DESIGN OF A MINIATURE RECTANGULAR PATCH ANTENNA FOR 5G APPLICATIONS

Md. Firoz Ahmed[1], M. Hasnat Kabir[1] and Abu Zafor Muhammad Touhidul Islam[2]
[1]Department of Information and Communication Engineering, University of Rajshahi, Rajshahi, Bangladesh
[2]Department of Electrical and Electronic Engineering, University of Rajshahi, Rajshahi, Bangladesh
E-Mail: hasnatkabir11@gmail.com

ABSTRACT

The demands of tiny, high data rates and wide bandwidth systems have led to the development of the fifth generation (5G) communication technology. In this paper, a compact rectangular patch antenna employing amalgam method (AM) is developed to fulfill these requirements. The AM is formed by combining a slotted patch with a faulty partial ground structure. The operating frequency is selected as 3.5 GHz for 5G applications (2.9 to 4.4 GHz). FR4_epoxy dielectric substrate material having a size of 30 mm × 20 mm is used to design the proposed antenna, which has a dielectric constant of 4.4, a thickness of 0.8 mm, and a loss tangent of 0.02. A microstrip feedline method with a characteristics impedance of 50 Ω is used to excite the patch. The antenna is designed and simulated by utilizing high-frequency structure simulator (HFSS) software. The outcomes of the simulation show that the antenna achieves a bandwidth of more than 1.2 GHz, VSWR of 1.18, peak gain of 2.50 dB with a directivity of 2.67 dB, and efficiency of 96.25%.

Keywords: rectangular patch antenna, 5G, FR4_epoxy substrate, microstrip feedline, bandwidth, HFSS.

Manuscript Received 15 December 2022; Revised 18 August 2023; Published 30 August 2023

INTRODUCTION

The development of the 5G network has recently made a drastic change in the field of wireless communication systems. It offers high-speed data transmission rates of more than 1Gbps to broadcast live events, high-definition video streaming, autonomous driving, robotics, aviation, and healthcare applications, etc. [1]. The conventional fiber optic internet connection can almost be replaced by 5G wireless technologies. The benefit of 5G over other conventional mobile cellular technologies is its capacity to concurrently transmit voice and high-speed data. The lower and upper ends of the fifth-generation frequency range are roughly 3-5 GHz and 24-71 GHz, respectively, depending on the 5G implementation regulations in different countries [2]. The present generation of mobile devices and various types of sensors are connected by 5G technology using sub-6 GHz frequencies. High-gain wideband antennas are essential for maintaining high-speed transmission and reception in wireless communication systems. Low-profile antennas are also preferred for applications such as mobile base stations, inter-satellite communication, missiles, and more. Microstrip patch antennas (MPAs) are a better option than other types of antennas for certain application scenarios. MPA has several advantages, including smaller size, less weight, affordable production, simple installation, mechanical robustness, and design freedom [1]. It also reduces the excitation of additional undesirable modes. MPAs can be utilized in smaller electronic devices to increase portability and efficiency because of their tiny structure [3]. However, poor gains and restricted bandwidth are the key drawbacks of microstrip patch antennas [4]. MPA is the suitable choice for 5G applications because of its significant benefits. Therefore, these applications need a high data bit rate, broad bandwidth and speed. A variety of enhancement strategies can be used to improve the performance of an antenna such as gain, bandwidth, efficiency, and quality factor. For instance, a thicker substrate would increase the bandwidth since more surface waves would move over it and radiate from the patch. Thus, the antenna gains decrease, which could affect the overall performance of the antenna. The effectiveness of the antenna is also impacted by the size of the patch and feedline [5].

