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Millimeter-Wave Rectangular Microstrip Patch Antenna Design For 5G Applications

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ABSTRACT

Until now, the fourth generation (4G) communication system is already been standardized. But, Fifth Generation (5G) is defined as the upcoming major task for mobile communication systems beyond the current deployed 4G. In this research article an inverted U-Shaped slot single-band rectangular microstrip patch antenna for mm-wave 5G (Fifth Generation) applications is proposed. The proposed antenna achieved a high bandwidth by choosing the proper selection of slot dimensions and position in the radiating patch. The overall size of the proposed antenna is 4 x 5 mm^2 (LxW) with a 0.508 mm substrate height. The proposed inverted U-Shaped slot patch antenna resonates over a frequency range from 63.28-90 GHz having a super-wide impedance bandwidth of 26.76 GHz. A maximum gain of 6.11 with a maximum radiation efficiency of 92.48% at 79 GHz is also observed. The gain of 4.04 dBi, 5.99 dBi and 5.99 dBi at frequencies 71.03, 75, and 80 GHz, respectively are also achieved. Other radiation parameters like E and H-plane, surface current and 3D (Three-Dimensional) gain plots are also studied and analyzed. The proposed antenna has a super-wide bandwidth and suitable for 5G mm-wave (millimeter wave) communication. The

proposed design can also be used for satellite and radar communication as 40-75 GHz for V-band, 60-90 GHz for E-band and 75-110 GHz for W-band are the new proposed satellite bands.

Keywords: Fifth Generation, Microstrip Patch Antenna, Milli-Meter wave ,Bandwidth, Directivity.

1. INTRODUCTION

In last two decades, an enormous evolution is seen in the wireless devices which are connected to each other through wireless networks. Due to wireless technology, people's interest has greatly increase to share, convey and aware in social functions together[1]. Different Mobile and wireless communication networks such as GSM (Global system for mobile communication), 2G (2nd Generation), 2.5G, 3G (3rd Generation) and 4G (4th Generation) made a marvelous change in world[2]. As a tendency, up to now, the 4G wireless communication system is standardized already. And next, the 5G (Fifth Generation) standard is expected to be deployed completely in 2022 and onward within few years [3].

Upcoming 5G wireless communication will provide more advantage to the world and will make an important difference because the 5G wireless technology has all type of advanced characteristics which make it a most powerful way of wireless communications and will bring changes all over the world. However, the 5G standard is yet to be confirmed as the technology is to be fledged. Some 5G bands for upcoming wireless communication are shown in Fig. 1 [4].

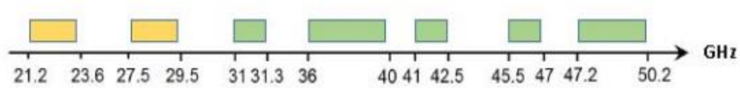


FIG .1. 5G BANDS FOR UPCOMING COMMUNICATION

In addition to this, the WRC-19 (World Broadcast Conference-2019) the key spectrum for 5G application is 20–90 GHz[5] and prepared appropriate frequencies bands ranges from 24.25-27.5, 31.8-33.4and 37-40.5GHz bands respectively, for mm-wave communications as shown in Fig.2[6]. The proposed prime spectrum for 5G application is 20–90 GHz.

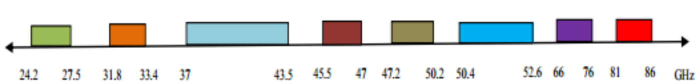


FIG. 2. MM-WAVE 5G FREQUENCY BANDS

To meet the needs of 5G such as high capacity, high data rate, more users, high reliability, lower response time(latency), new thoughts and antenna designs are greatly required in the field of 5G technology, which is a key challenge for 5G wireless communication system [7]. As we are familiar with that mm-wave has a huge band of bandwidth. i.e. from3-300 GHz [8]. For 5G Wireless Communications FCC (Federal Communications Commission) assigned the frequency spectrum listed as 5GHz (5.1-5.85GHz), 28GHz (27.5-28.35 GHz), 37GHz (37-38.6GHz), 39GHz (38.6-40 GHz), 64-71 GHz band contain outdated cellular licensing and Wi-Fi for both local area network and wide area network [9].

