International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

Vol. 41 No. 2 November 2023, pp. 498-506

Inset Fed Rectangular Patch Antenna Design for ISM Band Applications

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Abstract – Wireless communication systems rely on efficient and compact antennas to transmit and receive signals. Microstrip patch antennas have gained popularity due to their small size, low profile, and ease of fabrication. In this study, an inset fed microstrip rectangular patch antenna using a partial ground plane is designed for ISM band applications in the frequency range of 2.4 - 2.4835 GHz. The antenna is made on a low-cost FR4 substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm. The dimensions of the antenna is 28.35 × 37.58 mm^2. The antenna is fed by an inset feedline, which provides a compact and efficient feeding mechanism. The design of the antenna is carried out using CST Microwave Studio software. The performance of the antenna is evaluated based on various parameters such as return loss, bandwidth, VSWR, directivity, gain, and radiation pattern. The simulation results indicate that the proposed antenna achieves a return loss (S_{11}) of -27.339 dB, a bandwidth of 0.01478 GHz (147.8 MHz), and a VSWR of 1.09. Additionally, the antenna provides a gain of 2.97 dBi, a directivity of 4.7 dBi, and an efficiency of -1.726 dB (67.20%). Overall, this design meets the requirements of decreased antenna size, lightweight, low profile, cost-effectiveness, simple manufacturing, and good performance for ISM band applications.

Keywords – Patch Antenna, Small Size, ISM Band, Bandwidth, CST.

I. INTRODUCTION

The rapid growth of wireless communication networks and the increasing number of remote devices have created a high demand for antenna configurations [1]. Microstrip antennas, unlike traditional microwave antennas, offer several advantages and can cover a wide bandwidth ranging from 100 MHz to 100 GHz. These antennas can be designed in various shapes and sizes and possess different properties. A Microstrip Patch Antenna (MPA) consists of a transmitting patch on one side of a dielectric substrate, which can have either a planar or non-planar shape, and a ground plane on the other side. Different configurations, such as square, annular-ring, circle, rectangle, symmetrical triangular, and dipole, have been extensively studied in recent years. These antennas have a low profile, lightweight design, cost-effective manufacturing, thin profile setup, and can achieve direct and circular polarization with simple feed mechanisms. They can also be easily integrated with microwave integrated circuits. Microstrip patch antennas offer a high power-handling capacity, making them suitable for transmitting and receiving low-power signals. Their unique characteristics make them potential candidates for applications in radar systems and wireless communication systems [2-4].

Microstrip patch antennas do have some limitations, including slow transfer speeds and modest required gain. However, various approaches have been proposed to increase the impedance bandwidth of these antennas. These approaches typically involve reducing radiation loss and minimizing metalized territory on the dielectric substrate [5-7]. In certain applications such as high-performance aircraft, spacecraft, satellites, and missiles, low-profile antennas are necessary due to size, weight, cost, performance, ease of installation, and aerodynamic profile constraints. To enhance antenna performance, an inset-fed antenna using Defected Ground Structure (DGS) has been presented, offering high bandwidth and low return loss. However, this antenna has a directivity of only 3.049 dBi [8]. Other research works have proposed different designs to address the limitations of microstrip patch antennas. For example, a rectangular patch antenna with a novel top-plane switching beam and ground-plane slits was proposed, and a circular-shaped DGS was utilized to reduce antenna size by approximately 74.5 percent. Additionally, a star-shaped microstrip patch antenna with a microstrip feed line for ISM band was demonstrated, achieving an impedance bandwidth of 67.6 MHz and a gain of 6.6 dBi. Another design involved a rectangular inset-fed microstrip patch antenna with and without DGS, achieving a bandwidth of 21 MHz and a gain of 5.647 dB [9-13]. It is worth noting that microstrip patch antennas find applications in various sectors, including mobile radio and wireless communications, where governments and commercial entities have similar criteria for antenna performance and specifications.

