Defence Science Journal, Vol. 68, No. 6, November 2018, pp. 566-571, DOI : 10.14429/dsj.68.12669

Internet of Things Controlled Reconfigurable Antenna for RF Harvesting

V. Arun* and L.R. Karl Marx#

*Department of Electronics and Communication Engineering, Anna University Regional Campus, Madurai - 625 019, India
#Department of Electronics and Communication Engineering, Thiagarajar College of Engineering, Madurai - 625 019, India
*E-mail: arunece@autmdu.ac.in

ABSTRACT

Internet of Things (IoT) controlled a reconfigurable antenna with PIN diode switch for modern wireless communication is designed and implemented. Direct contact of biasing network with the antenna is eliminated and the switching unit is manipulated through IoT method. The proposed antenna has ring structures, in which the outer ring connects the inner ring structure through a PIN diode switch. The dimension of the proposed antenna is reported as 50 mm × 50 mm and its prototype has been made-up on epoxy-Fr4 substrate with 1.6 mm thickness. This antenna setup is made to reconfigurable in four bands (4.5 GHz, 3.5 GHz, 2.4 GHz, and 1.8 GHz) through switching provided by IoT device (NodeMCU). The antenna has a good return loss greater than -10dB.In switching state 2 the antenna has a return loss of -30 dB peak is attained at 3.4 GHz of operating frequency. Similarly the gain response of antenna is good in its operating bands of all switching states and obtained a maximum gain of 2.7 dB in 3.5 GHz. Bidirectional radiation pattern is obtained in all switching states of the antenna.

Keywords: Reconfigurable antenna; Internet of Things antenna; PIN diode switching antenna; Frequency reconfiguration; RF Harvesting

NOMENCLATURE

Area of the ring structure	a
Antenna frequency	F
FR4substrate thickness	h
Relative permittivity	ε_r
Resonant frequency	f_r

1. INTRODUCTION

Modern communication devices are supported by more than one service and are extensively must for today's communication[1]. Reconfigurable antenna is a perfect entrant to meet such demand in today's communication. Reconfigurable antennas are categories based on: Polarisation reconfigurable[2], pattern reconfigurable[3], and frequency reconfigurable[4]. This reconfigurability is achieved by altering the physical structure of the antenna that is by connecting or disconnecting the radiating elements of antenna structure[5]. Various switching techniques are employed for reconfiguration that are provided by devices such as PIN diode, varactor diode, MEMS switched and photoconductive switches[6]. Reconfigurable antenna design with PIN diode and varactor diode requires external cable connection to provide DC bias to the lumped elements[7]. Though the MEMS switches provides high isolation between the lumped elements and DC biasing circuitry, the switching speed is very low compared to other switching mechanism[8]. Micro-controller switching mechanism makes more time efficient without any human hindrance. The reconfigurability of the Antenna can be controlled by programming the microcontroller[9]. The RF Energy harvesting using the reconfigurable antenna is an uptrend research area. In addition to that energy harvesting this micro controller programmed antenna can auto fit to the remote location for the RF Energy harvesting persistence[5,10]. Dual tone RF harvesting antenna is discussed; it harvests in GSM and UMTSb and. But it's bulky in size due to Yagi antenna array[11]. In these existing techniques the controlling of antenna and switching should done with a manual connectivity to micro-controller. The IoT controlled Reconfigurable antenna eliminates the human assistance and function the antenna switching.

This paper presents the NodeMCU (ESP8266) as a device to achieve the IoT controlled reconfigurable antenna. Also it is employed as a switching element in the PIN Diode.

2. DESIGN PROCEDURE OF RING ANTENNA

The basic shapes of microstrip patch antennas are found to be rectangular[15], triangular and circular. Among these circular/annular ring shape antenna is analysed and found to be simple and better with respect to multiband frequency operation and in placement of feed point[16]. The Antenna has simple monopole ring structure that is fed by microstrip feed line technique with length of 11 mm and width 4 mm. It consists of three layers: The upper radiation patch, the inner substrate that is made up of epoxy-FR4 material of thickness 1.6 mm and the bottom ground plane. The upper and bottom layer of antenna is made up of copper material of thickness 0.04 mm. The inner and outer diameter of the first ring is 34 mm and 38 mm and the

Received : 05 February 2018, Revised : 06 September 2018
Accepted : 10 October 2018, Online published : 31 October 2018

second ring is 22 mm and 26 mm, respectively. Both the rings are connected in the upper side with a square patch of 4 mm × 4 mm. The antenna ground is taken to be 50 mm × 50 mm to allow radiation above and below the substrate is described in the Table 1.

