A reconfigurable switching diode loaded patch antenna for S, C, X, Ku, and K bands applications

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ABSTRACT

A reconfigurable patch loaded via a switching radio frequency (RF) diode has been designed, investigated, and fabricated. The fabricated microstrip is able to adjust among several frequencies. A spectrum analyzer is used to test and measure different modes of operations. The proposed antenna is offered a new solution of uncomplicated and incomplex design via eliminating the biasing circuit while maintaining the finest performance. Two fast-switching diodes have been inserted as a new electrical reconfiguration technique. Thus, the suggested antenna is skilled to function in different bands. An ultra-small size antenna of 31×21 mm^2 has offered various operating frequencies such as S-band at 2.4 GHz, C-band at 4.97 GHz, 5.06 GHz, 5.18 GHz, 5.1 GHz, and 7.94 GHz, X-band at 10.73 GHz, 10.91 GHz, and 11.9 GHz, Ku-band at 13.52 GHz, 14.78 GHz, 14.97 GHz, 15.63 GHz, 16.4 GHz, 17.3 GHz, and 17.48 GHz, and K-band at 19 GHz. The manufactured reconfigurable patch antenna is proficient for several wireless technologies for instance industrial scientific medical band (ISM): Bluetooth, wireless-fidelity (Wi-Fi), ZigBee, internet of things (IoT), WiMAX, and smart power meters. Also, long term evolution (LTE), 5G applications, fixed wireless systems (FWS), and satellite communication applications.

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1. INTRODUCTION

An antenna is the eye and ear of any wireless communication system. It's talented to create a connection between any qualified devices remotely. As a fact, there is much necessity for mobility and compatibility within wireless technologies. Thus, the antenna design has been carried out in a substantial number of researches. The reconfigurable patch antenna has the exclusive capability to adjust frequency, pattern, and polarization properties to meet certain demands [1].

An electrically reconfigurable technique is used to deliver the reconfigurable microstrip antenna its unique ability [2]. This method is accomplished by using radio frequency (RF) switches such as PIN diode, radio-frequency microelectromechanical system (RF-MEMS), and varactor diode [3]. In addition, a frequency-reconfigurable antenna is widely adopted due to support for several operating frequencies (various supporting applications) [4]. A fast-switching diode is a newly used in electrically reconfiguration method in this research to make our fabricated antenna support many wireless applications. Many researchers have conducted the design of the reconfigurable antenna. Dildar *et al.* [5] presented a frequency-reconfigurable microstrip that works in five modes using four PIN diodes. Nine different bands have been obtained from the designed antenna with a marginally large size and limited antenna gain. George and Lili [6] have shown frequency and polarization reconfigurable microstrip via ten PIN diodes. A complicated biased circuit that functions all the PIN diodes has been found which offered only five frequency bands but with a good capability of polarization. Kumar *et al*. [7] offered a frequency reconfigurable patch that operates in multiband. Three series of PIN diodes have been used. Multilayer substrates (Roger 5880 and air-filled gap) have been found to increase radiation efficiency. Vamseekrishna *et al*. [8] projected 12 PIN diodes-based frequency reconfigurable microstrip for microwave sensing applications. An IoT is controlled all PIN diodes biasing which adds more complexity to the design while giving the antenna the ability to alter the operating frequency.

Ahmad *et al*. [9] presented a compound (frequency and pattern) reconfigurable antenna using eight PIN diodes. The antenna is suitable for sub-6 GHz applications and works on different bands and several main lobe directions. Limited gain and low return loss have been noted under specific functional frequencies. Palsokar and Lahudkar [10] provided a frequency and pattern reconfigurable patch using a PIN diode. Two modes have been noticed with three working bands have been offered by the design. Biasing connection lines are moved away from the structure and a noticeably large-sized antenna has been observed. Ghaffar *et al*. [11] have shown a flexible pattern and frequency reconfigurable microstrip via two PIN diodes. The antenna has two L-shaped added to the patch. Large-sized antenna geometry has been noted. Singh *et al*. [12] have illustrated pattern and frequency reconfigurable antenna. The designed patch has added five PIN diodes with a closed ring resonator (CRR). A low profile, multiple operational frequencies, and a complicated biased circuit have been found. The researches [13]–[18] have used PIN diode to steer the radiation pattern of the constructed antenna to support various wireless applications. Jabber and Thaher [19] presented a frequency-reconfigurable antenna using a PIN diode. Tri-band has been offered to work for cognitive radio applications. Large-sized two ports antenna with no practical manufacture delivered have been distinguished. Edward *et al*. [20] offered frequency reconfigurable with Wilkinson power divider (WPD) via eight PIN diodes. Two bands, limited return loss in some cases, and more complexity have been offered by the fabricated antenna. Tu *et al*. [21] have shown a compound reconfigurable antenna with three PIN diodes. Multiple functioning frequencies (6) with a compact size design has been offered with more complexity due to the biasing circuit of the added PIN diodes. In paper [22]–[25] proposed similar techniques of using PIN diodes for an electrically reconfigurable patch for frequency, polarization, and radiation pattern. The challenges of this research are reduction in the complexity of the antenna design structure related to the biasing circuit and limiting the need for advanced fabrication devices.