Patch antennas are indeed suitable for the mentioned purposes. They offer several advantages such as a low profile, flexibility to conform to planar and non-planar surfaces, cost-effectiveness through modern printed circuit technology, mechanical strength on rigid surfaces, compatibility with MMIC plans, and adaptability in terms of frequency, polarization, shape, and impedance selection. The square, rectangular, dipole (strip) and circular patch antennas are widely recognized due to their ease of analysis, fabrication, and favorable radiation properties, including low cross-polarization radiation. The ISM radio bands, allocated globally for industrial, scientific, and medical applications other than telecommunications, are in the frequency range of 14 - 15 GHz. These bands are utilized for various purposes such as broadcast process heating, microwaves, and medical diathermy machines. To prevent electromagnetic interference and disruption of radio communication within the same frequency range, specific frequency bands have been designated for ISM device operation [14-15].

The primary objective of this study is to evaluate the efficacy of an inset-fed microstrip rectangular patch antenna with a partial ground plane approach for ISM band applications within the frequency range of 2.4 GHz to 2.4835 GHz. The antenna design incorporates an FR4 substrate material with a dielectric constant of 4.3, and the microstrip inset feed line technique is employed to ensure proper impedance matching. Additionally, a partial ground plane is utilized to enhance the antenna's bandwidth and minimize return loss. The Computer Simulation Technology (CST) microwave studio software is utilized to simulate and evaluate the performance of the proposed antenna design.

II. ANTENNA DESIGN

The proposed antenna design utilizes FR4 as the construction material, which has a thickness of 1.6 mm and a dielectric constant of 4.3. The ground and patch of the antenna are made of copper, which is a lossy metal. To feed the antenna, an inset-feedline configuration is employed. This means that the feedline is positioned within the antenna structure, allowing for efficient power transfer to the radiating element. By using FR4 as the substrate material and copper as the conductive material for the ground and patch, along with the inset-feedline feeding technique, the antenna design aims to achieve optimal performance and desired characteristics. The geometry of the proposed antenna is depicted in figure 1.

The proposed antenna's dimensions are designed using the following equations:

Patch width (W) [19]:

$$\mathrm{W} = \frac{\mathrm{c}}{2\mathrm{f_r}\sqrt{\frac{(\varepsilon\mathrm{r}-1)}{2}}}$$

Where, c = light speed in vacuum

$\mathrm{f_r}$ = resonant frequency

Substrate height (h) [19]:

$$\frac{\mathrm{W}}{\mathrm{h}} > 1.$$

Effective dielectric constant ($\varepsilon_{\mathrm{reff}}$) [19]:

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

Patch length (L) [19]:

$$\Delta L = L_{\mathrm{eff}} - 2\Delta L$$

$$L_{\mathrm{eff}} = \frac{c}{2f_r\sqrt{\varepsilon_{\mathrm{reff}}}}$$

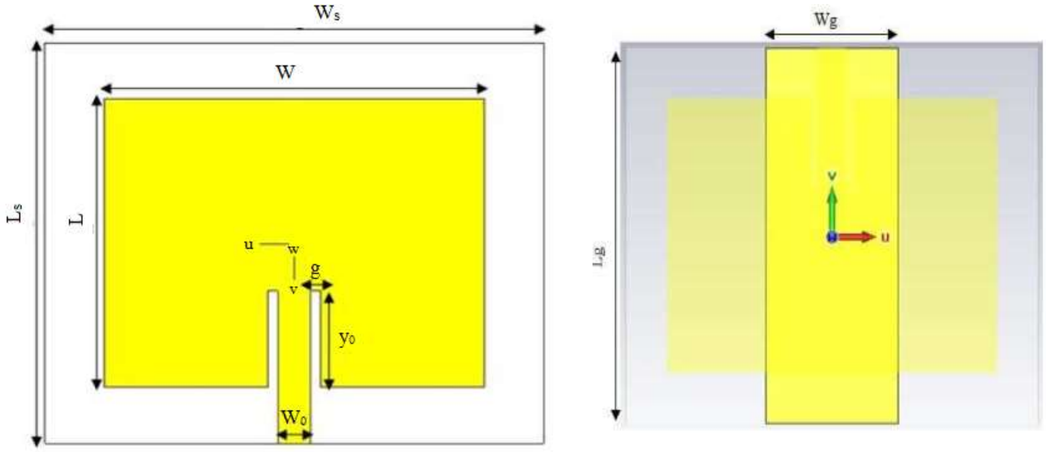
$$\Delta L = 0.412h\frac{(\varepsilon_{\mathrm{reff}} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{\mathrm{reff}} - 0.258)(\frac{w}{h} + 0.8)}$$

Ground plane measurement [19]:

$$L_g = L + 6h$$

$$W_g = W + 6h$$

The patch antenna's dimensions are listed in Table 1.