Table 1. Details of length and width of the antenna

Ring antenna (Parameters)	Dimension (mm)
Patch length	50
Patch width	50
Outer ring diameter	38
Inner ring diameter	26
Centre patch diameter	10
Feed length	11
Feed width	4
Ground plane length	50
Ground plane width	50
FR4 Substrate thickness	1.6

The antenna is designed with the help of circular patch antenna dimension equation as follows[12].

$$a = \frac{F}{\left\{1+\frac{2h}{\Pi\varepsilon_r F}\left[\ln\left(\frac{\Pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

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

where a is area of the ring structure and F is antenna frequency. The substrate FR4 thickness and relative permitivity is denoted as h and ε_r correspondingly. After including the fringing effect of the circular patch antenna, the effective radius (a_e) of the patch antenna is derived from the Eqn. (3) as follows,

$$a_e = \left\{1+\frac{2h}{\Pi\varepsilon_r a}\left[\ln\left(\frac{\Pi a}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}} \quad (3)$$

With the assistance of Eqn. (3) the resonant frequency (f_r) of the antenna is derived as per the Eqn. (4)

$$\left(f_r\right)_{110} = \frac{1.8412\nu_0}{2\Pi a_e\sqrt{\varepsilon_r}} \quad (4)$$

The outer ring patch is connected to the inner ring patch with PIN diode D1 and the inner ring is in contact with the center circular patch with PIN Diode D2.

Here in this proposed work SOD323 PIN diodes are used, which provides switching to the reconfigurable antenna. The antenna is simulated using HFSS simulator tool and the switching is provided using Lumped RLC boundary. The detail layout structure of antenna is as shown in the Fig. 1.

The prototype model testing is made with Vector Network Analyser (VNA) of 0 - 18 GHz.

The equivalent circuit of the ring antenna will consist of lumped values of ground, PIN diode and radiating element of ring patch structure. This combined element of ring shaped antenna consists of parallel and series combination of RLC elements. At ON state of this antenna's reconfigurable switching process the capacitance of respective PIN diodes (D1, D2) are getting cancelled.

3. IOT SWITCHING

Switching for this antenna is provided by PIN Diode which is controlled by NodeMCU unit as like the micro-controller switching device[3]. The block diagram for IoT based switching of Ring Antenna with the help of PIN Diode switches is shown in the Fig. 3. The NodeMCU switches the Diodes D1 and D2 as per the software programmed in it.

The Biasing voltage from the NodeMCU can switch on and off the D1 and D2 PIN diodes. Based on the diode switching of

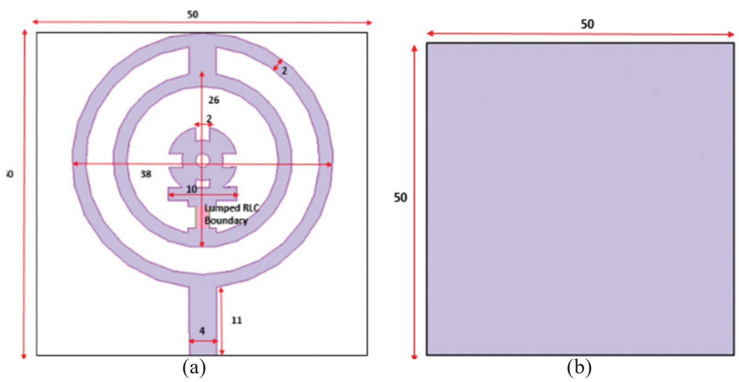


Figure 1. Antenna layout: (a) Top view and (b) Bottom view (all dimensions are in mm).