A microstrip patch antenna was developed by the authors of [6-7] employing a partial ground plane with slots and U-shaped slots. They found gains of 3 dB and 2.24 dBi, as well as bandwidths of 300 MHz and 360 MHz, respectively. The rectangular patch antenna was designed in [8-9] by using RT–5880 substrate, which has thicknesses of 1.574 mm and 1.57 mm. The bandwidth and gain of their antenna were 50 MHz and 72 MHz and 13.2 dB and 5.51 dB, respectively. The TLC-30 dielectric substrate was utilized in [10-11] with a permittivity value of 3, a thickness of 1.5 mm, and 1.575 mm in order to function at 3.1 GHz and 2.4 GHz, respectively. They achieved gains of 2.9 dB and 2.7 dBi, respectively. A multiband patch antenna was constructed by using an inset feed with several slots [12-13]. The analysis revealed gains of 5.06 dB and 4.752 dB. The antenna in [12] had a bandwidth of 4.5 GHz. A rectangular microstrip patch antenna was made by [14] using Rogers Ultralam1217 dielectric substrate. A gain of 7.944 dB was attained by the antenna. In [15], a microstrip patch with a rectangular T-shaped antenna was created. This antenna had the greatest bandwidth and gain of 1.5 GHz and 2.52 dB, respectively. A faulty ground configuration was employed to construct a rectangular microstrip patch antenna [16-17]. The simulation results show that the bandwidth and gain of the antenna were found to be 233.2 MHz and 3.661 dB, respectively [17]. Slits were used in [18] to create a microstrip patch antenna. It was found that this antenna's bandwidth and gain were 1.23 GHz and 6.35 dB, respectively. A 3.5 GHz microstrip patch antenna was developed in [19] applying three distinct substrate materials, such as FR-4, RT-5880, and TLC-30, each with a different relative permittivity. The FR4, RT-5880, and TLC-30 substrate materials each had gains and bandwidths of 3.338 dB, 4.660 dB, and 5.083 dB and 247.1 MHz, 129.7 MHz, and 177.2 MHz, respectively. In [20], a defective ground structure (DGS) was used to design a high-gain antenna. Peak gain, bandwidth, and efficiency for the constructed antenna were found to be 6.21 dB, 0.863 GHz, and 80 %, respectively. In [21], a multiband patch antenna was accomplished by utilizing an inset feed scheme. The simulation's findings showed a gain of 5.9755 dB and a bandwidth of 0.05 GHz. In [22], a tiny rectangular patch antenna with high gain and low cross-polarization features was designed, providing a gain of 6.62 dB, a bandwidth of 0.21 GHz, and an efficiency of 89%.

However, several antenna designs are mentioned in the literature [3, 6, 8-9, 11-15, 17, 20-22]. The major limitations of these antennas are their large size, and narrow bandwidths [6, 8-9, 17, 20-22]. In this paper, a miniature rectangular patch antenna using amalgam methodologies is proposed for 5G applications in order to decrease antenna size and boost bandwidth.

ANTENNA STRUCTURE

The geometry of a compact rectangular patch antenna using the amalgam method (AM) is depicted in Figure 1. A slotted patch and a faulty partial ground construction are combined to create the AM. The size of the patch is 14 mm × 18 mm. It comprises a right-angle triangular slot (p = q = 6 mm, r = 8.48 mm) and rectangular slots (L_{p1}= 8 mm, W_{p1}= 2 mm, $L_{p5} = L_{p6} = W_{p2} = W_{p3} = W_{p4} = 0$ .5 mm, $L_{p2} = L_{p3} = L_{p4} = 7$ mm, $W_{p5} = W_{p6} = 6.5$ mm). The patch is made on the top of the FR4 substrate. The dimension of the FR4 substrate is 30 mm × 20 mm. It has a dielectric constant of 4.4, a thickness of 0.8 mm, and a loss tangent of 0.02. A microstrip feedline having a dimension of 15 mm × 2 mm is used to excite the patch. A partial ground plane of 20 mm × 14 mm with a single rectangular slot having the dimension of 3 mm × 2 mm is inserted on the rare side of the dielectric material. Partial grounding converts the patch antenna's narrow band features into wide band properties. It also diminishes back lobe radiation and the energy stored in the substrate. Slots minimize the VSWR, return loss, and overall size of the antenna. It improves the bandwidth and gain of the antenna. The various parameter values of the proposed antenna are shown in Table 1.