(a) (b)

Figure 1. Geometry of the proposed antenna with partial ground plane (a) Front view and (b) Back view

Table 1. Geometrical parameters of the proposed antenna

Parameters	Value
Substrate dielectric constant, ε_r	4.3
Substrate thickness, h (mm)	1.6
Ground plane length, L_g (mm)	40
Ground plane width, W_g (mm)	50
Substrate length, L_s (mm)	40
Substrate width, W_s (mm)	50
Copper thickness, t (mm)	0.035
Patch length, L (mm)	28.35
Patch width, W (mm)	37.58

Width of the feed, W_0 (mm)	3.137
Inset length, y_0 (mm)	5.5
Inset gap, g (mm)	1
Partial ground width, W_g (mm)	30
Partial ground length, L_g (mm)	40

III. SIMULATED RESULTS AND DISCUSSION

The simulation results of the single-element rectangular patch antenna, obtained using CST software are presented in Figures 2 to 5. These figures display various antenna metrics such as return loss (S11), VSWR, gain, and directivity. The CST software has been utilized to simulate the antenna design and generate these metrics. The purpose of presenting these simulation results is to provide a basis for analyzing and evaluating the performance of the suggested antenna. By examining these antenna parameters, one can achieve insights into the antenna's performance and make informed judgments about its effectiveness.

3-1. Return Loss (S_{11})

Return loss refers to the reflected power from the load (antenna) due to a mismatch in the communication connection. It is typically measured in dB and indicates the quality of the impedance match between the source (feed line) and the load (antenna). A lower return loss value indicates a better impedance match and less power wasted in the load, resulting in maximum power transfer and improved performance. The return loss is calculated as the ratio of reflected power (P_r) to incident power (P_i), expressed in dB. The return loss should be as high as possible, represented by a negative number, indicating that the reflected power is significantly lower than the incident power. The return loss (S_{11}) for the proposed antenna is shown in figure 2. In the case of the proposed antenna, the lowest return loss is -27.339 dB at a frequency of 2.435 GHz, indicating good impedance matching between the microstrip feed line and the radiating patch.

A return loss of -27.339dB corresponds to a reflection coefficient of 0.04306, meaning that approximately 4.306% of the incident power is wasted in the antenna, while 99.82% of the available power is transmitted into the antenna. The return loss graph is also used to determine the antenna's bandwidth, which is defined as the frequency range over which the return loss is less than -10 dB. In the case of the planned antenna, the estimated bandwidth is 0.1478 GHz (147.8 MHz), with an upper cutoff frequency of 2.5096 GHz and a lower cutoff frequency of 2.3616 GHz. This bandwidth is better than that observed in references [16-18].

