Design of Reconfigurable Triangular Microstrip Patch Antenna with T-Stub for C-Band and X-B and Applications

G. Mohan[1], M. Pranay Kumar[2], Thasneem[3]
[1, 3](Ph.D Scholar, Dept. of ECE, Chaitnya Deemed to be University, Telangana, India)
[2](Assoc. Professor, Dept. of ECE, Chaitnya Deemed to be University, Telangana, India)

ABSTRACT: *In this article a Co-Planar Waveguide (CPW) fed triangular microstrip patch antenna is presented for C & X-band applications. The triangular shaped patch is utilized to reduce the metallization and to improve the radiation characteristics. The triangular shaped patch is placed on the low cost FR4 substrate with dielectric constant 4.4 and loss tangent is 0.025. To achieve the frequency reconfigur ability a T-shaped stub is placed above the triangular shaped patch and connected via a PIN diode. The overall size of the antenna is 15x25x1.6〖mm〗^3. The proposed design is simulated using commercially available 3D-EM software CSTMWS. From the operating characteristics of the proposed antenna is observed that it is very useful for C-band (4-8GHz) & X-band (8-12GHz) applications. The triangular patch and T-shaped is connected via a PIN frequency reconfigurability is achieved. If the diode is ON the proposed antenna is used to operate for C-band applications. Where as, the diode is OFF the proposed antenna is used to operate for X-band applications.*

KEYWORDS -*Co-Planar Waveguide (CPW), Triangular patch, Reconfigurability, T-stub, PIN diode*

I. INTRODUCTION

Microstrip antennas have gained significant popularity owing to its structural characteristics and advantageous features such as a low profile, cost-effectiveness, lightweight nature, and ease of integration onto VLSI circuit boards. Furthermore, microstrip antennas have been utilized for operation at frequencies spanning single, dual, and triple bands [1]. The primary limitation of microstrip antennas is their restricted bandwidth. Reconfigurable antennas have garnered considerable interest in recent times due to their potential uses in wireless communications, electronic surveillance, and countermeasures. These antennas possess the ability to modify their features in order to get selectivity in terms of frequency, bandwidth, polarization, and gain adjustments [2]. The adjustment of the resonance frequency is achieved through the modification of the radiating element's form. Microstrip antennas are extensively employed for the purpose of achieving reconfigurability, owing to its inherent benefits such as a compact design, reduced weight, cost-effectiveness in manufacturing, and seamless integration with radio frequency (RF) devices. One limitation associated with the rudimentary printed antenna designs is their limited impedance bandwidth nature. Controlling the state of switches put in the antenna, such as PIN diodes or RF MEMS, enables the attainment of frequency band selectivity. The switches can perform various functions on reconfigurable antennas, such as adjusting the resonant frequency by modifying the antenna feed location [3], controlling the electrical length of slots [4], connecting or disconnecting elements in antenna arrays [5], or expanding the total length of the antenna by connecting parasitic elements to the radiating patch [6]. In order to provide a dependable prediction of the antenna frequency behavior, it is imperative to thoroughly account for the non-ideal radio frequency (RF) characteristic of the PIN diodes during the simulations [7]. PIN diodes are frequently employed as RF switches because to their attributes, including compact size, affordability, minimal insertion loss, satisfactory isolation, and favorable switching performance [8]. Nevertheless, the incorporation of diodes within the antennas necessitates the implementation of a biasing circuit and DC blocks to mitigate any potential interference with the RF signal. This factor significantly impacts the overall performance of the antenna and should be duly accounted for in the simulation model. This paper presents a design of reconfigurable triangular microstrip patch antenna for C&X-band applications.