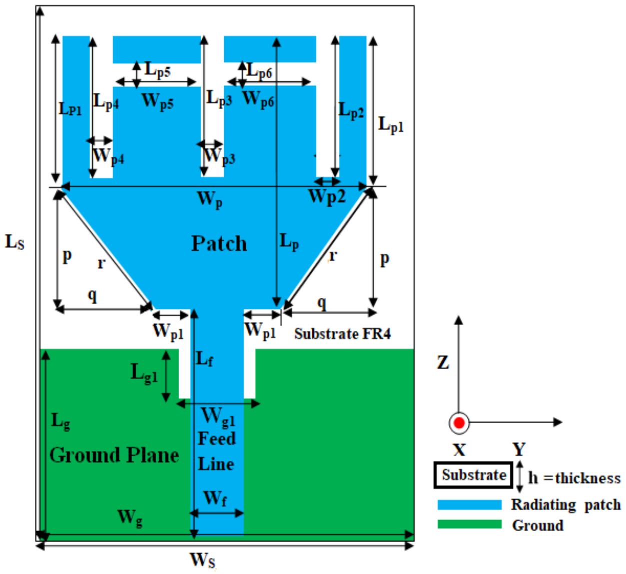

Figure-1. Proposed antenna structure.

Table-1. Design Parameters of the proposed antenna.

Parameters	Values (mm)
Ws = W_g	20
Ls	30
h	0.8
Wp	18
$L_p = L_g$	14
L_f	15
$W_f = W_{g1} = W_{p1}$	2
L_{g1}	3
L_{p1}	8
$L_{p5}=L_{p6}=W_{p2}=W_{p3}=W_{p4}$	0.5
$L_{p2}=L_{p3}=L_{p4}$	7
$W_{p5}=W_{p6}$	6.5
p = q	6
r	8.48

SIMULATED RESULTS AND DISCUSSION

The properties of the proposed antenna such as return loss, bandwidth, VSWR, radiation pattern, gain, directivity, and efficiency are discussed in this section. High-Frequency Structure Simulator (HFSS) has been used to design, analyze, and simulate the antenna. The parameters have been presented clearly based on the results.

Return Loss

Return loss describes how electrical power is transferred from the feed point to the antenna. It plays a crucial role in ensuring that the impedance matching criterion is met. To maximize power transfer and minimize reflection at the load terminal, impedance matching is the process of designing the antenna's input impedance or matching it to the associated RF circuitry's output impedance. Impedance matching is achieved by using a 50-ohm characteristic impedance. A return loss value of -10 dB is used as the reference level, implying that 90% of the power is received by the antenna and only 10% is reflected, which is regarded as excellent for mobile communication. The return loss (RL) for the proposed antenna is shown in Figure 2. The lowest return loss of the suggested antenna is -21.32 dB at 3.5 GHz, which indicates good impedance matching between the feed line and the radiating patch. The antenna radiates maximum power at this frequency and reflects minimum power. So, a return loss of -21.32dB dB means that the reflected power is -21.32dB dB lower than the incident power. In this case, 99.31% of the available power is transmitted into the antenna.

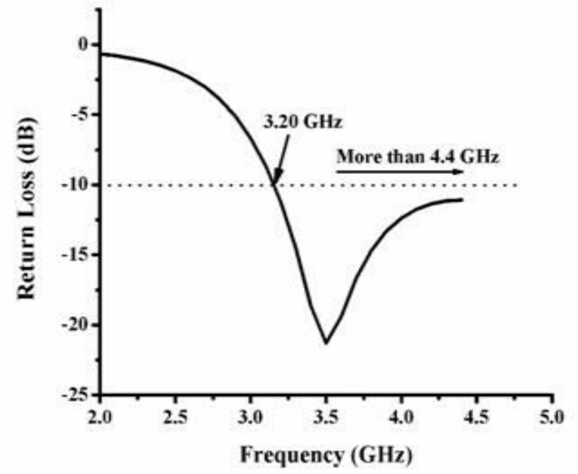

Figure-2. Return loss of the proposed antenna.

The return loss graph is used to compute the bandwidth. The frequency range over which the RL is less than -10 dB can be considered the antenna's bandwidth which is shown in Figure 2. The bandwidth can also be expressed as a percentage of the band's center frequency.

Bandwidth (BW) = Higher cut-off frequency - Lower cut-off frequency

The planned antenna has an upper and lower cut-off frequency of more than 4.4 GHz and 3.20 GHz, respectively. The estimated bandwidth of the antenna is more than 1.2 GHz, which is better than that reported in refs [6, 8-9, 17, 20-22].