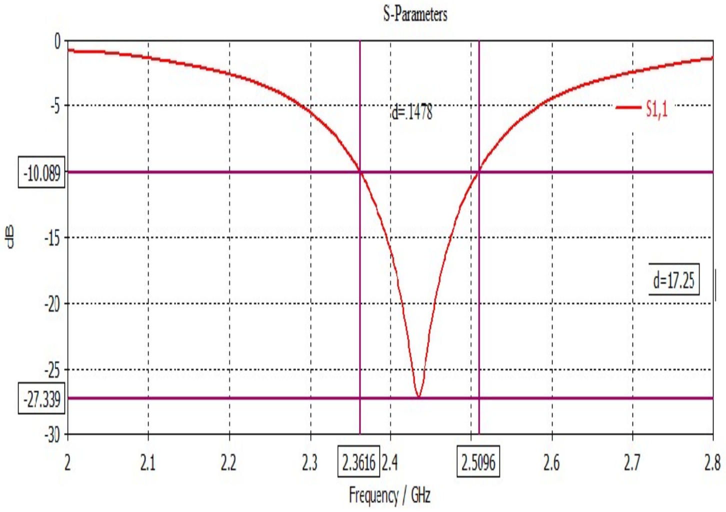


Figure 2. Return loss of the proposed antenna

3-2. VSWR

The Voltage Standing Wave Ratio (VSWR) is a metric used to measure the impedance matching between an antenna and the connected radio or transmission line. It indicates the extent to which the antenna reflects the signal before radiation. A high VSWR suggests poor impedance matching. In practical terms, it is desirable for the VSWR to be between 1 and 2 in order to minimize loss in reflection. The VSWR value provides insight into the efficiency of the system. A lower VSWR indicates a better match between the impedance of the antenna and the feed line or transmission line, resulting in higher power supplied to the antenna. Impedance mismatches within the connector can cause signal reflections, which contribute to the VSWR. The VSWR can be calculated from the reflection coefficient as:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Figure 3 displays the Voltage Standing Wave Ratio (VSWR) versus frequency graph of the designed antenna. The VSWR value obtained for the antenna is 1.09, which is less than 2. This indicates a perfect match between the antenna and the feed line throughout the frequency band. A VSWR of 1.09 implies that approximately 99.82% of the power is efficiently supplied to the antenna, resulting in a very low loss of mismatch, specifically 0.0049 dB. This suggests that the antenna has been properly designed and exhibits efficient operation. The low VSWR value and minimal mismatch loss indicate that the antenna is well-matched to the feed line, allowing for effective power transfer and minimizing signal reflections. These results further support the conclusion that the antenna design has been successful and meets the desired performance criteria.

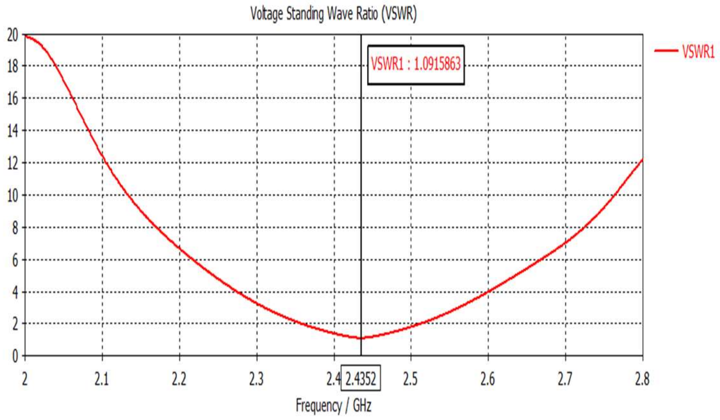
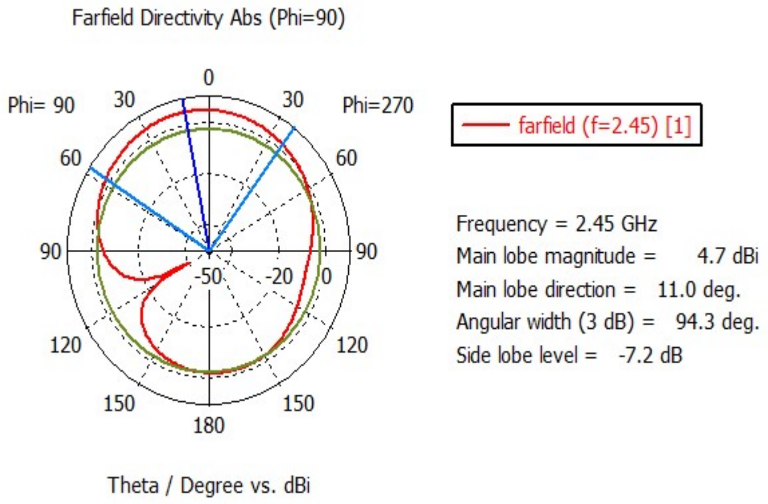