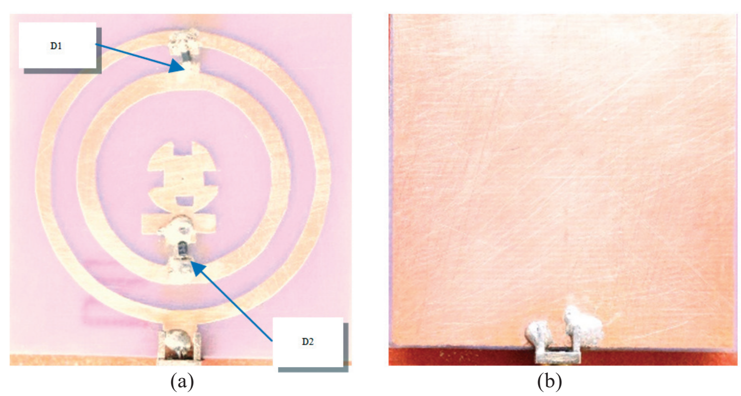


Figure 2. Prototype design of ring antenna with PIN diodes D1 and D2 (a) Front view (b) Back view.

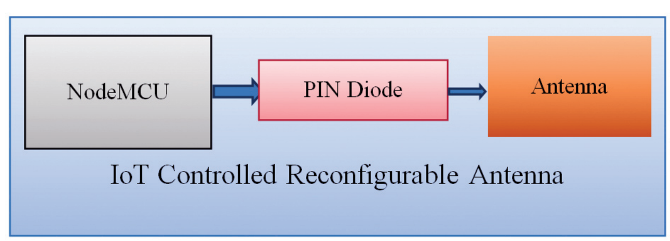


Figure 3. Block diagram of IoT based reconfigurable ring antenna.

ON and OFF, the flow of RF signal through the Ring Antenna is varied and the different band of operating frequencies can be achieved.

The NodeMCU unit itself consists of WiFi based connectivity with the Internet. This combined reconfigurable antenna and NodeMCU unit control, change of program and monitor through World Wide Web. The prototype model of PIN diode embedded Reconfigurable Ring shaped antenna is connected with the IoT device (NodeMCU) is as shown in above Fig. 4.

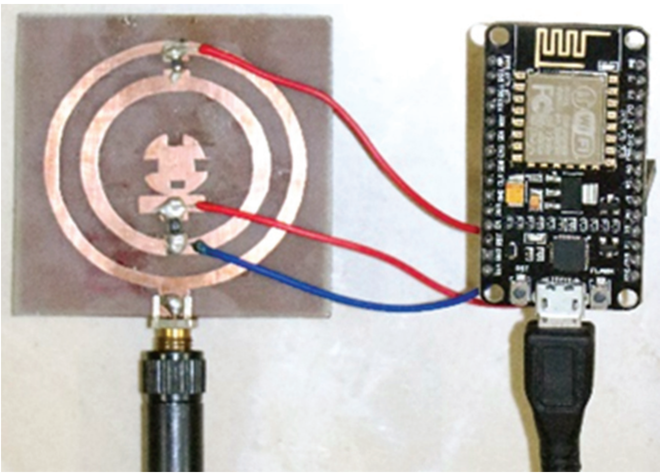


Figure 4. IoT device connected with the ring antenna.

4. RESULTS AND DISCUSSION

The proposed IoT-based reconfigurable antenna is designed and validated using HFSS software. In the experimental measurement PIN diodes used as a switching element and the Prototype antenna results are obtained with VNA. When the D1 and D2 is in off state the antenna operates in the frequency band of 2 GHz to 5 GHz and suitably providing peak response (*fp*) in 4.5 GHz frequency range, this is considered as a state '0' of the antenna and the results are as shown in the Fig. 5(a). In the state '1', the D1 is in on condition while the D2 is remains off condition, and the obtained frequency range of 2 GHz to 3.7 GHz and concentrates on 3.5 GHz band is as shown in Fig. 5(b).

As shown in the Fig. 6(a) the return loss results for stage 3, where the diodes D1 and D2 is in OFF and ON conditions respectively. Here in this state the operating frequency ranges from 1.8 GHz to 3.4 GHz, and it focuses the 2.4 GHz Band. In state 4 both the diodes are in ON condition and the results as shown in Fig. 6(b). In this state the frequency ranges from 1 GHz to 3.7 GHz and it concentrates on the 1.8 GHz band. There is a discrepancy between simulated and measurement results due to switch installation and measuring environment.

