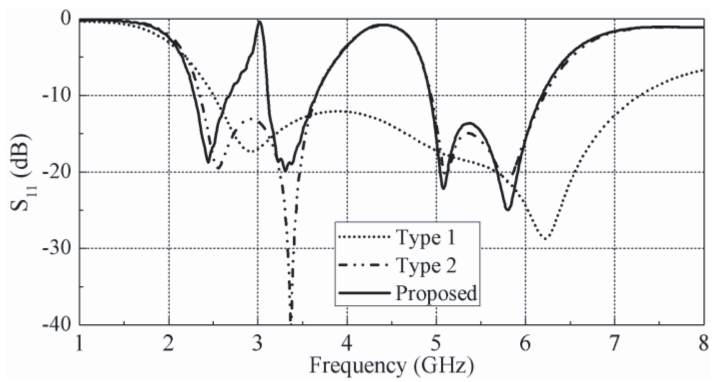


Figure 4. Simulated returned loss results for the step-wise evolution of the proposed antenna.

loss bandwidth from 2.5 to 7.28 GHz has been chosen as a basic structure, as shown in Figure 3 (Type 1). By placing the modified open-stub bandstop filter in the feed line of the UWB antenna (Type 2), a wide bandwidth is notched from 3.7 to 4.95 GHz. The simulated result is shown in Figure 4 as Type 2. A complementary split ring resonator (CSRR) structure can be used for band-notched operation [16]. The undesired frequency band at 3 GHz is notched by introducing a CSRR into the circular patch of the antenna, as indicated by the proposed antenna in Figure 3. Thus, a tri-band antenna is achieved which covers WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz bands.

The electric field distributions of the proposed antenna have been plotted in Figure 5 at frequencies of 2.4, 3, 4.5, and 5.5 GHz to understand the effect of the designed triple-band antenna. It is seen that at 2.4 GHz and 5.5 GHz, electric field is mainly distributed on the edges of the radiating patch as shown in Figures 5(a) and 5(d), respectively. Thus, the antenna radiates at this frequencies. As indicated in Figure 5(b), the electric field distribution becomes more concentrated on the CSRR of the patch at

Table 1. Optimized dimensions of the proposed antenna.

Dimension	(mm)	Dimension	(mm)	Dimension	(mm)
L	40	W_1	2	d	0.5
L_g	17.5	W_2	1	p	5
L_s	18.5	W_f	3	g_s	9.5
L_1	4	S	7	g_c	3
L_2	8.5	R_D	17	g_v	0.5
W	40	R_1	5	g_1	2
W_s	0.5	R_2	4.5	-	-

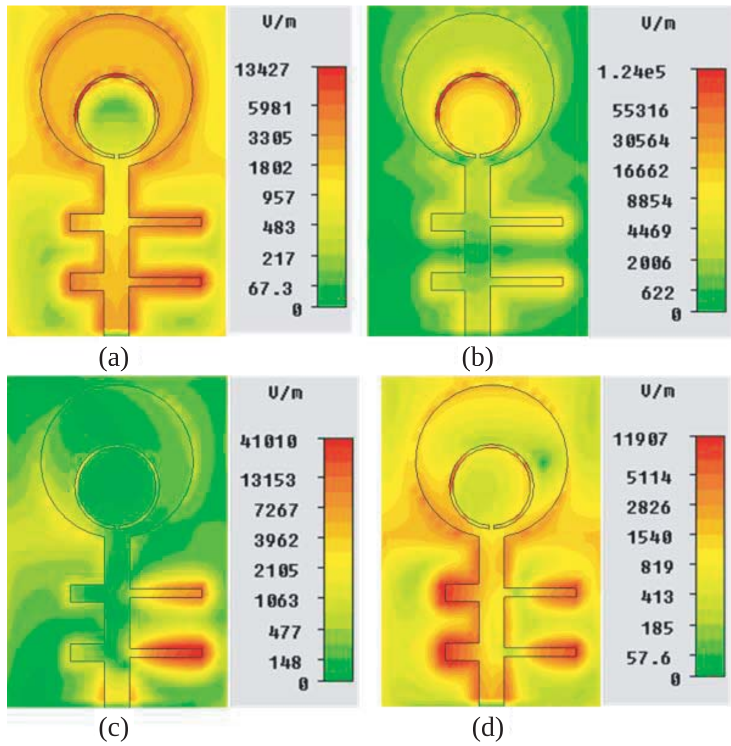


Figure 5. Simulated electric field distributions for the proposed antenna, (a) 2.4, (b) 3, (c) 4.5 and (d) 5.5 GHz.