2. SUGGESTED ANTENNA DESIGN AND MANUFACTURING

The suggested antenna design geometry is illustrated in Figure 1. The profile of the patch antenna has been optimally calculated. In (1) and (2) [4], [26] have been used to calculate the radius of the circular patch.

$$R = \frac{F}{\{1+\frac{2h}{\pi\varepsilon_r F}[ln(\frac{\pi F}{2h}+1.77726)]\}^{1/2}} \quad (1)$$

$$F = 8.791 \times \frac{10^9}{f\sqrt{\varepsilon_r}} \quad (2)$$

Where R is the radius of the circular microstrip patch, h is the thickness of the microstrip substrate, F is constant, f is the center frequency, and ε_r is the substrate material relative dielectric.

A lossy copper sheet has been used to cover the ground plane of the patch antenna. The thickness is 0.035 mm with a fully ground shape that has been considered and used for peak performance. The proposed antenna structure size was chosen wisely and calculated to be 31×21×0.035 mm. These size dimensions are used for the substrate and the ground plane. The substrate material is flame retardant (FR-4) which has a relative permittivity of 4.2 and 1.6 mm of thickness. In addition, higher frequencies make the FR-4 struggle to function well, especially beyond 5 GHz [4], [26]. Thus, we have carried out a solution with a fully ground plane geometry that makes the current flow much easier along the surface of the patch. Consequently, our antenna design has functioned successfully even at much higher frequencies. On the other hand, complex calculations have been noticed while designing any circular patch antenna [4], [26]. While our microstrip antenna design has limited the complexity and sustained ultimate antenna performance. A ring with 1 mm in size and has a radius of 9.93 mm from the center point of the patch. The outer ring was followed by another ring 1 mm in size with a 7.93 mm radius from the antenna center. The gap between the two rings is 1 mm in size. The inside circular patch antenna has a diameter of 4.5 mm at the center. The feed line is (3.6×4.8) mm in size that connected with the outer ring directly. The feed line width has been calculated widely using (3) [4], [26]:

$$W_f = \frac{7.48\times h}{e^{\left(z_o\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}-1.25\times t} \quad (3)$$

Where W_f is the width of the feed line, z_o is the impedance, and t is the thickness.

A reconfiguration is a technique that makes the antenna has the ability to change its parameters. An electrical reconfiguration is widely adopted due to the capability of varying the frequency, polarization, and pattern of antenna performance. The electrical reconfiguration is set using a switching radio frequency (RF switch). RF microelectromechanical system (MEMS), PIN diode, and varactor diode are the common types of RF switches which been used for reconfiguring the microstrip antenna. All these switches need biasing circuits. The biasing circuit adds more complexity to the antenna design. An extensive literature survey has been carried out to eliminate the need for biasing circuits by replacing the RF switch (MEMS or PIN or varactor) with a switching diode. A new fast-switching diode has been used without any biasing circuit which removes complexity and reduces the fabrication process and charge. Two fast switching diodes 1N418W [27] are adopted in different modes and used using an external circuit connected with the patch antenna directly. This method helps to eliminate the need of using a highly cost instrument to print very tiny RF switches to the microstrip antenna. Table 1 illustrates four modes of two switching diodes of the proposed electrically reconfigurable microstrip antenna.