The comparison table for the four switching states diode's condition, its working/ resonant frequency range and bandwidth for the appropriate states of the antenna is as given in Table 2.

The radiation pattern in E-plane (i.e. X-Z plane represented in brown colour) and the radiation pattern in H-plane (i.e. Y-Z plane represented in red colour) at 2.4 GHz in OFF state and 3.2 GHz and 4.5 GHz in ON state is revealed in the Figs. 7(a), 7(b) and 7(c). The radiation pattern remains same for all the

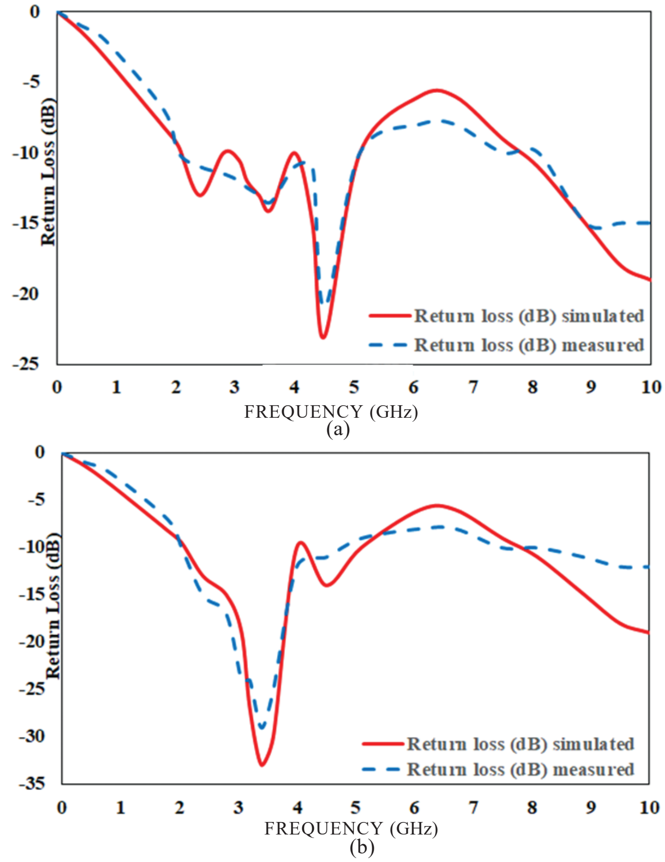


Figure 5. Measured and simulated return loss: (a) state 1 and (b) state 2.