VSWR

Voltage standing wave ratio (VSWR) is a metric that measures the impedance matching between the antenna and the feedline line connected to it. It is also known as the standing wave ratio. A high VSWR is an indicator that before radiation the antenna reflects the signal. In practical terms, the VSWR should be between 1 and 2 for less loss in reflection. Based on the value of VSWR we find how the system is operated efficiently. The lower the VSWR, the better the impedance of the antenna is matched to the feed line or transmission line, and the higher the power supplied to the antenna. The VSWR is caused by impedance mismatches between the input and the reflected signal within the connector, which results in certain signals being reflected.

The Voltage Standing Wave Ratio (VSWR) versus frequency graph of the designed antenna is shown in the Figure-3. The VSWR of the proposed antenna is 1.18 at 3.5 GHz, which is less than 2 which indicates that the antenna matches perfectly. This means the antenna is properly designed in the entire frequency band. A VSWR of 1.18 indicates around 99.31 percent of the power supplied to the antenna (i.e. 0.02973 dB mismatch loss).

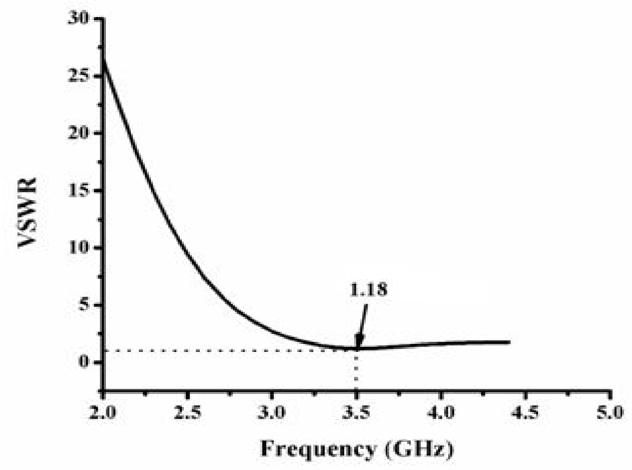

Figure-3. VSWR of the proposed antenna.

Radiation Pattern

The radiation pattern of the antenna describes its radiation properties when measured on the surface of a sphere with a fixed radius. It is analyzed employing a spherical coordinate system. From Figure 4, it has been observed that the antenna is showing an omnidirectional radiation pattern. The antenna radiates a maximum power of 20.243 dB at the resonant frequency of 3.5 GHz.

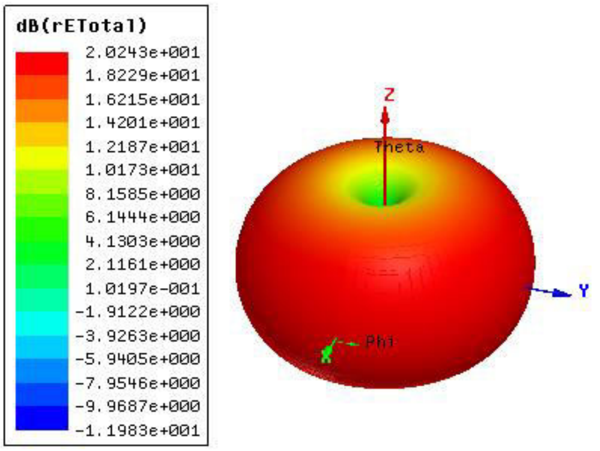

Figure-4. The 3D far-field radiation pattern of the proposed antenna.

Directivity

It is the capability of an antenna to concentrate electromagnetic energy in a specific direction. The simulation result of the directivity of the proposed antenna at various operating frequencies is shown in Figure 5. The peak directivity ranges from 2.43 dB to 3.03 dB within the operating frequency range from 3.20 GHz to more than 4.4 GHz. The suggested antenna attains a directivity of 2.67 dB at the resonant frequency of 3.5 GHz. The lower directivity of the planned antenna indicates that it can transmit and receive radio frequency energy almost equally in all directions, whereas the higher directivity indicates that it can transmit or receive energy in a specific direction. The various directivities given by the recommended antenna allow it to be employed for a wide range of directivity-based applications. Low directivity antennas are advantageous for mobile applications while high directivity antennas are advantageous for stationary installations like satellite TV.