Printed antennas or microstrip patch antennas are the most significant antennas due to its planar surface. There are various microstrip antennas types and the mostly used antenna are the rectangle and square microstrip patch antenna [10]. Such antennas types are used in a wide-ranging applications i.e. airplane, satellite broadcasting, arms, mobile phones and in medical systems, because of some important features such as lightweight with low profile (conformal), easy to fabricate, simple feeding (m-line feeding, aperture coupled feed etc.), easy to use in an array configuration by a reasonable directivity (about 6-8 dB is typical)[10]. Furthermore, it has a dis advantages of lower bandwidth (but can be improved using various devised techniques) [11-12] and losses due to surface wave, many workings have been done to use as stacked patch or an air cavity opening in more than one substrates. But these techniques may rise complexity and cost [13]. The technique of feeding is one of the most important features which is used to improve the impedance bandwidth. However, the feeding choice of technique depends on antenna fabrication, cost, and implementation of hardware with extra radiation, and matching of impedance [14].

Newly, most researcher delivered different antenna design techniques for 5G applications. Efri and Marani [15] proposed an antenna of triple band resonating on 24, 38and 38GHz was proposed having a bandwidth ≥1000 MHz is achieved. A microstrip patch antenna of single band for 5G wireless application was presented by Jyoti Agarwal [16] resonating on 60GHz which is appropriate for the mm-wave frequency. The antenna was consist of H and E slot designed on the radiating patch having a bandwidth of 4.028 GHz ranging from 57.981-62.009 GHz. The FCC allotted the 59-64 GHz bands as an unlicensed band which suitable for the small range and wireless communication of high speed [17]. Marwaet. al. [18] an antenna of dual band resonating on 38 and 60 GHz was presented for 5G mobile devices. The impedance bandwidth was 2 and 3.2 GHz achieved respectively. In order to cover a wide spectrum for upcoming 5G communications, an inverted U-Shaped slot single antenna element is introduced in designing in order to achieve a wideband. The proposed design is enable a coverage above 62 GHz. The best feature of our proposed antenna is that at operate over a frequency range starts from 63.28 GHz up to almost 90 GHz with a wide bandwidth of 26.72 GHz. The proposed design can be used for satellite and radar communication as 40-75 GHz for V-band, 60-90GHz for E-band and 75-110GHz for W-band. Numerous printed antennas are designed using different techniques for the mm-wave 5G applications [19-25].

In this paper, we proposed an antenna of small size for a 5G mm-wave application having a wide bandwidth of 26.72GHz with high radiation efficiency and high gain. The rest of the paper is organized as follows: Section 2 discusses the design of the antenna and section 3 discusses the results and discussion.

2. ANTENNA DESIGN AND STRUCTURE

The front view of the proposed antenna is presented in Fig.1. The overall size of the proposed microstrip patch antenna is 4x5x0.508 mm^3 (Lx Wxh). The Rogers TMM4 substrate is used as a dielectric material having relative permittivity (ϵ_r) of 4.5 and loss Tangent of 0.002 with the height of the substrate is 0.508 mm. Microstrip inset feed line is used for the designing of the proposed antenna. The feed width (w_f) is 0.5 mm and feed length L_f is 2 mm. The radiating patch dimensions (L_p×W_p) are (1.70×1.95 mm). To cover a wide spectrum for upcoming 5G communication, an inverted U-Shaped slot is introduced at the top edges of the radiating patch. The dimensions of the inverted U-Shaped slot vertical part 0.1x1 mm^2 (LxW) and the dimensions of the horizontal part are 0.1x1.25m m^2.The perspective view and back view (Ground) of the proposed antenna as shown in Figs.2-3 respectively. The parametric values of the proposed antenna for mm-wave 5G communication are listed below in Table 1. The Parameter values of the proposed microstrip patch antenna are calculated using formulas, stated below. Using mathematical equations [26], the single band microstrip patch antenna dimensions are calculated, like equation 1 is used for calculation of width where f_0 is the resonant frequency, c is the speed of light and ϵ_r is the dielectric constant of the substrate. Equation 2 is for the actual length of patch.