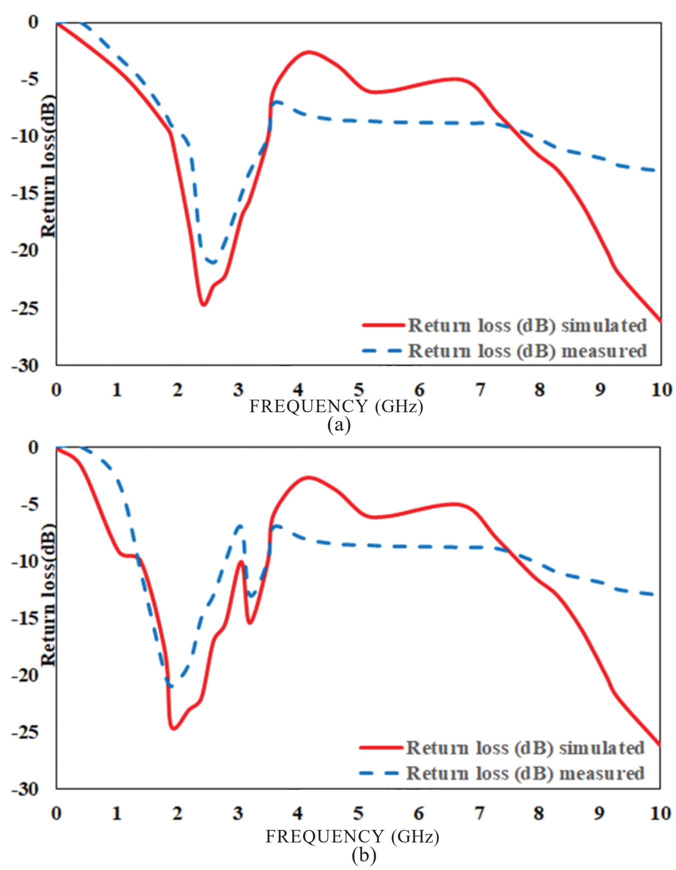


Figure 6. Measured and simulated return loss: (a) state 3 and (b) state 4.

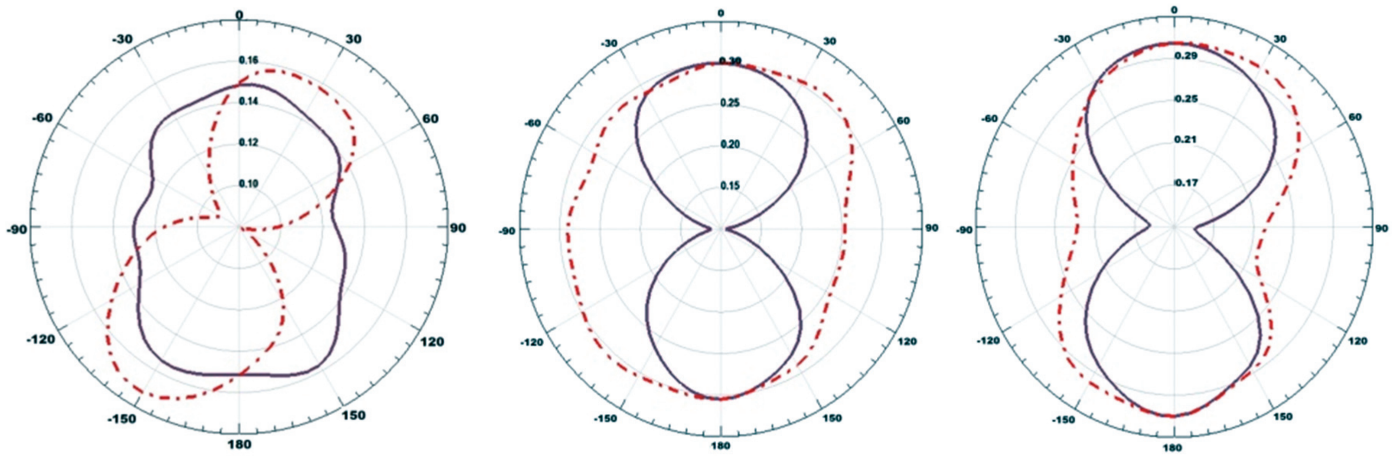


Figure 7. Radiation pattern: (a) state 1, (b) state 3, and (c) state 4.

Table 2. Comparison of Four switching states

Antenna switching states	PIN Diode		Working/ resonant frequency (GHz)	Bandwidth (GHz)
	D1	D2		
0, 0 (state 1)	OFF	OFF	2 - 5 (fp = 4.5)	3
0, 1 (state 2)	OFF	ON	2 - 3.7 (fp = 3.5)	1.7
1, 0 (state 3)	ON	OFF	1.8 - 3.4 (fp = 2.4)	1.6
1, 1 (state 4)	ON	ON	1 - 3.7 (fp = 1.8)	2.7

reconfigured frequencies and bidirectional radiation pattern is obtained in the all switching states of antenna.

The following Fig. 8 shows the cumulative gain plot of the proposed antenna's four switching states. It is inferred that the antenna presents a positive gain in operating frequency bands all the states. In state 1, the maximum gain of 2.5 dB is obtained at the frequency of 4.5 GHz. Similarly, in the state 2 and state 3, a gain of 2.7 dB and 1.9 dB is obtained at 3.5 GHz and 2.4 GHz, respectively. Where, in 4th state a peak gain of 1.6 dB at 1.8 GHz and a moderate gain of 0.7 dB at 3.5 GHz is obtained.