Figure 3. VSWR of the proposed antenna

3-3. Directivity

Directivity refers to the directionality of the radiation pattern from an antenna. It indicates the concentration of radiated power in a specific direction. An antenna with zero directivity radiates power equally in all directions, while an antenna with high directivity concentrates power in a specific direction. In applications where signals need to be transmitted and received in all directions, such as mobile devices, omni-directional antennas are typically used. These antennas have low or no directivity, allowing for coverage in all directions. On the other hand, in applications where long-distance communication in a specific direction is required, such as satellite television or wireless backhaul, high directivity antennas are employed. These antennas focus power in a particular direction, allowing for efficient transmission and reception over long distances. In the case of the designed antenna, its far-field directivity is depicted in figure 4. The directivity of the antenna is measured to be 4.7 dBi at a frequency of 2.45 GHz. This indicates that the antenna concentrates its radiated power in a specific direction at that frequency, making it suitable for applications that require transmission and reception over longer distances in a particular direction.

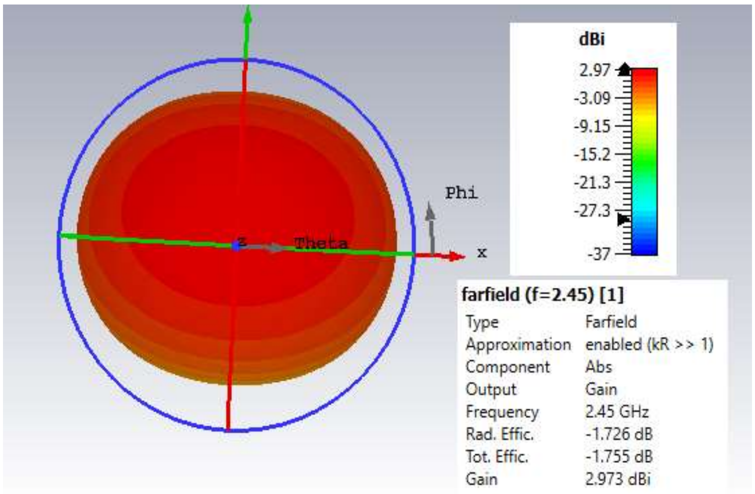


Frequency = 2.45 GHz
Main lobe magnitude = 4.7 dBi
Main lobe direction = 11.0 deg.
Angular width (3 dB) = 94.3 deg.
Side lobe level = -7.2 dB

Figure 4. Directivity of the proposed antenna

3-4. Gain

The gain of an antenna refers to its ability to convert electrical energy into radio waves in a specific direction. A higher gain means that the antenna focuses more power in a particular direction, while attenuating signals from other directions. On the other hand, a lower gain implies a wider radiation pattern and limited range. In the context of the designed antenna, the gain is shown in Figure 5 and is measured to be 2.97 dBi at a frequency of 2.45 GHz. This indicates that the antenna is capable of directing a significant amount of power in a specific direction at that frequency. It is important to note that an ideal antenna, known as an isotropic antenna, radiates signals equally in all directions, resulting in a gain of 0 dBi. In practice, real antennas have a gain that is greater than 0 dBi, and their directivity (ability to focus power in a specific direction) is typically greater than their gain. An ideal antenna would have the same directivity and gain, resulting in an efficiency of 100%. Overall, the gain of the designed antenna indicates its ability to focus power in a specific direction, enhancing its performance in transmitting and receiving signals at the frequency of 2.45 GHz.



farfield (f=2.45) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 2.45 GHz
Rad. Effic. -1.726 dB
Tot. Effic. -1.755 dB
Gain 2.973 dBi

Figure 5. Gain of the proposed antenna

3-5. Efficiency

The efficiency of an antenna is a measure of how effectively it converts input power into radiated power. A higher efficiency indicates that the antenna is delivering a larger amount of input power, while a lower efficiency suggests that a significant amount of input power is either consumed or reflected away due to impedance mismatch. Figure 5 depicts the efficiency of a proposed antenna, showing that it attains a value of -1.726 dB (67.20%). This means that the antenna is able to utilize a significant portion of the input power it receives. For optimal performance, it is desirable to have a high antenna efficiency. A higher efficiency ensures that more of the input power is converted into useful radiated power, resulting in better overall performance of the antenna system.

3-6. Summary of the Simulated Results

Table 2 presents a summary of the simulation findings for the antenna that has been developed for this study. The performance parameters of the antenna used in this research are shown in this table employing fundamental antenna properties including resonant frequency, return loss (S_{11}), VSWR, bandwidth, gain, and directivity.