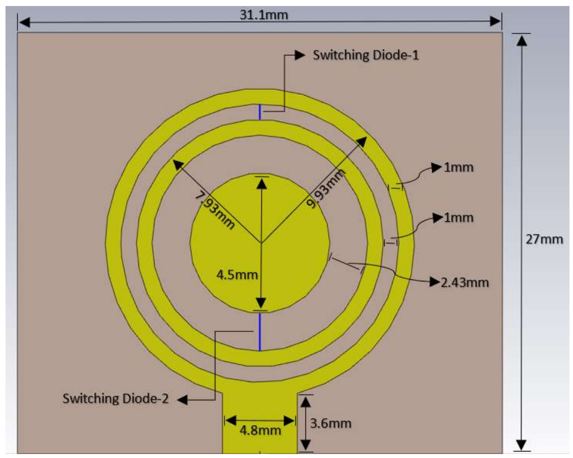

Figure 1. The geometry of the suggested antenna

Table 1. The modes, values, and states of the switching diode

Mode	Diode state	Value
1	Diode-1 off diode-2 off	1 ohm and 4 PF
2	Diode-1 on diode-2 off	1 ohm and 4 PF
3	Diode-1 off diode-2 on	1 ohm and 4 PF
4	Diode-1 on diode-2 on	1 ohm and 4 PF

Switching diode-1 is placed between the two outer rings in the top center allowing more freely current surface to follow along feedline reaching the patch ring. Switching diode-2 is added between the second ring and the center circular patch in the bottom following the same idea. Figure 2 demonstrate the manufactured antenna while testing.

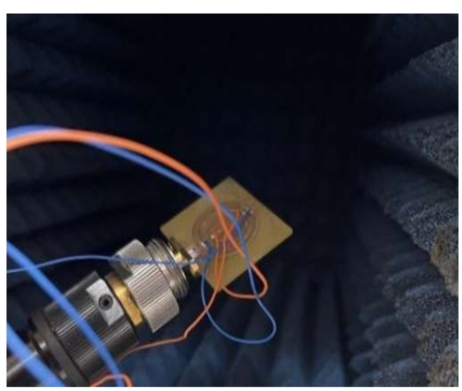

Figure 2. The manufactured reconfigurable antenna

3. RESULTS AND DISCUSSION

There are four modes of operation that have been practically tested via a vector network analyzer (VNA). Mode-1 is tested when switching diode-1 is removed from the external circuit (switched ON) while switching diode-2 is removed from the external circuit (switched OFF). The functional frequencies of this mode are 5.06 GHz, and 7.94 GHz at C-band, 10.73 GHz, and 11.9 GHz at X-band, and 14.78 GHz, and 17.58 GHz at Ku-band. The return loss of the suggested antenna (S11) for the obtainable frequencies are -30.17 dB, -18 dB, -10.62 dB, -10.58 dB, -27.7 dB, and -10.23 dB correspondingly. Figure 3 demonstrated the reflection coefficient (S11) in dB versus functional frequencies in GHz for mode-1.

In mode-2 the switching diode-1 was added to the antenna fabricated design using an external circuit (switched ON) while keep switching diode-2 was removed. The occupied frequencies under this mode are 4.97 GHz at C-band, and 14.97 GHz, and 17.3 GHz at Ku-band. The S11 obtained under this mode are -17.94 dB, -31.29 dB, and -11.02 dB respectively. Figure 4 illustrated the return loss versus occupied frequencies for mode-2.

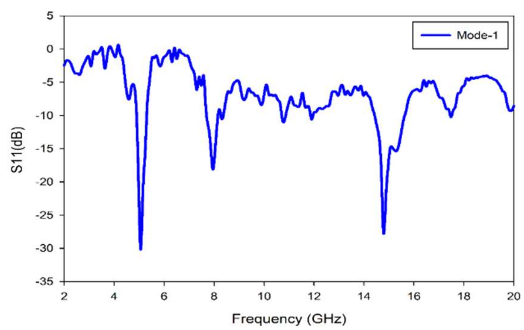

Figure 3. S-parameter (S11) for mode-1

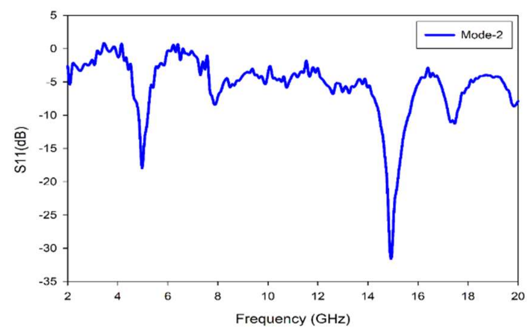

Figure 4. S-parameter (S11) for mode-2

In mode-3 the switching diode-1 was removed and switched diode-2 was added to the manufactured antenna patch (switching diode-1 is OFF, and switching diode-2 is ON). The obtained frequencies under this technique are 2.4 GHz at S-band, 5.1 GHz at C-band, 16.4 GHz at Ku-band, and 19 GHz at K-band. The reflection coefficient of the accessible frequencies are -29.98 dB, -16.73 dB, -30.86 dB, and -12.33 dB respectively. The S11 versus frequency is shown in Figure 5.