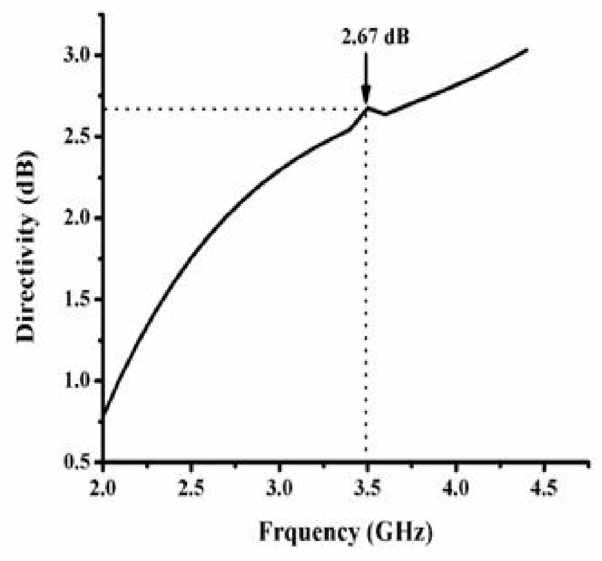

Figure-5. Directivity of the proposed antenna.

Gain

Gain is the process of converting electrical energy into radio waves traveling in a specific direction. The gain result of the proposed antenna is shown in the Figure 6. The peak gain ranges from 2.30 dB to 2.94 dB within the operating frequency range from 3.20 GHz to more than 4.4 GHz. The planned antenna yields a gain of 2.50 dB at the resonant frequency of 3.5 GHz. The lower gain of the recommended antenna indicates that it can transmit and receive RF energy in almost any direction without the need for extremely precise targeting, whereas the higher gain indicates that more power is received or transmitted in one direction and it attenuates all other signals from other directions. The suggested antenna can be used for numerous gain-based applications due to the different gains it provides. Low gain antennas are used for point-to-multipoint and short-range communication, whereas high gain antennas are useful for high speed communication.

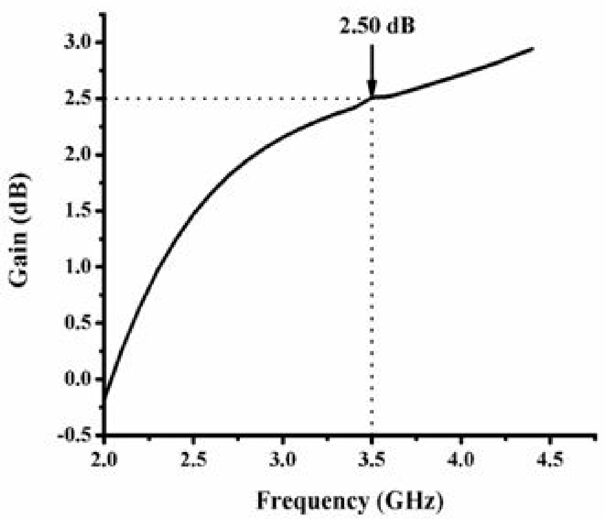

Figure-6. Gain of the proposed antenna.

Efficiency

The ratio of total energy radiated to net energy received by the antenna is crucially indicated by antenna efficiency. The simulated efficiency graph of the proposed antenna is depicted in Figure 7. As can be observed, the efficiency ranges from 0.9706 (97.06%) to 0.9796 (97.96%) for most of the 5G frequencies under concern and the antenna achieves a peak efficiency of 96.25% at the resonant frequency of 3.5 GHz. The recommended antenna can effectively radiate the input power into free space due to its efficiency of 96.25%. Long battery life, a large communication range, and low error rates can be anticipated as a result of its high efficiency.

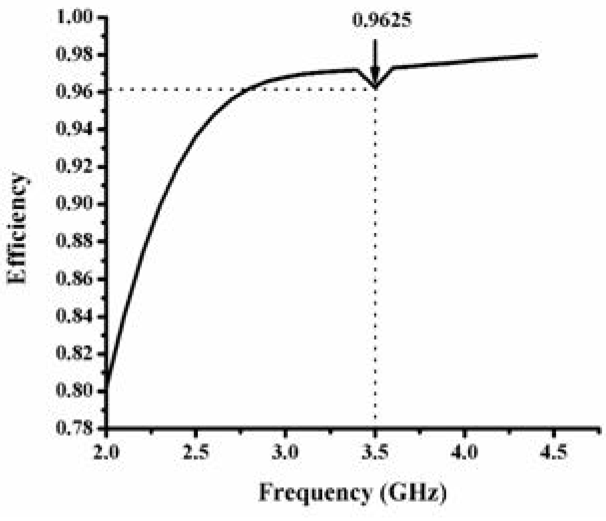

Figure-7. Efficiency of the proposed antenna.