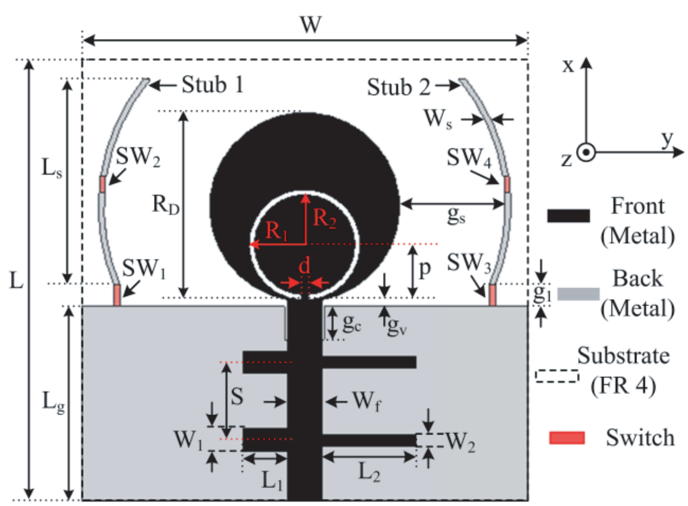


Figure 6. Geometry structure of the proposed pattern reconfigurable antenna.

3 GHz. So, it is effective to generate a notch at about 3 GHz. Results in Figure 5(c) show that electric field is denser on open-stubs of the feed line. It is revealed that the wide stopband from 4 to 5 GHz is achieved using the open-stubs mounted on the microstrip feed line.

The proposed antenna shown in Figure 3 has partial ground plane and gives omnidirectional radiation pattern. To make the pattern reconfigurable, two parasitic arc-shaped stubs are designed in the back side of the circular patch that works as a reflector. The antenna radiation pattern is switched from omnidirectional to one of two different directional modes by activating one of the stubs. These reflectors will be connected to the ground plane by activating the electronic switches. The final model of the proposed pattern reconfigurable antenna is shown in Figure 6. A rectangular slit in the middle of the upper edge of the ground plane is made for proper impedance matching at the higher frequency band. The detailed optimized dimensions of the antenna are presented in Table 1. When switches SW1 and SW2 are ON, and SW3 and SW4 are OFF, stub 1 will be activated, and the antenna will operate in Mode 1. If switches SW1 and SW2 are OFF, and SW3 and SW4 are ON, stub 2 will be connected to ground, and the antenna will be reconfigured to Mode 2. Antenna will operate in Mode 0 when all the switches are in OFF state. Prototypes of the fabricated antennas are shown in Figure 7.