Table 2. Summary of the simulated results of the proposed antenna

Performance Parameters	**Antenna**
Resonant frequency (GHz)	2.435
Return loss (dB)	-27.339
VSWR	1.09
Bandwidth (MHz)	147.8
Gain (dBi)	2.97
Directivity (dBi)	4.7

IV. COMPARISON WITH RECENTLY DEVELOPED WORKS

The suggested antenna in Table 3 is compared to the performance of a few newly developed antennas in terms of resonant frequency, return loss, bandwidth, and VSWR. The recommended antenna has a VSWR of 1.09, indicating that it has a good impedance match and minimal signal reflection. It also has a wide bandwidth of 147.8 MHz, which allows it to efficiently transmit signals over a range of frequencies. In comparison to the antennas mentioned in references [16–18], the proposed antenna is much smaller in size, indicating its compact design. It also has a wider bandwidth than the antennas in those references, suggesting that it can cover a broader range of frequencies. However, the planned antenna's VSWR is higher than the one provided in reference [18], indicating a slightly less precise impedance match. Nonetheless, it is lower than the VSWR values mentioned in references [16-17], indicating that the proposed antenna has a better impedance match than those antennas. Regarding the return loss, the intended antenna has a larger value than the one in reference [18], indicating a stronger ability to convert incoming signals into electromagnetic waves. However, it has a lower return loss than the antennas mentioned in references [16-17], suggesting that it may not be as efficient in converting signals as those antennas. Overall, the reduced return loss of the intended antenna suggests that it can effectively convert incoming signals into electromagnetic waves, while its VSWR and bandwidth make it a suitable choice for various frequency ranges.

Table 3. Comparisons of the preceding and present designed inset-fed microstrip rectangular patch antennas

References	**Antenna Size (mm^2)**	**Resonant frequency (GHz)**	**Return loss (dB)**	**Bandwidth (MHz)**	**VSWR**
[16]	2500	2.58	-14.09	40	1.492
[17]	….	2.45	-14.4	20	1.471
[18]	1085.2	2.393	-38.86	58	1.02
Proposed Antenna	1065.4	2.435	-27.339	147.8	1.09

V. CONCLUSION

In this article, an inset feedline rectangular patch antenna with partial ground plane for ISM band applications has been successfully designed. The antenna's performance has been evaluated using CST Microwave Studio. The designed antenna achieves a -10 dB impedance bandwidth of 147.8 MHz, ranging from 2.3613 GHz to 2.5091 GHz, with a return loss of -27.339 dB. It also exhibits a gain of 2.97 dBi, a directivity of 4.7 dBi, and an efficiency of -1.726 dB (67.20%). These specifications make the antenna suitable for various wireless communication standards, including Bluetooth (2.4 to 2.485 GHz), WiMAX (2.3 to 2.4 GHz), Microwave ovens (2.4 to 2.48 GHz), RFID (2.4 to 2.5 GHz), S-Band (2.3 to 2.4 GHz), Wireless Communication Services (WCS) 2.345 to 2.360 GHz, and 4GLTE (2.3 to 2.315 GHz). Future studies in antenna design will focus on fabricating and evaluating the performance of the proposed antenna, both in practical and simulated environments. The integration of this single-component design into an array on a single substrate shows promise for achieving higher gain, directivity, and efficiency compared to traditional single-component antennas. However, challenges such as optimizing the spacing and arrangement of antenna elements and ensuring proper electrical connectivity need to be addressed. With further research and development, this innovative antenna design has the potential to revolutionize antenna technology and enhance communication systems in various fields.

REFERENCES

[1] M. H. Tariq, S. Rashid, F. A. Bhatti, “Dual-Band Microstrip PatchAntenna for WiMAX and WLAN Applications”, International Journal of Multidisciplinary and Current Research, vol.2, pp. 104-108, 2014.

[2] S. C. Gao, L. W. Li, T. S. Yeo, M. S. Leong, “Small Dual-Frequency Microstrip Antennas”, IEEE Transactions on vehicular technology, vol. 51, No.1, pp. 1916-1917, 2002.