Table-2. Comparison of the proposed antenna with referenced antennas.

Refs.	Antenna Size (L × W ×h) mm^3	OBW (GHz)	BW (GHz)	Gain (dB)	Efficiency (%)
[3]	25.2×48×1.6	-	-	5.01	96.67
[6]	50×50×1.6	3.3 - 3.6	0.3	3	-
[8]	34.844×40.644×1.574	3.7693 - 3.8413	0.072	13.2	-
[9]	63.4×60.5×1.57	2.47 - 2.52	0.05	5.51	-
[11]	46×37×1.5	-	-	2.7 dBi	
[15]	22×24×0.25	2.90-4.48	1.58	2.52	98.474
[17]	45×35×1.6	3.3949-3.6281	0.2332	3.661	
[20]	28.03 × 23.45× 1.6	4.921-5.784	0.863	6.21	80
[21]	33.5 × 28.2× 1	3.48-3.53	0.05	5.9755	-
[22]	43.36 × 35× 1.575	3.44-3.65	0.21	6.62	89
This work	30 × 20 × 0.8	3.12-22.66	19.54	8.7	96.14

OBW = Operating bandwidth, BW = Bandwidth.

COMPARISON WITH RECENT WORKS

Table-2 shows the comparison of the suggested antenna with other referenced antennas. It is evident from the table that most of the researchers such as [3, 6, 8-9, 11, 15, 17, 20-22] were tried to enhance the gain and bandwidth of the antenna. However, their planned antenna is massive, and they were able to achieve a limited bandwidth [6, 8-9, 17, 20-22]. An incredible 13.2 dB gain was achieved by using a large antenna [8]. The proposed antenna is compact in size and has a bandwidth of over 1.2 GHz (3.20 GHz to more than 4.4 GHz), which is higher than that of the referenced antennas [6, 8-9, 17, 20-22]. It has a gain of 2.50 dB, which is lower than that stated in the references [3, 6, 8-9, 11, 15, 17, 20-22]. Despite having a lower gain, the proposed antenna has a wider bandwidth, which improves data transfer rates. So, we can conclude that the recommended antenna satisfies the criteria for 5G wireless communication.

CONCLUSIONS

In this article, a miniature rectangular patch antenna for 5G applications using amalgam method has been successfully designed, simulated, and investigated. The simulation has been done by using high-frequency structure simulator (HFSS). The outcomes of the simulation demonstrate that the suggested antenna can be a good candidate for 5G applications since it has a broader bandwidth of more than 1.2 GHz (from 3.20 GHz to more than 4.4 GHz), a gain of 2.50 dB, a VSWR of 1.18, a directivity of 2.67 dB, an efficiency of 96.25%, and a minimal return loss of -21.32 dB.

REFERENCE

[1] Wei H., Tzuang C. K. C. and Fan Y. 2014. New antenna technology for 5G wireless communications [Guest editors' introduction]. China Communications. 11(11).

[2] Sayidmarie K. H., McEwan N. J., Excell P. S., Abd-Alhameed R. A. and See C. H. 2019. Antennas for Emerging 5G Systems. International Journal of Antennas and Propagation, 2019. pp. 6-9.

[3] Ferdous N., Hock G. C., Hamid S. H. A., Raman M. N. A., Kiong T. S. and Ismail M. 2019, June. Design of a small patch antenna at 3.5 GHz for 5G application. In IOP Conference Series: Earth and Environmental Science (268(1): 012152). IOP Publishing

[4] Yaduvanshi R. S., Parthasarathy H. and De A. 2011. Magneto-Hydrodynamic Antenna Design and Development Analysis with prototype. International Journal of Advanced Computer Science and Applications. 2(2): pp. 97-104.

[5] Nagapushpa K. P. and Chitra K. N. 2017. Studying applicability feasibility of OFDM in upcoming 5G network. International Journal of Advanced Computer Science and Applications, 8(1), pp. 216-226.

[6] Cheekatla A. R. and Ashtankar P. S. 2019. Compact micro strip antenna for 5g mobile phone applications.