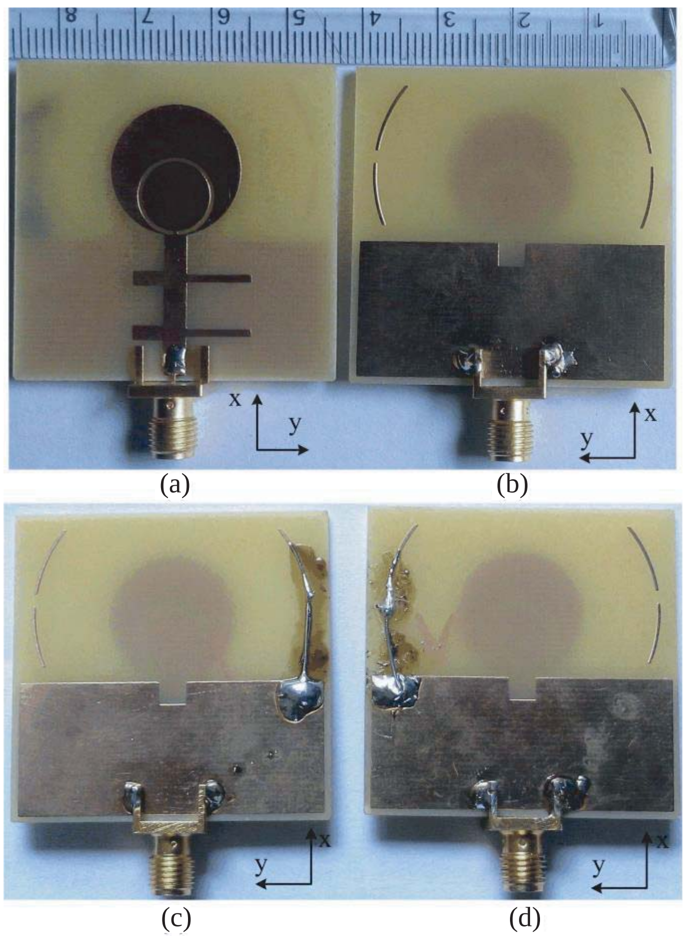
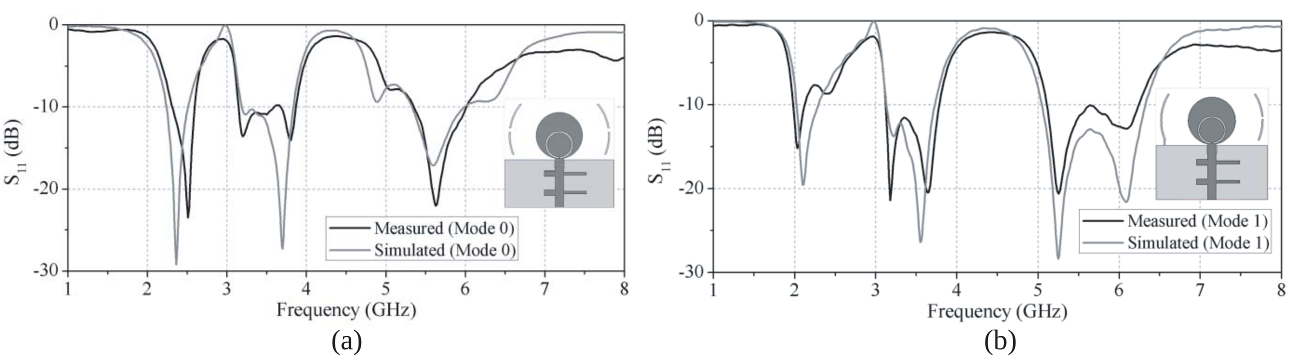
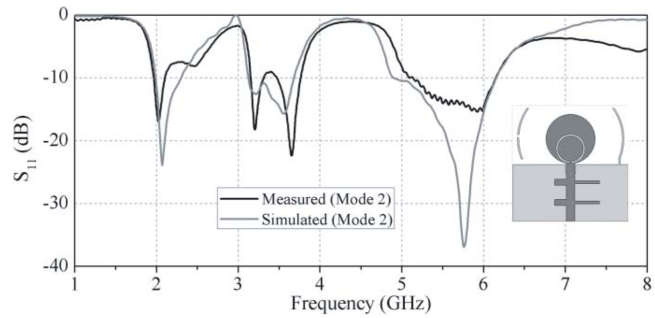


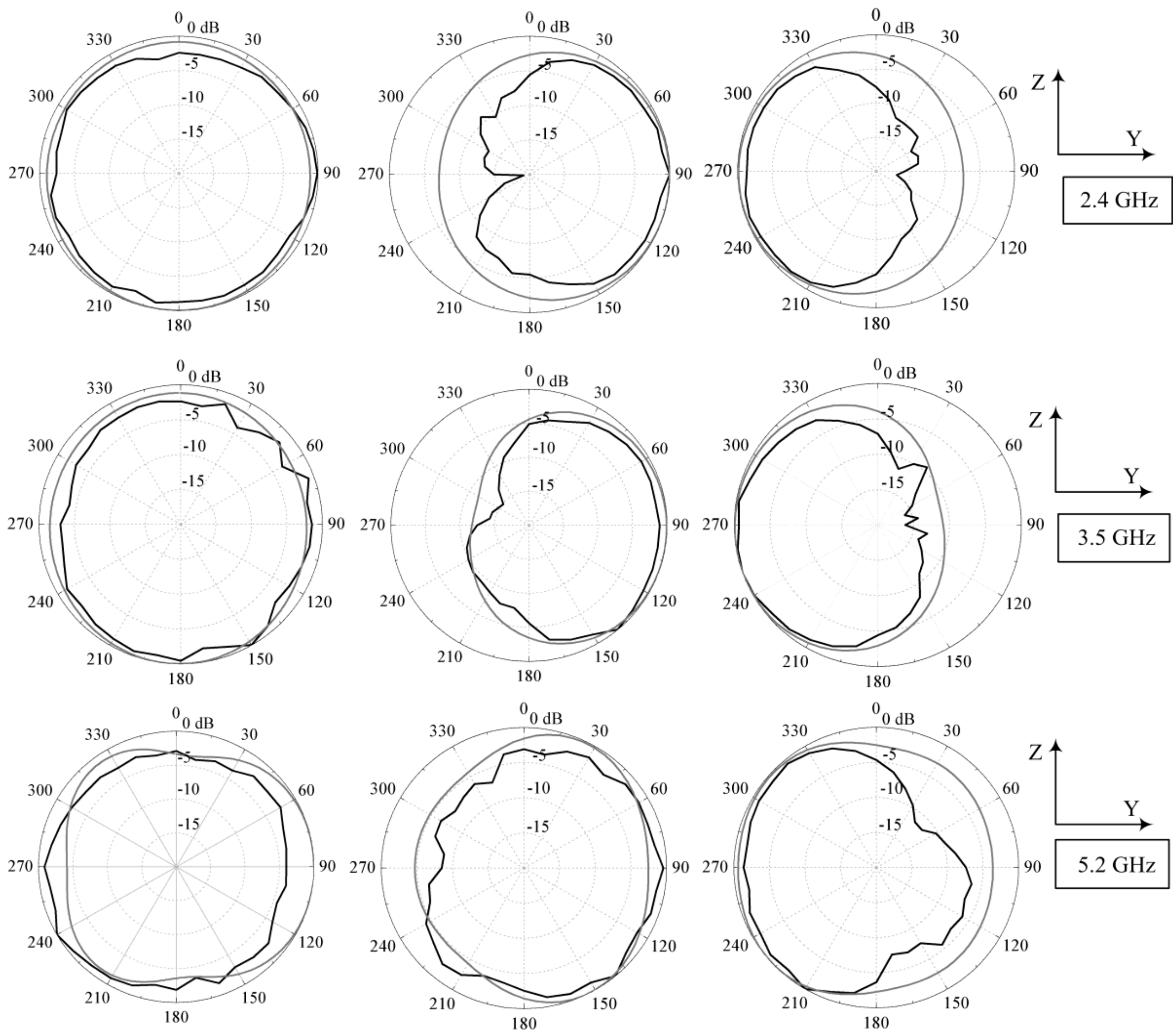
Figure 7. Prototype of the optimized antennas: (a) Top View, (b) bottom view at mode 0, (c) bottom view at mode 1, (d) bottom view at mode 2.





