N-Shaped Frequency Reconfigurable Antenna with Auto Switching Unit

Arun V. [1], KarlMarx L.R. [2], Jegadish K.J. Kumar [3], and Christy C. Vimlitha [1]

[1] Department of Electronics and Communication Engineering
Anna University Regional Campus Madurai, Madurai, 625019, India
arunece@autmdu.ac.in, cvimilitha@gmail.com

[2] Department of Electronics and Communication Engineering
Thiagarajar College of Engineering, Madurai, 625015, India
lrkarlmarx@tce.edu

[3] Department of Electronics and Communication Engineering
SSN College of Engineering, Kalavakkam, Chennai, 603110, India
jegadishkj@ssn.edu.in

Abstract **─** These days the need for reconfigurable antenna is widely increased in the field of multi band wireless communication. The proposed new design of N-shaped antenna structure consists of two PIN diodes for switching purpose. They are switched automatically by a pre-programmed Arduino microcontroller unit to attain the reconfiguration of four-different bands without changing the physical dimension of the antenna. The four switching bands are 3.5 GHz (WiMAX), 2.46 GHz (WLAN), 1.2 GHz (GPS) and 2.1 GHz (UMTS). It has a center stub with two N-shaped stub carrying PIN diodes. The stubs are connected with a 50ohm microstrip feed line. The measured return loss closely follows the simulation results. Also it exhibits a good impedance matching during the four switching states. The simulation has been done through Ansoft HFSS and measured results are obtained from a Vector Network Analyzer (VNA). The obtained VSWR value lies beneath 2 for all obtained bands. The radiation pattern of the antenna is bidirectional for all the four-switching states.

Index Terms **─** Auto switching antenna, multi frequency, N-shaped microstrip patch antenna, PIN diode antenna, reconfigurable antenna.

I. INTRODUCTION

In recent days, the reconfigurable antenna has been used extensively in the field of wireless communication, satellite communication, radio frequency (RF) devices and radar systems due to its functionality and versatility [1]. Normally a basic patch antenna works on a single or fixed band of frequencies [2]. But restructuring or reconfigurable antenna can work in various operating frequencies [3] and it can be used indifferent wireless applications such as Bluetooth, Wi-Fi, UMTS, GPS and WLAN. Polarization switching, pattern switching, bandwidth switching and frequency switching are the different switching operations performed by reconfigurable antenna [4]. In this paper, the concept of frequency switching is focused at large. For switching the various frequency bands, switches like PIN diodes [5], Varactor diodes [6], and RF MEMS [7] switches are being used.

Reconfigurable antennae with RF MEMS switches have the switching speed ranging from 1-200µsec. This is normally considered as low for most of the applications [8]. Antennae resorted with Varactor diode has variable capacitance due to varying bias voltage and it produces vast tuning ability. The design of biasing network with Varactor diode is in consideration to the reconfigurable antenna design [9]. Most of the reconfigurable antenna is designed with PIN diodes as it provides fast switching. The switching speed ranges from 1-100nsec. The fast switching provides dynamic reconfiguration ability [10] than other switching components. Hence, PIN diodes have been extensively used in reconfigurable antenna design.

In this paper frequency reconfigurable N-shaped antenna has been presented. Here two PIN diodes with an auto switching unit is used to obtain the multiple frequency bands. The frequency reconfiguration is achieved through switching ON/OFF the D1 & D2 diodes which is mounted on the patch. This paper covers six sections, where the Section I gives a common introduction about reconfigurable antenna. Section II describes the design of the proposed antenna and Section III gives the principle of auto switching unit using Arduino UNO board for the proposed N-shaped antenna. It is followed by Section IV, where the simulated and measured results of proposed antenna

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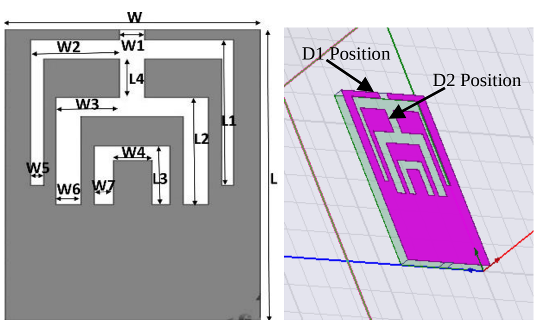
have been briefly explained. Section V carries the comparison of proposed antenna with other factors. Finally, Section VI concludes the paper.