II. ANTENNA DESIGN

The triangular shaped microstrip patch antenna is designed on the dielectric substrate FR4, with relative permittivity ε_r = 4.4 and the thickness is h = 1.6mm. The resonant frequency is calculate as follows [9]

$$f_r = \frac{C k_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2C}{3R\sqrt{\varepsilon_r}}(m^2 + mn + n^2) \quad (1)$$

Where C is velocity of the light in free space and k_{mn} is wave number. It is calculated by [9]

$$k_{mn} = \frac{4\pi}{3R}\sqrt{m^2 + mn + n^2} \quad (2)$$

Therefore, from the above equation for lowest order resonance frequency, is given [10]

$$f_r = \frac{2C}{3R\sqrt{\varepsilon_r}} \quad (3)$$

Where f_r is the resonance frequency, R is the length of the triangular patch.

The triangular patch has 3 sides with length R, as depicted in fig.1. The length of the triangular patch R, the following equation is used [11].

$$R = \frac{2C}{3f_r\sqrt{\varepsilon_r}} \quad (4)$$

Finally, the height of the patch is calculated by L_p is given by

$$L_p = \sqrt{R^2 - \left(\frac{1}{2}R\right)^2} \quad (5)$$

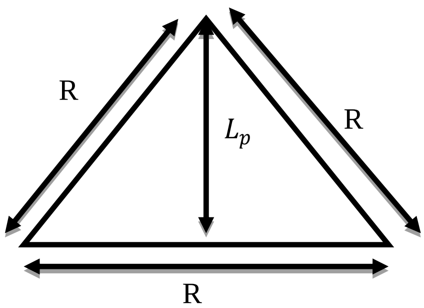
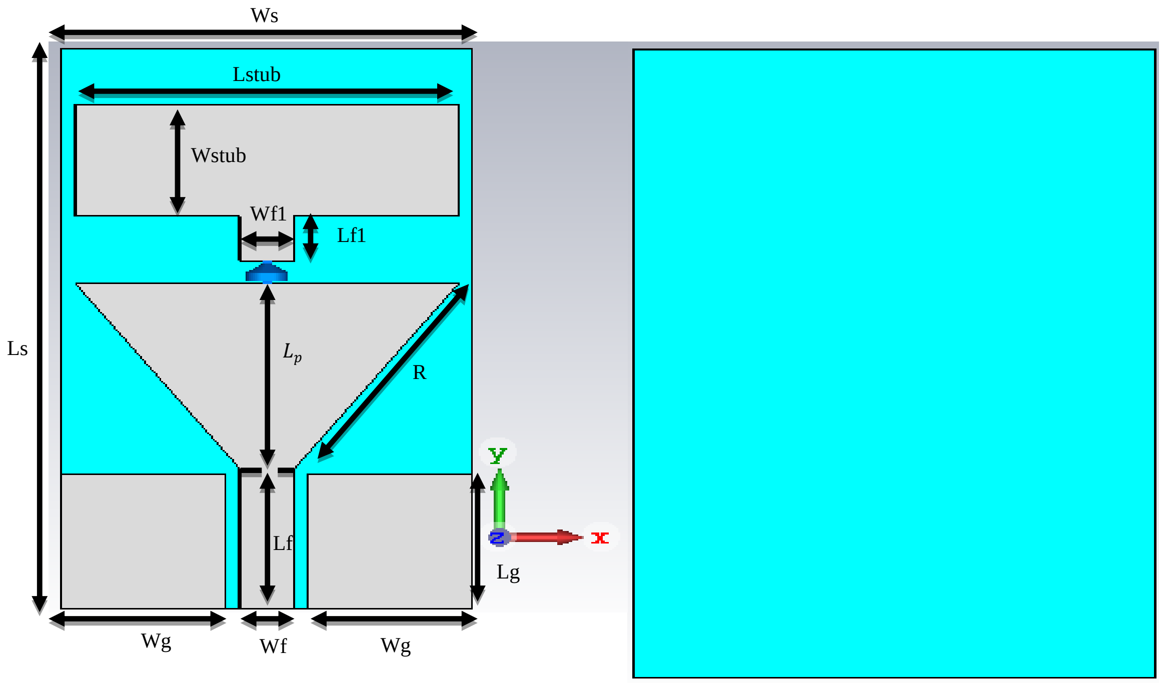


Fig.1 Triangular patch microstrip antenna

The triangular patch is designed using the above equations with dimensions of 6mm X 10.24mm. The T-shaped stub is placed on the rectangular patch with dimension of 12mm X 3mm. The spacing between the patch and T-shaped stub is optimized to achieve the better operating results. The front view and rear view of the proposed reconfigurable triangular shaped microstrip antenna is depicted in Fig.2. The dimensions of the proposed design is tabulated in Tabale-1.