In mode-4 both switching diode-1 and 2 are added to the fabricated reconfigurable microstrip antenna (switching diode-1 and 2 are ON). The operative frequencies of this mode are 5.1 GHz, and 7.94 GHz at C-band, 10.91 GHz at X-band, and 13.52 GHz, 15.63 GHz, and 17.48 GHz at Ku-band. The S11 of the reachable frequencies are -18.64 dB, -23.14 dB, -23.84 dB, -15.77 dB, -23.56 dB, and -13.29 dB respectively. The gained S11 versus frequency for mode-4 are presented in Figure 6.

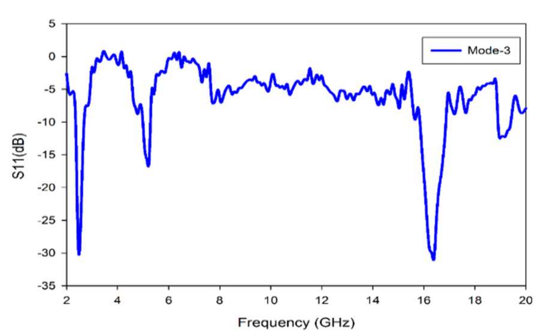

Figure 5. S-parameter (S11) for mode-3

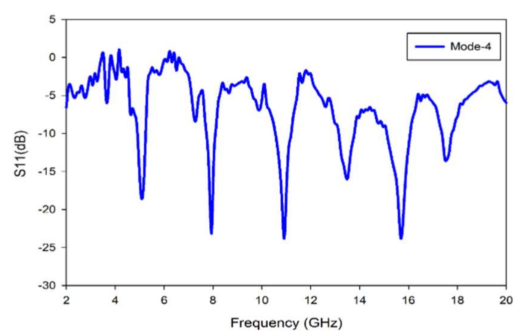

Figure 6. S-parameter (S11) for mode-4

The simulation results of the s11 from the CST is illustrated in Figure 7. The majority of the operating frequencies appeared and meet up with the measured test. While, the minority of the operating frequencies appeared only in the measured test such as: 2.4 GHz, and about 5 GHz. The gain results for all modes of operation are illustrated in Figure 8. The power gain of the proposed antenna is in range between 1 dB reaching around 8 dB which is consider acceptable at certain frequency and excellent at others. Figure 9 presents the radiation pattern of the operating frequencies for the simulated results under all modes of operations.

Table 2 shows an extensive comparison of the proposed manufactured reconfigurable microstrip antenna using a new switching technique with various reported similar research. It is clear to note that our suggested design offers a very compact size with no biasing circuit that eliminates additional complexity that is added to the antenna design. Also, a large number of supporting functional frequencies have been reached using only two fast-switching diodes.