II. PROPOSED N-SHAPEDANTENNA DESIGN

The proposed frequency reconfigurable N-shaped antenna has dimension of 20mm*30mm as shown in the Fig. 1 (a). The antenna has a track width of 4mm all over the patch and it is fed by 50Ω microstrip feed line connected with a standard connector. The antenna's software model has been designed using Ansoft HFSS software and it is shown in Fig. 1 (b). The prototype antenna has been fabricated on FR4 epoxy material of dielectric constant 4.4 with a thickness of 1.6mm. The antenna has a ground plane with dimension as that of patch. The antenna is coated with Tin material as it provides improved frequency reconfigurability. RF PIN diodes namely SOD323 are used for switching the frequency in four different states. In HFSS the PIN diodes are designed with Lumped RLC boundary and it is indicated in Fig. 1 (b) as D1 and D2 position. Two PIN diodes D1 and D2 are mounted on the antenna radiating patches as shown in the Fig. 2 (a), and Fig. 2 (b) shows the ground plane of the antenna. The switching is provided with the help of auto switching unit which consist of a preprogrammed Arduino UNO board.



(a) (b)

Fig. 1. (a) Dimension of tree shaped antenna (all dimensions in mm) [W=20, W1=1.5mm, W2=7mm, W3= 5mm, W4=4mm, W5=1mm, W6=1.8mm, W7=1.5mm, L=30, L1=15mm, L2=12mm, L3=5mm, L4=3mm]; (b) simulation design in HFSS.

The length (l) and width (w) for designing the proposed N-shaped reconfigurable patch antenna is obtained from the following Equations from (1) to (4). The width (w) and effective dielectric constant (ε_{reff}) of the patch can be resolute through the Equations (1) and (2):

$$w = \frac{c}{2f}\sqrt{\left(\frac{2}{\varepsilon_r + 1}\right)}, \tag{1}$$

where c = free space velocity of light, f = resonant frequency, and ε_r = dielectric constant of substrate;

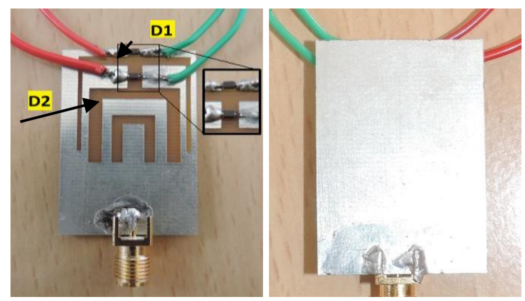
$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2}\frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}}. \tag{2}$$

The extension patch length (Δl) is given by the Equation (3) through which the actual patch length (l) can be calculated from Equation (4):

$$\Delta l = 0.412h\frac{(\varepsilon_r + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_r - 0.258)\left(\frac{w}{h} + 0.8\right)}, \tag{3}$$

where w = width of the patch,

$$l = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta l. \tag{4}$$



(a) (b)

Fig. 2. (a) Fabricated antenna with PIN diodes - front view, and (b) ground plane - back view.

III. AUTO SWITCHING UNIT

The auto switching unit consists of a pre-programmed Arduino Uno board connected with the proposed N-shaped antenna has been shown in Fig. 3. The output of the reconfigurable antenna is connected to the voltage multiplier unit which is designed with LTC3108. The output of multiplier unit is connected to the Arduino board's A_0 pin (Analog I/O port) and ground (GND) pin. The diodes D1, D2 of the proposed N-shaped reconfigurable antenna is connected with the Arduino board's Digital I/O ports 11, 12 respectively.

The pre-programmed Arduino board switches the diodes D1 and D2 consecutively. The received analog signal in the A_0 port is digitized through the inbuilt ADC unit. The diode reaches its next state one by one after 5s delay as per the program. Thus, the diode switching state starts with state 1 (0,1) where the diode D2 in ON and D1 in OFF condition. It is consecutively followed by the other states of PIN diode after every 5s delay as follows; (1,0), (1,1) and (0,0). The switching state of the PIN diodes (D1, D2) is given in the Table 1. In every switching state, the output of the reconfigurable antenna is read by the analog ports and the digitized value is compared with the previous stored value. Finally, the best value for the state where signal of the antenna is strong is selected and that switching state is chosen to remain as the antenna state for the RF harvesting.

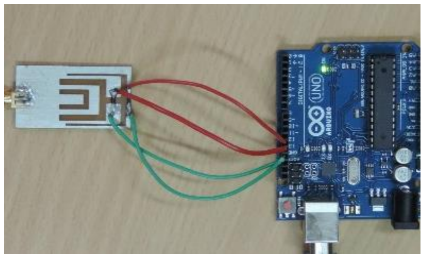


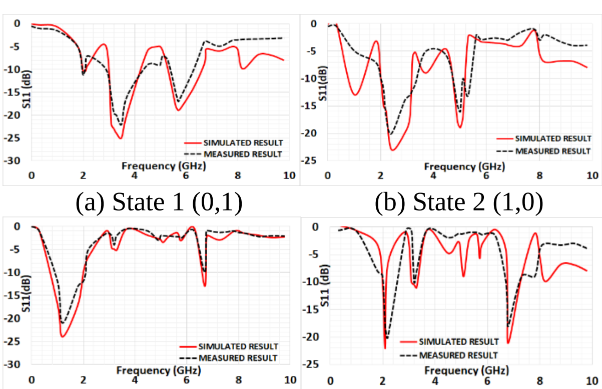
Fig. 3. Auto switching unit with the proposed antenna.