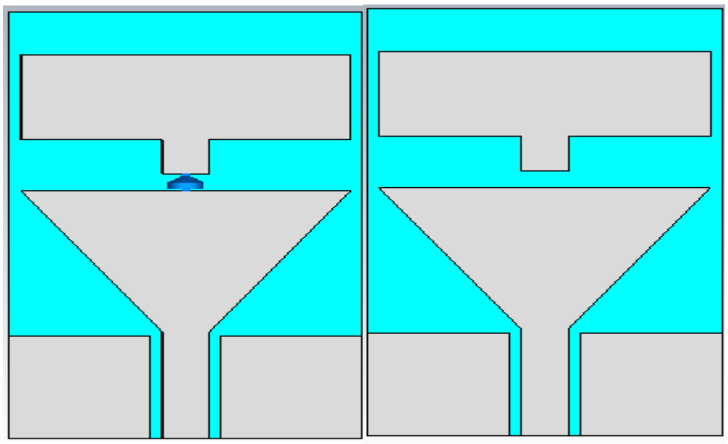
(a) Front View (b) Rear View

Fig.2 Proposed reconfigurable triangular microstrip patch antenna

Table-1. The dimensions of the proposed design

S. No	Dimension	Value (mm)
1.	Lg	6
2.	Wg	6
3.	Ls	25
4.	Ws	15
5.	Lf	6.25
6.	Wf	2
7.	R	6
8.	Lp	10.24
9.	Wf1	2
10.	Lf1	2
11.	Lstub	12
12.	Wstub	3

A Co-Planar Waveguide (CPW) feeding is used with dimension of $6X6mm^2$. This feeding technique reduces the design complexity. The length and width of the feed line is optimized to $6.25X2mm^2$. The gap between the rectangular patch and the T-stub is optimized to 1mm to connect the PIN diode with specification of MMP7062.



(a) PIN diode ON condition (b) PIN dioide OFF condition

Fig.3. The ON-OFF conditions of the PIN diode

As the diode is an active element if can be acts as an ON and OFF switch. When the diode is ON the diode acts as forward bias and the entire current will be allowed from the rectangular patch to the T-shaped stub. When the diode is in OFF condition the diode acts as a reverse biased and no current is allowed from the patch to the stub. In this condition, the patch and stub are connected via electromagnetic coupling. The ON & OFF conditions of the proposed antenna is depicted in Fig.3. Therefore, by operating the PIN diode to ON & OFF the operating characteristics of the proposed design is acting as reconfigurable antenna. The overall dimension of the proposed reconfigurable antenna is 25X15X1.6mm^3.

III. RESULTS & DISCUSSION

The return loss plot of the triangular microstrip patch antenna with CPW feeding is shown Fig.4. Due to the optimization of the shape of the patch from regular rectangular shape to triangular shape the operating frequency is achieved from 4.8GHz- 13.24GHz. The minimum return loss of -42.84dB is achieved at 10.69GHz.