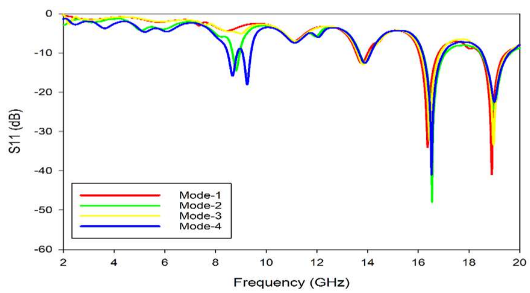

Figure 7. Simulated S-parameter (S11) for all modes

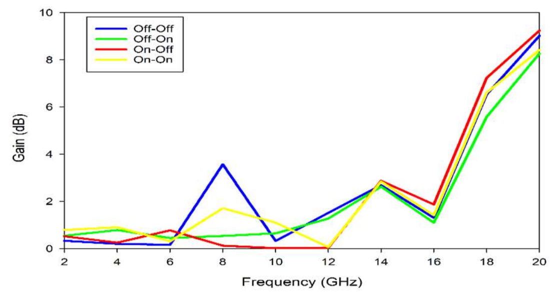

Figure 8. Gain versus frequency for all modes

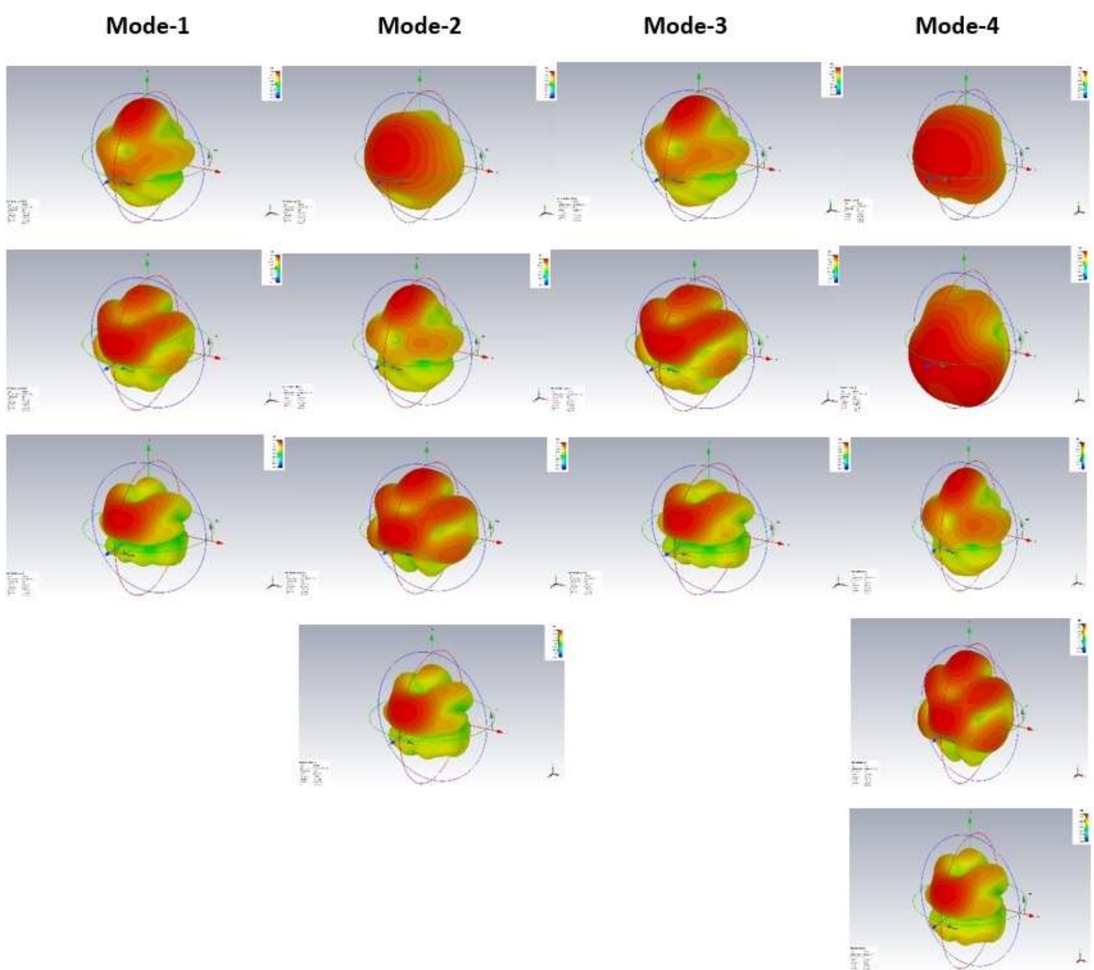

Figure 9. The radiation pattern for all modes

Table 2. A comparison between recently published research and this research

Ref.	Size (mm)	Operating frequency (GHz)	Band	Biasing need	Number of frequencies
[9]	27×30	2.6; 3.5; 4.2; 4.5; 5; 5.5	Single; dual	Yes	6
[10]	58×66	2.47; 3.8; 5.36	Single; dual	Yes	3
[11]	50×40	1.8; 2.1; 2.45	Single; dual	Yes	3
[12]	29×34	1.8; 2.1; 2.2; 2.4; 2.6; 3.5; 4;5	Single; dual	Yes	8
[13]	23×31	3.1; 6.8	Single; dual	Yes	2
[14]	40×50	1.8; 2.1; 2.4	Single; dual	Yes	3
This work	31×21	2.4; 4.9; 5; 5.1; 5.18; 7.9; 10.7; 10.9; 11.9; 13.5; 14.7; 14.9; 15.6; 16.4; 17.3; 17.4; 19	Multi-band	No	17

4. CONCLUSION

A new switching technique based on two fast-switching diodes for frequency reconfigurable microstrip antenna has been created and tested. Four modes have been habited along with small-sized, no biasing needed, and easy manufactured antenna. This design offers a well-designed and straightforward design that eliminates the complexity and advanced production devices. Multi-bands have been offered that are well-matched with modern technologies like; industrial scientific medical band (ISM): Bluetooth, wireless-fidelity (Wi-Fi), ZigBee, internet of things (IoT), WiMAX, and smart power meters. Similarly, long term evolution (LTE), 5G applications, fixed wireless systems (FWS), and satellite communication applications.

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