The obtained gain values for the four switching states of the antenna are as given in Table 3. Where, the Fig. 9 shows the current distribution in antenna switching from state 1 to state 4. In switching state 3 (D1-ON; D2-OFF), the majority of the current flow is distributed in the lower side of the circular ring patch antenna. In state 4 (D1-ON; D2-ON) the current in concentrated both in the outer and inner ring of the antenna.

Table 3. Maximum gain obtained at each switching state

Switching states	Peak gain
State 1	2.5 dB at 4.5 GHz
State 2	2.7 dB at 3.5 GHz
State 3	1.9 dB at 2.4 GHz
State 4	1.6 dB at 1.8 GHz

Due to the variation in current distribution different frequency reconfiguration is obtained.

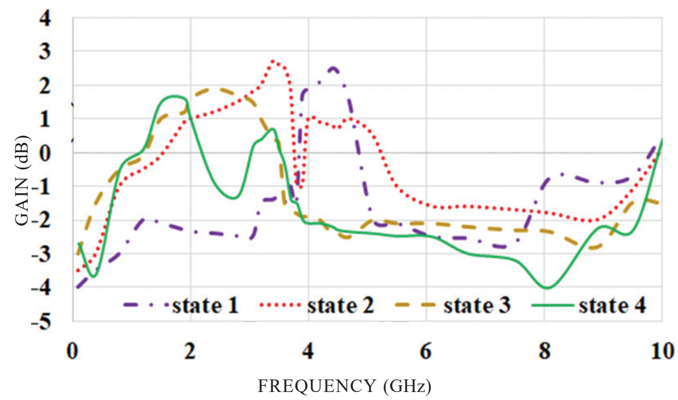


Figure 8. Measured gain plot of the antenna.

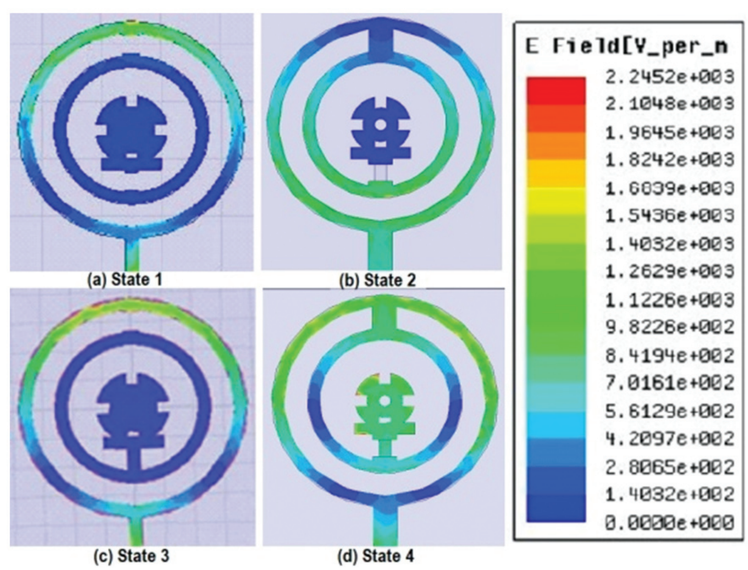
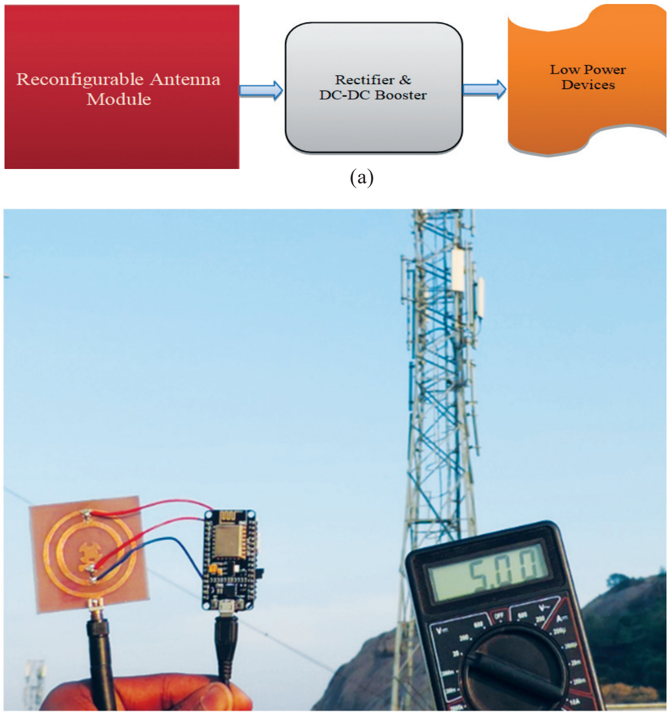