International Journal of Applied Engineering Research. 14(2): 108-111.

[7] Ashish J. and Rao A. P. 2019, November. Design and Implementation of Compact Dual band U-slot Microstrip Antenna for 2.4 GHz WLAN and 3.5 GHz WiMAX Applications. In 2019 International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India. pp. 1084-1086.

[8] Sajjad H., Sethi W. T., Zeb K. and Mairaj A. 2014, March. Microstrip patch antenna array at 3.8 GHz for WiMax and UAV applications. In 2014 International Workshop on Antenna Technology: Small Antennas, Novel EM Structures and Materials, and Applications (iWAT), Sydney, Australia. pp. 107-110.

[9] Sampe J., Yunus N. H. M., Yunas J., Pawi A. and Rhazali Z. A. 2018. Design and fabrication of a dual band 1.8/2.5 GHZ antenna for RF energy harvester. Int. J. Eng. Technol. 7, pp. 3574-3578.

[10] Pakkiam K. T. and Mandeep J. S. 2016. November. Design of multiband parallel strip patch antenna for DCS/WLAN/WIMAX and RFID applications. In 2016 IEEE Industrial Electronics and Applications Conference (IEACon), Kota Kinabalu, Malaysia, pp. 348-353.

[11] Pakkiam K. T., Mandeep J. S. and Islam M. T. 2012, November. Design of microstrip antenna for modern wireless communication. In 2012 International Symposium on Telecommunication Technologies, Kuala Lumpur, Malaysia. pp. 42-46.

[12] Mahabub A., Rahman M. M., Al-Amin M., Rahman M. S. and Rana M. M. 2018. Design of a multiband patch antenna for 5G communication systems. Open Journal of Antennas and Propagation. 6(1): 1-14.

[13] Lurthumary J., Sri Kumar S., Shanthakumar L. S.& Tamil Kana l S. 2021. Design of multiband microstrip antenna for 5G wireless communication. International Journal of Innovative Research in Technology. 7, pp. 370-372.

[14] Maheswari T., Sankar V. U., Reddy S. S., Kumar B. P. and Rushendrababu K. 2019. Design of a Microstrip patch Antenna for 5G Wireless Applications. IJRAR-International Journal of Research and Analytical Reviews (IJRAR). 6(1): 510-515.

[15] Abdulbari A. A., Jawad M. M., Hanoosh H. O., Saare, M. A., Lashari S. A., Sari S. A. and Hussain Y. M. 2021. Design compact microstrap patch antenna with T-shaped 5G application. Bulletin of Electrical Engineering and Informatics. 10(4): 2072-2078.

[16] Sivaprakash S. C., Aniksha M., Aadithya M. and Nivetha K. 2022. Design of Rectangular Microstrip Patch Antenna for 5G mobile application. International Journal of Scientific Development and Research. 7, pp. 332-335.

[17] Paragya D. and Siswono H. 2020. 3.5 GHz rectangular patch microstrip antenna with defected ground structure for 5G. ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika. 8(1): 31-42.

[18] Musa U., Babani S., Yunusa Z. and Ali A. S. 2021, January. Bandwidth Enhancement of Microstrip Patch Antenna Using Slits for 5G Mobile Communication Networks. In 2020 International Symposium on Antennas and Propagation (ISAP). pp. 559-560.

[19] Ramli N., Noor S. K., Khalifa T. and Abd Rahman N. H. 2020. Design and performance analysis of different dielectric substrate based microstrip patch antenna for 5G applications. International Journal of Advanced Computer Science and Applications. 11(8): 77-83.

[20] Olawoye T. O. and Kumar P. 2022. A High Gain Antenna with DGS for Sub-6 GHz 5G Communications. Advanced Electromagnetics. 11(1), pp. 41-50.

[21] Elechi P. and John P. R. 2022. Improved Multiband Rectangular Microstrip Patch Antenna for 5G Application. Journal of Telecommunication, Electronic and Computer Engineering (JTEC). 14(2): 7-14.

[22] Ibrahim S. K. and Jebur Z. T. 2021, June. A High Gain Compact Rectangular Patch Antenna for 5G Applications. In 2021 International Conference on Communication & Information Technology (ICICT), Basrah, Iraq. pp. 156-160.