$$W = \frac{c}{f_0}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

$$L = L_{eff}\text{-}2\Delta L \quad (2)$$

Where L_{eff} is the effective length and can be determined as (3) and ΔL is the extension of length can be determined from expression (4).

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}} \quad (3)$$

$$\Delta L = (0.412h)\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

Where ϵ_{reff} is effective permittivity calculated from 5

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{1+12\frac{h}{w}}} \quad (5)$$

ϵ_r is the dielectric constant of the substrate, 'h' is the height of substrate and 'W' is the width of ground plane.

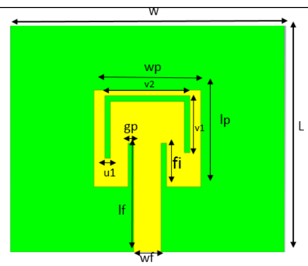


FIG. 1. FRONT VIEW OF PROPOSED ANTENNA

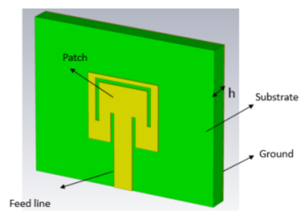


FIG.2. PERSPECTIVE VIEW OF ANTENNA

FIG.3. BACK VIEW (GROUND)

TABLE 1. PARAMETER VALUES OF PROPOSED RMP ANTENNA

Description	Name	Value (mm)
Length of Substrate and ground	L	4.00
Length of Patch	l_p	1.70
Thickness of Substrate Material	h_s	0.508
Width of Feed line	w_f	0.5
Width of U-slot	U_1	0.1
Length of Horizontal U-slot	V_2	1.45
Width of Substrate and ground	W	5.00
Width of Patch	w_p	1.95
Thickness of Patch	m_t	0.035
Length of Feed line	l_f	2.00

Length of U-slot	V_1	1.00

3. SIMULATION RESULTS

3.1 S-Parameter

The most significant feature in an antenna designing is the reflection coefficient (S_{11}) which defines impedance matching and bandwidth.The reflection coefficient is the loss of power signal returned/reflected due to incoherence in a transmission line. Basically, the S-Parameter describes the input to output relation between Ports. The S_{11} is also known as return/reflected loss. The 0dB S_{11} means that all the power of signal is reflected and -10dB means that 3dB power is transmitted to the antenna and -7dB of power is reflected, so the S_{11} should be less then -10dB than antenna perform effectively. The proposed antenna has a return loss of -55.90 dB at a resonating frequency of 71.03 GHz and below -10 dB at achieved and which starts from63.28GHz up to almost 90 GHz with the bandwidth of 26.72 GHz as shown in Fig. 4.

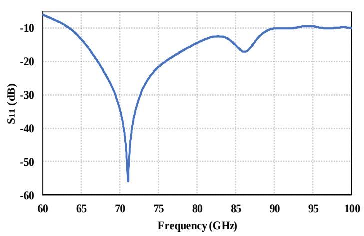


FIG. 4. SIMULATION REFLECTION COEFFICIENT OF THE PROPOSED MM-WAVE MICROSTRIP PATCH ANTENNA

3.2 Voltage Standing Wave Ratio

VSWR (Voltage Standing Wave Ratio) can be measured of how the power of radio-frequency is transmitted efficiently from a power source , into a load, through a transmission line. VSWR is the another parameter which indicates that the antenna can only be able to work where the optimum VSWR value is ≤ 2. Furthermore, if value of VSWR is small, than the antenna will perform better and vice versa. VSWR also define the matching of impedances to the transmission line. The VSWR of proposed antenna is 1.005 at 71.08 GHz as shown in Fig. 5.