IV. RESULTS AND DISCUSSION

In this section the comparison of simulated result and measured result of prototype antenna has been discussed. The simulation and measured values are obtained through HFSS and VNA respectively. The various antenna parameters for the four switching states of the proposed antenna is presented as follows.

A. Return loss

The return loss for the state 1, state 2, state 3 and null state is shown in the Fig. 4, where the dotted line represents the simulated result and solid line represent the measured result. In state 1 (i.e.) D1 is in OFF and D2 in ON condition. In this state the frequencies of 3.5 GHz and 5.7 GHz are obtained. Thus this state can be used for WiMAX (3.5 GHz) application. The diode D1 is in ON and D2 in OFF represent the state 2. Here the frequency band of 2.4 GHz (Bluetooth) and 5 GHz has been obtained. Similarly, in the 3rd state both the diodes are in ON condition, the frequency of 1.2 GHz is obtained. Finally, in null state (i.e.) both the diodes are in OFF condition. In this state the antenna achieves 2.1 GHz and 6.8 GHz frequency. The frequency attained in state 3 can be used for GPS application and in null state can be used for UMTS application. The difference is attributed between simulation and measured result due the fabrication inacuuracy, effect of the material, PIN diode quality and realization environment. Howerever these results are acceptable.



(a) State 1 (0,1) (b) State 2 (1,0)

(c) State 3 (1,1) (d) Null state (0,0)

Fig. 4. Simulated and measured return loss result.

Table 1: Comparison of various switching states

State	Diode	Operating Frequency
State 1 (0,1)	D1 OFF & D2 ON	3.5 GHZ, 5.7 GHz
State 2 (1,0)	D1 ON & D2 OFF	2.4 GHz, 5 GHz
State 3 (1,1)	D1 & D2 ON	1.2 GHz
Null state (0,0)	D1 & D2 OFF	2.1 GHz, 6.8 GHz

B. VSWR

The Voltage Standing Wave Ratio (VSWR) is obtained in minimum level in the permissible range (i.e.) below 2 for all the four switching condition of the diode D1 and D2. Hence, the simulated and measured result of the N shaped antenna for the null state is shown in the below Fig. 5.

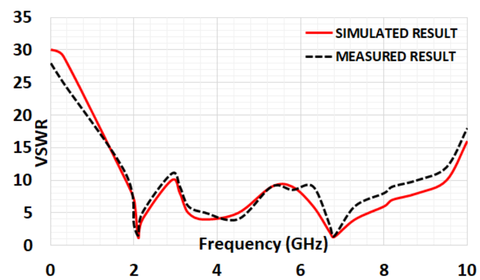
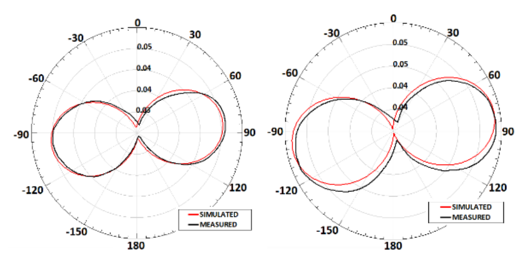


Fig. 5. Simulated and measured VSWR for null state.

C. Radiation pattern

The radiation pattern of proposed antenna in E-plane (x-z plane) and H-plane (y-z plane) at 2.1 GHz in null state is shown in Figs. 6 (a) and 6 (b) and also the 3-Dimensional radiation pattern is shown in Fig 7. Bi-directional radiation pattern is seen in both E- and H-plane of the proposed antenna in null state. Since the antenna has reconfigurable property, the radiation pattern will remain unchanged even though the operating frequency of the antenna is different.



(a) (b)

Fig. 6. Radiation pattern at 2.1 GHz in null state: E-plane (x-z plane), and (b) H-plane (y-z plane).

D. Gain

The simulated and measured gain plot for all the switching states are shown in the Fig. 8. The observed discrepancy between simulated and measured curve is mainly due to soldering effect of PIN diode. Table 2 shows the gain value obtained through simulation and measured in its operating frequency.

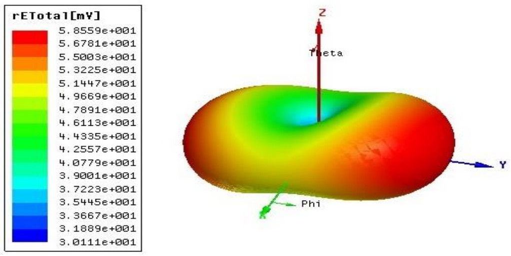


Fig. 7. Three-dimensional radiation pattern at 2.1 GHz.