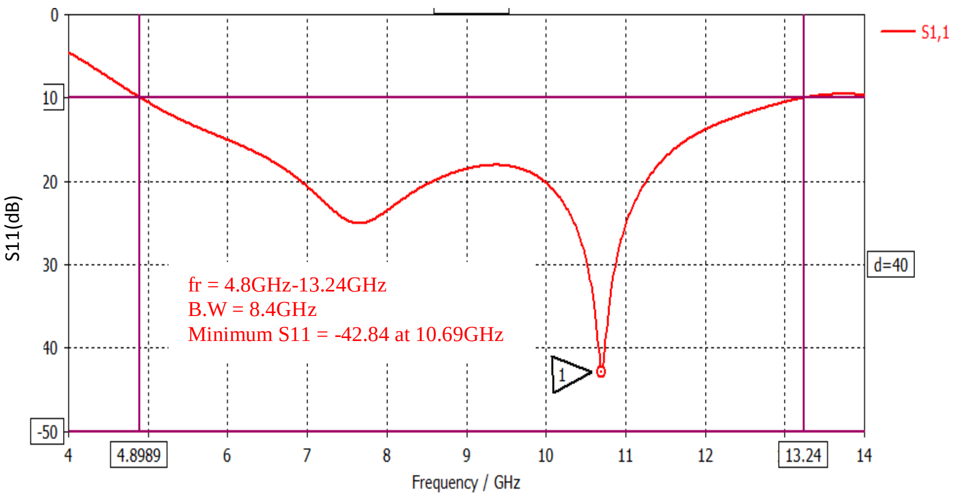


Fig.4. Return loss plot of the proposed antenna with triangular patch

The above mentioned frequency is covering the microwave bands like C-band i.e., 4-8GHz and X-band i.e., 8-12GHz applications. The C & X-bands are allocated by the Institute of Electrical and Electronics Engineers (IEEE) to be extended from 4 to 8 GHz and from 8 to 12 GHz, respectively.

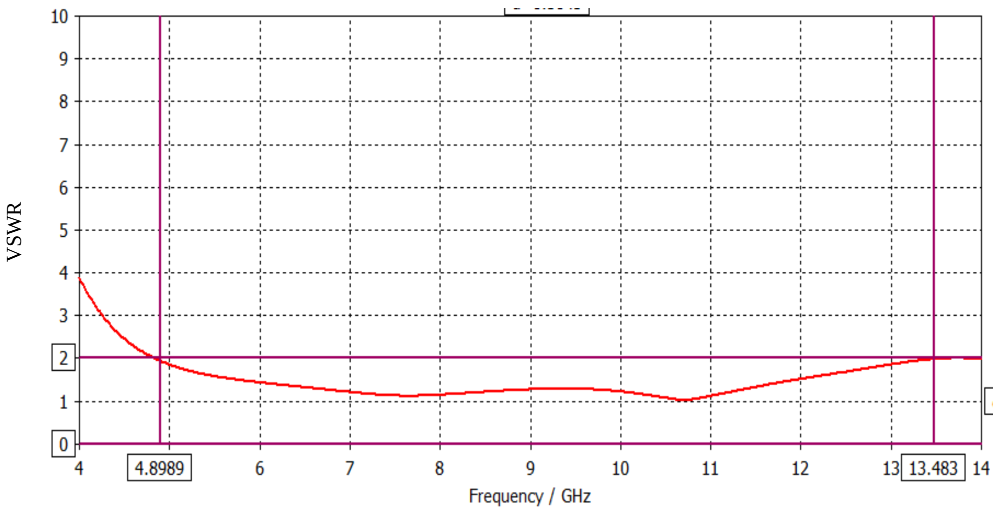


Fig.5. VSWR plot of the proposed microstrip antenna with Triangular patch

The C-band is used in many satellite communications, weather radar systems, some Wi-Fi devices, and some surveillance systems. The VSWR plot of the proposed microstrip antenna with triangular patch is shown in Fig.5. The VSWR<2 for the entire operating frequency from 4.8GHz-13.4GHz. The Triangular patch is connected with T-shaped stub via a PIN diode to achieve the reconfigurability.