Figure 9. Current distribution :(a) state 1,(b) state 2,(c) state 3, and (d) state 4.

5. RF ENERGY HARVESTING

This Novel experimental setup is made as shown in the Fig. 10 (a) to scavenge the various ranges of ambient RF energy and can act as a permanent energy harvesting resource for the low power VLSI devices.

Compared to the existing harvesting technologies, this



(a)

(b)

Figure 10. RF energy harvesting module: (a) Block diagram of IoT based reconfigurable ring antenna and (b) Testing setup.

proposed IOT controlled reconfigurable antenna module tunes to the appropriate frequency band available in that zone. The complete module has been fixed and tested in the open area of a building terrace in the range of 25 m away from the mobile phone tower (GSM 1800) is shown in Fig. 10 (b). With the help of DC to DC booster (LTC3105) circuit, the harvested energy from the antenna is rectified and boosted. Finally, a constant 5 V output is obtained from this embedded module.

6. CONCLUSIONS

This novel frequency reconfigurable ring antenna with IoT based controlled switch for wireless communication is presented. The importance of these techniques is that the total reconfigurable antenna setup is monitored and controlled from the remote in anywhere worldwide. The switching provided by NodeMCU with PIN diodes (SOD323) has high isolation and also high voltage interference with antenna radiation is eliminated. Switching bands of 4.5 GHz, 3.5 GHz, 2.4 GHz and 1.8 GHz are attained in each states of 1^{st}, 2^{nd}, 3^{rd} and 4^{th} state respectively. This prototype reached a maximum gain of 2.7 dB in 3.5 GHz, 2.5 dB in 4.5 GHz, 1.9 dB in 2.4 GHz, and 1.6 dB in 1.8 GHz. Bidirectional radiation pattern is attained in all condition and shows a positive gain response throughout its operating frequency band. This reconfigurable antenna can work on different wireless standards like GSM 1800, DCS 1900, ISM Band, Wi-Fi, Bluetooth, 4G (LTE), Wi-Max, WLAN and some of Satellite Frequency bands. A constant 5 v is obtained with the RF harvesting module in 1800 MHz band.