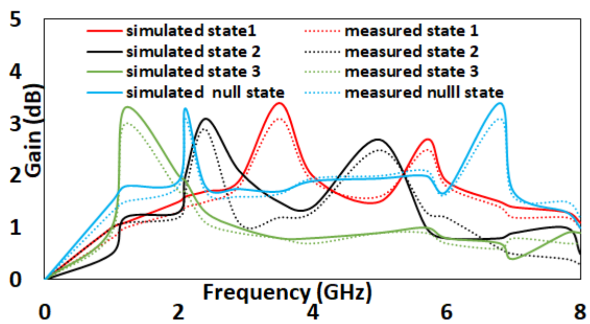


Fig. 8. Simulated vs. measured gain plot.

Table 2. Comparison of gain in various switching state

Diode State	Operating Frequency	Gain Simulated	Gain Measured
State 1	3.5 GHz	3.4 dB	3.1 dB
	5.7 GHz	2.7 dB	2.5 dB
State 2	2.4 GHz	3.1 dB	2.9 dB
	5 GHz	2.7 dB	2.5 dB
State 3	1.2 GHz	3.3 dB	3 dB
Null state	2.1 GHz	3.3 dB	2.9 dB
	6.8 GHz	3.4 dB	3.1 dB

V. ANTENNA COMPARISON

The obtained gain response of the proposed antenna design is stable (≈3dB) for all the switching states where as other antenna designs will not have such a kind of performance efficiency. The combined unit of proposed antenna with microcontroller is compact in size when compared with that of the existing methods and design standards [1], [9].

VI. CONCLUSION

In this paper, frequency reconfigurable N-shaped antenna for wireless communication application has been proposed and successfully implemented. The proposed antenna works on various wireless bands such as 3.5 GHz (WiMAX), 2.4 GHz (WLAN), 1.2 GHz (GPS), 2.1 GHz (UMTS) respectively. Two PIN diodes are automatically switches the different frequency band using Arduino board. Hardware prototype is tested in Lab setup with VNA. The radiation pattern of the antenna remains same for all the switching states of the diode and the antenna gain has been realized with maximum 3.4 dB and minimum of 2.7 dB gain. The measured results closely track the simulation result and confirms the antenna configuration.

REFERENCES

[1] C. G. Christodoulou, Y. Tawk, S. A. Lane, and S. R. Erwin, "Reconfigurable antennas for wireless and space applications," *Proceedings of the IEEE*, vol. 100, no. 7, pp. 2250-2261, 2012.

[2] N. J. Shimu and A. Ahmed, "Design and performance analysis of rectangular microstrip patch antenna at 2.45 GHz," In *Informatics, Electronics and Vision (ICIEV), 2016 5th International Conference on, IEEE*, pp. 1062-1066, 2016.

[3] P. K. Li, Z. H. Shao, Q. Wang, and Y. J. Cheng, "Frequency and pattern reconfigurable antenna for multistandard wireless applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 333-336, 2015.

[4] V. Arun and L. R. Karl Marx, "Micro-controlled tree shaped reconfigurable patch antenna with RF-energy harvesting," *Wireless Personal Communications*, vol. 94, no. 4, pp. 2769-2781, 2017.

[5] N. Ojaroudi, S. Amiri, and F. Geran, "A novel design of reconfigurable monopole antenna for UWB applications," *Applied Computational Electromagnetics Society Journal*, vol. 28, no. 7, 2013.

[6] R. Tandon and T. Singh, "Varactor diode loaded reconfigurable patch antenna with adjustable slots," *International Journal of Computer Applications*, vol. 128, no. 14, pp. 36-39, 2015.

[7] K. Opalli, E. Erdil, O. A. Civi, S. Demir, S. Koc, and T. Akin, "Tunable dual-frequency RF MEMS rectangular slot ring antenna," *Sensors and Actuators A: Physical*, vol. 156, no. 2, pp. 373-380, 2009.

[8] J. Costantine, Y. Tawk, S. E. Barbin, and C. G. Christodoulou, "Reconfigurable antennas: Design and applications," *Proceedings of the IEEE*, vol. 103, no. 3, pp. 424-437, 2015.

[9] I. Rouissi, J. M. Floc'h, H. Rmili, and H. Trabelsi, "Design of a frequency reconfigurable patch antenna using capacitive loading and varactor diode," In *2015 9th European Conference on Antennas and Propagation (EuCAP), IEEE*, pp. 1-4, 2015.

[10] V. Rajeshkumar and S. Raghavan, "A compact frequency reconfigurable split ring monopole antenna for WLAN/WAVE applications," *Applied Computational Electromagnetics Society Journal*, vol. 30, no. 3, 2015.