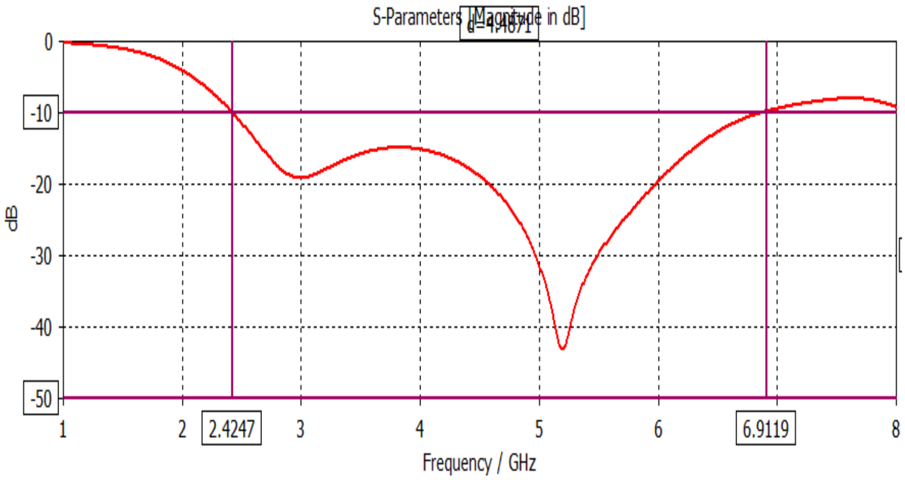


Fig.6. Return loss plot of the reconfigurable microstrip antenna with diode ON

When the diode is ON the proposed reconfigurable microstrip antenna is used to operate at C-band applications. The return loss plot of the reconfigurable microstrip antenna when the diode is ON shown in Fig.6. Due to this the proposed antenna is selecting only C-band frequency and rejecting the entire X-band frequency range. From the return loss plot is clearly observed that it is completely below -10dB for the frequency range from 2.4GHz to 6.9GHz.

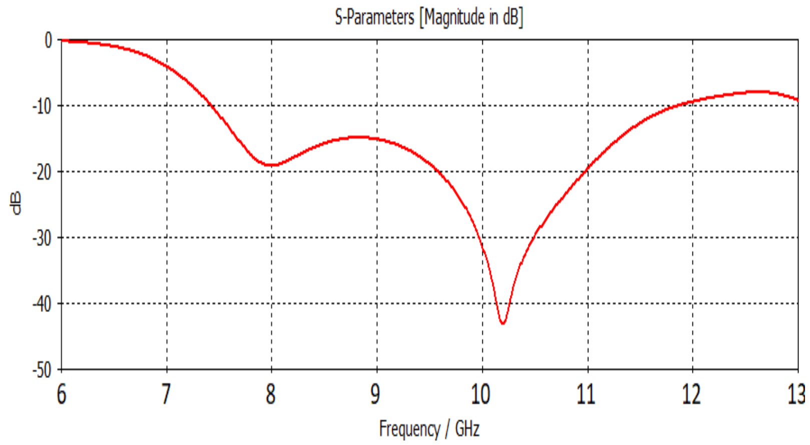


Fig.7. Return loss plot of the reconfigurable microstrip antenna with diode OFF

When the diode is OFF the proposed reconfigurable antenna is used to operate at X-band frequency range. If the diode is OFF there is open circuit between the triangular patch and T-shaped stub. The return loss plot of the proposed reconfigurable microstrip antenna with diode OFF condition is shown in Fig.7. From the plot it is clearly observed that it is selecting the X-band frequency. The operating frequency is 7.5GHz-12GHz. Therefore, the simple rectangular patch antenna can be used to operate at both the C & X-band frequencies. To reduce the interference caused by nearby systems the reconfigurable antenna is designed to select one of the bands from C&X-bands.