(c)

Figure 8. Simulated and measured return loss of the proposed antenna: (a) Mode 0, (b) Mode 1, (c) Mode 2.



(a) (b) (c)

Figure 9. Measured (black curves) and simulated (grey curves) normalized radiation patterns in the H-plane when the antenna is operating in: (a) Mode 0, (b) Mode 1, and (c) Mode 2.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The return loss is measured by using Agilent Keysight PNA Network Analyzer N5221A 10 MHz–13.5 GHz and compared with simulated results as shown in Figure 8. The simulated results show good agreement with the measured ones for all three operating conditions. The slight difference between them is due to connector and manufacturing tolerances. It is clearly shown that length of the stub affects the impedance bandwidth at 2.4 GHz and is slightly shifted to the left in Mode 1 and Mode 2.

The simulated and measured normalized radiation patterns in the H-plane of the proposed antenna are shown in Figure 9 at frequencies of 2.4, 3.5, and 5.2 GHz. The results show that the antenna has an omnidirectional radiation pattern in Mode 0 for all three test frequencies. When the antenna operates in Mode 1 condition, it activates stub 1, and radiation beams are concentrated away from the reflector in the $+y$ direction. In Mode 2, the radiation pattern is reconfigured in $-y$ direction. The measured antenna gain is shown in Figure 10 for all three operating modes. As the powers are directed in Mode 1 and Mode 2, the realized gain increases compared to Mode 0.

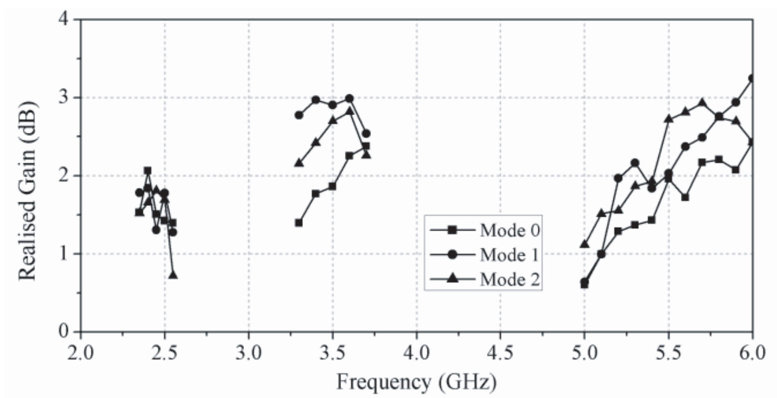


Figure 10. Measured realized gain of the proposed antenna.

4. CONCLUSION

This article discusses a pattern reconfigurable tri-band antenna. The proposed antenna is of small size, low profile and covers WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz bands. By activating the parasitic reflectors, the antenna becomes flexible to be used in cognitive radio applications. The omnidirectional radiation pattern is useful for cognitive radio sensing purposes, where the directional modes are to be used for communication in a particular direction.

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