REFERENCES

1. Shah, S.A.A.; Khan, M.F. ; Ullah, S. & Flint, J.A. Design of a multi-band frequency reconfigurable planar monopole antenna using truncated ground plane for Wi-Fi, WLAN and WiMAX applications. *In* IEEE International Conference on Open Source Systems and Technologies (ICOSST), 2014, pp. 151-155. doi: 10.1109/ICOSST.2014.7029336
2. Sulakshana, Chilukuri & Lokam Anjaneyulu. Reconfigurable antennas with frequency, polarization, and pattern diversities for multi-radio wireless applications. *Int. J. Microwave Wireless Technol.,* 2017, **9**(1), 121-132. doi: 10.1017/S1759078715000926
3. Zhang, Jian; Yang, Xue-Song; Li, Jia-Lin & Wang, Bing-Zhong. Triangular patch yagi antenna with reconfigurable pattern characteristics. *App. Computational Electromagnetics Soc. J.,* 2012, **27**(11), 918-924.
4. Costantine, Joseph; Youssef, Tawkb & Christos, G. Christodoulouc. Reconfigurable antennas and their applications. *In* Handbook of Antenna Technologies, Springer, Singapore, 2015. pp. 1-30. doi: 10.1007/978-981-4560-75-7_61-1
5. Arun, V. & Karl Marx, L.R. Micro-controlled tree shaped reconfigurable patch antenna with RF-energy harvesting. *Wireless Personal Commun.,* 2017, **94**(4), 2769-2781. doi: 10.1007/s11277-017-3975-z
6. Yang, Xiaofan; Yao, Chen; Longfang, Ye; Manxi, Wang; Min, Yu & Qing, Huo Liu. Frequency reconfigurable circular patch antenna using PIN diodes. *In* IEEE International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2016, **2**, pp. 606-608. doi: 10.1109/ICMMT.2016.7762382
7. Onodera, Shoichi; Ryo, Ishikawa; Akira, Saitou & Kazuhiko, Honjo. Multi-band reconfigurable antennas embedded with lumped-element passive components and varactors. *In* IEEE Microwave Conference Proceedings (APMC), 2013 Asia-Pacific, pp. 137-139. doi: 10.1109/APMC.2013.6695216
8. Christodoulou, Christos G.; Youssef Tawk; Steven A. Lane & Scott R. Erwin. Reconfigurable antennas for wireless and space applications. *In* Proceedings of the IEEE, **100**(7), pp. 2250-2261. doi: 10.1109/JPROC.2012.2188249
9. Genovesi; Simone; Agostino, Monorchio; Michele, Borgese Borgese; Sara, Pisu, & Fabio, Michele Valeri. Frequency-reconfigurable microstrip antenna with biasing network driven by a PIC microcontroller. I*EEE Antennas Wireless Propag. Lett.*, 2012, **11,** 156-159. doi: 10.1109/LAWP.2012.2185673
10. Pal, Heena & Choukiker, Yogesh Kumar. Design of frequency reconfigurable antenna with ambient RF-energy harvester system. *In* International Conference On Information Communication and Embedded System (ICICES2016), India, 2016, **2**(1), 1-5. doi: 10.1109/ICICES.2016.7518857
11. Sun, Hucheng; Yong-xin, Guo; Miao, He & Zheng, Zhong.

A dual-band rectenna using broadband yagi antenna array for ambient RF power harvesting. *IEEE Antennas Wireless Propag. Lett.,* 2013, **12**, 918-921. doi: 10.1109/LAWP.2013.2272873
12. Balanis, A. Handbook of antenna theory, analysis and design. Ed. 3. Wiley publications 2010.
13. *Zeroday*. A lua based firmware for wifi-soc esp8266. *Github*.
14. Wiguna, Hari. NodeMCU LUA Firmware : *Hackaday.*
15. Arun, V.; KarlMarx, L.R.; Kumar, Jegadish K.J. & Christy, Vimilitha C. N-shaped frequency reconfigurable antenna with auto switching unit. *Appl. Comput. Electromag. Society J.*. 2018, **33**(6), 710-713.
16. Lee, K.F.; Luk, K.M. &Dahele, J.S. Characteristics of the equilateral triangular patch antenna. *IEEE Trans. Antennas Propag.,* 1988, **36**(11), 1510-1518. doi: 10.1109/8.9698

CONTRIBUTORS

Mr Arun V. received his Graduation and Post-graduation in Electronics and Communication Engineering from Anna University, India, in 2008 and 2010, respectively. Currently pursuing his PhD in Anna University, India. Presently working as an Assistant Professor at Electronics and Communication Engineering Department, Anna University – Chennai, Regional Campus Madurai, India.His research interests include: Reconfigurable antenna and RF microwave communication systems.
In the current study, he designed the novel antenna structure, simulated in HFSS and fabricated the prototype. He programmed the NodeMCU controller for the testing purpose. He performed the RF Energy scavenging in the outdoor testing setup.

Dr L.R. Karl Marx received his BE from Madurai Kamarajar University, India and ME from Thapar Institute of Engineering and Technology, India, and PhD from National Institute of Technology Trichy, India, in 1988, 2000, and 2011, respectively. Presently working as an Associate Professor at Thiagarajar College of Engineering. His research interest includes : Design of actuators, microstrip antennas, microwave sensors, RFID antennas for readers and tags, embedded system.
In the current study, he gave the idea for the design of novel antenna structure, simulation in HFSS and fabrication in the prototype. He also gave the idea for choosing the NodeMCU for controlling and testing purpose. He modelled the outdoor experimental test setup.