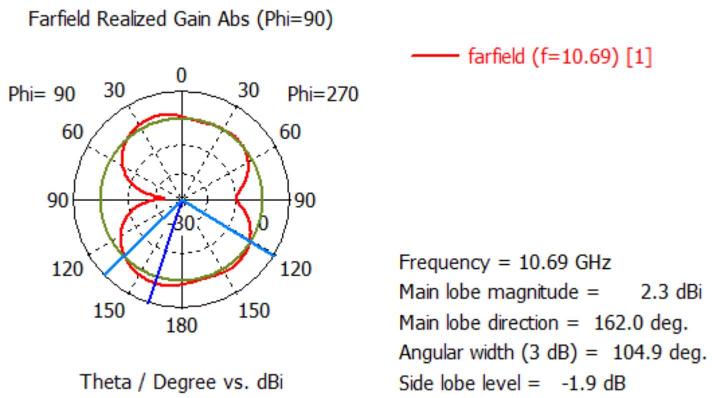


Fig.8. Far-field gain plot of the microstrip antenna with triangular patch

The far-field 2D-gain plot of the proposed microstrip antenna with triangular patch is shown in Fig.8. The peak gain obtained is 2.3dBi at the operating frequency of 10.69 GHz. The gain plot shows the Bi-directional radiation pattern due to the CPW feeding. As there is no ground plane at the backside of the dielectric substrate the shape of the radiation pattern resembles the shape of the figure of eight.

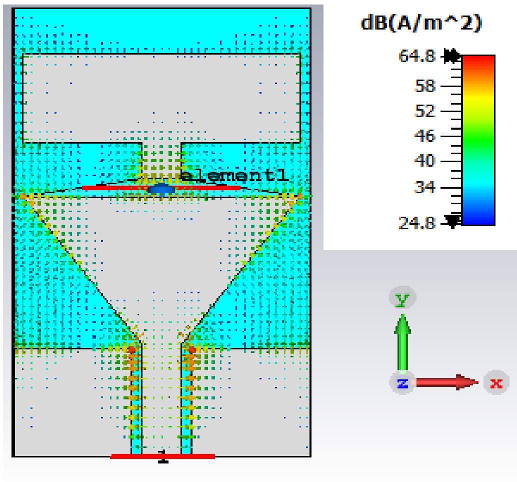


Fig.9 The current density distribution of the proposed reconfigurable microstrip antenna

The current density distribution of the proposed reconfigurable microstrip antenna is shown in Fig.9. From the plot it is observed that the maximum current of 64.8dB (A/m^2) is coupled between the CPW feed and the feed line and between the triangular patch and the T-shaped stub. The proposed antenna offers the linear polarization due to all the field lines are oriented in upward direction from the feed point of view. Table-2 compares the proposed work with related works.

Table-2. Comparison between the proposed filtenna and related works

Reference	Number of switches	Operating frequencies (GHz)	Size $(\lambda g \times \lambda g)$
[12]	1-PIN diode	3.9 to 4.82	1.24 × 0.56
[13]	2 FETs	2.4; 4.2; 3.3; 5.4	0.69 × 0.69
[14]	2 PIN diodes, 2 varactors	0.58; 0.86; 1.1; 2.48	0.49 × 0.27
[15]	4 PIN diodes	2.48; 3.5; 5.5; 2.45; 5.49	0.68 × 0.68
[16]	8 PIN diodes	1.1; 2.25; 3.1	1.06 × 1.04
[17]	12 PIN diodes	2.75; 2.86; 3.1; 3.26	1.22 × 0.91
Proposed work	1- PIN diode	2.4-6.9, 7.5-12	0.15 x 0.25

IV. CONCLUSION

The reconfigurable microstrip antenna with T-shaped stub for C&X-band applications is presented. The triangular shaped patch is utilized to achieve the higher operating frequency characteristics. Further, a T-shaped stub is extended via a PIN diode to achieve the reconfigurable frequency characteristics. Before introducing the T-shaped stub and PIN diode the antenna covering the frequency range from 4.8GHz – 13.4GHz. The peak gain achieved is 2.3dBi. After introducing the PIN diode and a T-stub the frequency reconfigurability is achieved and when the diode is ON the antenna covering on C-band frequency i.e., from 2.4GHz-6.9GHz. Whereas the diode is in OFF condition the antenna is covering the X-band frequency i.e., from 7.5GHz-12GHz. The proposed antenna is simulated using CSTMWS and the all the operating parameters are analyzed.

V. FUTURE SCOPE

In near future the proposed antenna will be fabricated and measured. The measurement results will be compared with simulated results to test the concurrence between the simulated and measured.

REFERENCES

[1] S. Onat, L. Alatan, S. Demir, "Design of triple band reconfigurable microstrip antenna employing RF MEMS switches*", IEEE APS International Symposium*, 2, 2004, 1812 -1815.