[3] Garima, D.Bhatangar, J.S.Saini, V.K.Saxena, L.M.Joshi, “Design of Broadband Circular Microstrip Patch Antenna With Diamond Shaped Slot”, Indian Journal of Space And Physics, vol.40, pp.275-278,2011.

[4] J. A. Ansari, A. Mishra, N. P. Yadav, P. Singh, “Dualband Slot Loaded Circular Disk Patch Antenna for WLAN Application”, International Journal Of Microwave And Optical Technology, vol.5, No.3, pp. 124-129, 2010.

[5] G.Clementi, N.Fortino, J.-Y.Dauvignac, et al., ‘Frequency and time-domain analysis of different approaches to the backing of an UWB slot antenna’, IEEE Trans. Antennas Propag., vol. 60, No.7, pp.3495–3498, 2012.

[6] N.Ojaroudi, M.Ojaroudi, " Novel design of dual band-notched monopole antenna with bandwidth enhancement for UWB applications, IEEE Antennas Wirel. Propag. Lett., vol.12, pp. 698–701,2013.

[7] G.P.Gao,M.Li,S.F.Niu,X.J.Li,B.N.Li,J.S.Zang, “Study Of Novel Wideband Circular Slot Antenna Having Frequency Band Notched Function”,Progress In Electromagnetic Research(PIER)96, pp.141- 154, 2009.

[8] P. A. Nawle and R. G. Zope, “Rectangular microstrip patch antenna for 2.4 GHz communication using defected ground structure”, IJAFRC, vol. 2, No. 1, pp. 1–11, 2015.

[9] A. R. Chandran, et al., “Microstrip patch-based switched beam antenna at 2.45 GHz for wireless sensor network applications”, Journal of Electromagnetic Waves and Applications, vol. 31, no. 13, pp. 1333–1341, 2017.

[10] A. Ghaloua, et al., “A Miniature Microstrip Antenna Array using Circular Shaped Dumbbell for ISM Band Applications”, International Journal of Electrical and Computer Engineering (IJECE), vol. 8, No. 5, pp.3793-3800, 2017.

[11] L. Nageswara Rao, “Design and Development of Star Shaped Microstrip Patch Antenna for ISM Band Applications”, International Journal of Management, Technology And Engineering, vol. 8, No.11, pp. 1965-1969, 2018.

[12] M.S. Islam, M.I.Ibrahimy, S.M.A. Motakabber, and A.Z. Hossain,” A rectangular inset-fed patch antenna with defected ground structure for ISM band”, In 2018 7th International Conference on Computer and Communication Engineering (ICCCE) (pp. 104-108). IEEE, 2018.

[13] K.S. Ryu, A. Kishk, “UWB antenna with single or dual band-notches for lower WLAN band and upper WLAN band”, IEEE Trans. Antennas Propag., vol. 57, No.12, pp. 3942–3950, 2009.

[14] Y.Li, W.Li, W. Yu, et al., “A small multi-function circular slot antenna for reconfigurable UWB communication applications”, IEEE Antennas and Propagation Society Int. Symp. (APSURSI), pp. 834–835, 2014,

[15] A.A. Kalteh, G.R. DadashZadeh,M. Naser-Moghadasi, et al., “Ultrawideband circular slot antenna with reconfigurable notch band function”, IET Microw. Antennas Propag., vol.6, No.1, pp. 108–112, 2012.

[16] K. Anusury, S. Dollapalli, H. Survi, A. Kothari and P. Peshwe, “Microstrip Patch Antenna For 2.4 GHz Using Slotted Ground Plane”, In: 2019 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT): IEEE: 1-6

[17] A. Mallik, and S. Kundu, “ Design of a novel dual-band microstrip patch antenna operating at 2.45 GHz and 2.84 GHz with practical implementation”, In: Computer and Information Technology: IEEE: 40-5

[18] A. M. Abdulhussein, A. H.Khidhir, and A. A. Naser, “2.4 GHz Microstrip Patch Antenna for S-Band Wireless Communications”, In Journal of Physics: Conference Series, Vol. 2114, no. 1, p. 012029, 2021.