[2] D. Peroulis, K, Sharabandi, L.P.B, Katehi, "Design of Reconfigurable Slot antennas", *IEEE transactions on antennas and propagation*, 53(2), 2005, 645 -654.

[3] N. Behdad, K. Sarabandi, "Dual-band reconfigurable antenna with a very wide tunability range*", IEEE transactions on antennas and propagation,* 54(2), 409-416, Feb. 2006.

[4] B.A. Cetiner, H. Jafarkhani, Hui Jae Yoo. Jiang-Yuan Qian, A. Grau, F. De Flaviis, "Multifunctional reconfigurable MEMS integrated antennas for adaptive MIMO systems", *IEEE Communications Magazine*, 42(12), pp.62 -70, December 2004.

[5] A.H.M. Zahirul Alam, Md. Rafiqul Islam, "Reconfigurable patch antenna by RF MEMS switches", *IEEE International Symposium on Mechatronics and its Applications*, 2009.

[6] A.W.M. Lee, S.K. Kagan, M. Wong, R.S. Singh, E.R. Brown, "Measurement and FEM modeling of a reconfigurable patch antenna for use in the wideband gap filler satellite system", *IEEE APS Symposium*, Vol. 1, pp. 379-382, 22-27 June 2003.

[7] S. Liu, M. Lee, C. Jung, G.P. Li, F. Flaviis, "A Frequency Reconfigurable Circularly Polarized Patch Antenna by Integrating MEMS Switches*", IEEE APS International Symposium*, Vol. 2A, pp. 413-416.

[8] H. Kimouche, A. Mansoul, "A compact reconfigurable single/dual band antenna for wireless communications", *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference* on, pp. 393 - 396, 11-15 April 2011.

[9] R.K. Vishwakarma, J.A. Ansari, M.K. Meshram, "A 2.4 GHz Switched Beam Antenna for Indoor Applications Using Angle of Arrival Estimation", *Indian Journal of Radio Space Physics*, 35, 2006, 293–296.

[10] P.Arunagiri, C. Naveen Kumar, K. Adhavan, "A Design of Dual Band Triangular Microstrip Patch Antenna for WLAN Applications", *International Journal for Research in Applied Science & Engineering Technology*, 4(4),April 2016, 88-92.

[11] Ramesh Boddu, Arindam Deb, and Jibendu Sekhar Roy, "Design of a Compact Microstrip Filtenna for Miniaturized Devices to Access Internet of Things Using Long Term Evolution*", Advanced Electromagnetics Journal*, 12(4), December 2023.

[12] P.-Y. Qin, F. Wei, and Y. J. Guo, "A wideband-to-narrowband tunable antenna using a reconfigurable filter*," IEEE Transactions on Antennas and Propagation*, 63(5), 2015, 2282–2285.

[13] T. Aboufoul, A. Alomainy, and C. Parini, "Reconfiguring UWB monopole antenna for cognitive radio applications using GaAs FET switches," *IEEE Antennas and Wireless Propagation Letters*, 11, (2012), 392–394.

[14] D. Zhao, Y. Han, F. Liang, Q. Zhang, and B.-Z. Wang, "Low power optically controlled patch antenna of reconfigurable beams," *International Journal of Antennas and Propagation*, 2014.

[15] H. Boudaghi, M. Azarmanesh, and M. Mehranpour, "A frequency-reconfigurable monopole antenna using switchable slotted ground structure*," IEEE Antennas and Wireless Propagation Letters*, 11, 2012, 655–658.

[16] M. R. Hamid, P. Gardner, P. S. Hall, and F. Ghanem, "Switched band Vivaldi antenna," *IEEE Transactions on Antennas and Propagation*, 59(5), 2011, 1472–1480.

[17] A. Mansoul, F. Ghanem, M. R. Hamid, and M. Trabelsi, "A selective frequency-reconfigurable antenna for cognitive radio applications," *IEEE Antennas and Wireless Propagation Letters*, 13, 2014, 515–518.