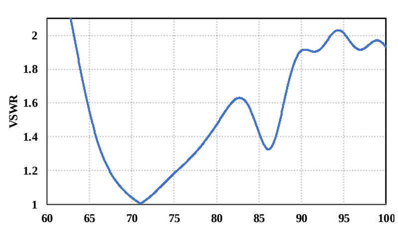
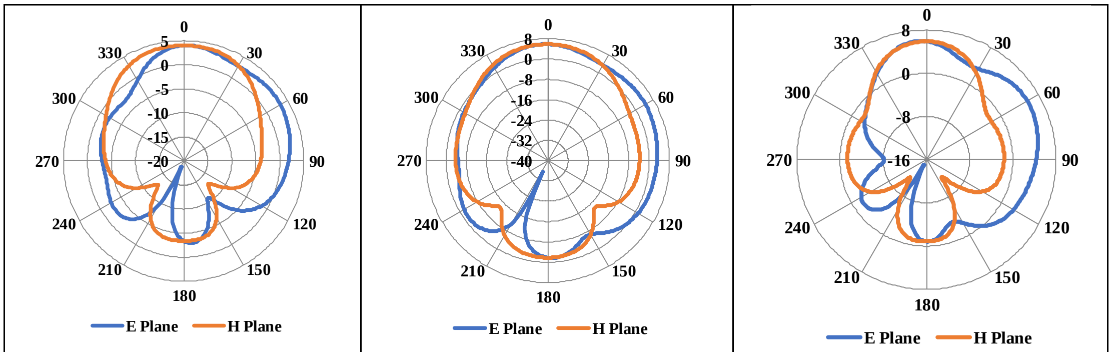


FIG.5. VSWR OF PROPOSEDRECTANGULAR MICROSTRIP PATCH(RMP) ANTENNA

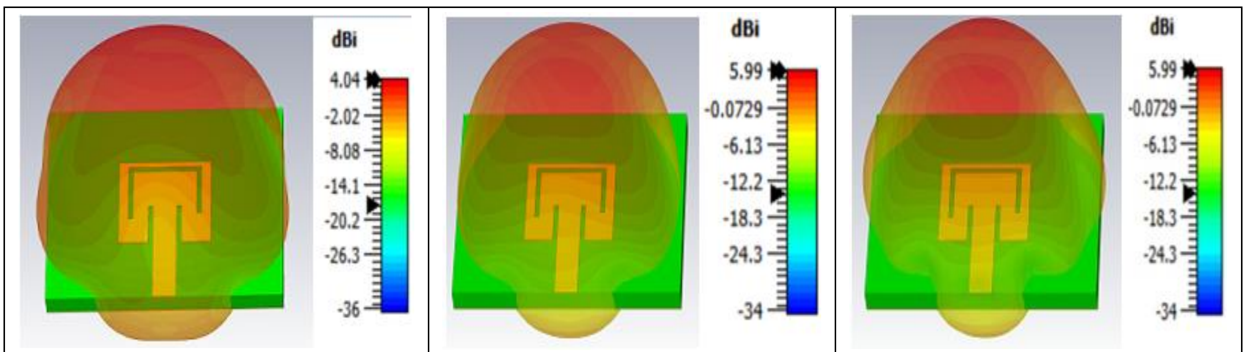
3.3 Radiation Patterns

The gain patterns and radiation efficiencies are obtained by exciting the antenna with 50 ohm matched load. The simulated radiation pattern (2D and 3D) of proposed a resonating frequency are shown in Figs. 6(a-c)-7(a-c)respectively. The gain of proposed antenna design are 4.04dBi, 5.99dBi, and 5.99dBi at 71.03GHz, 75GHzand 80 GHz respectively.



(A) 71.03 GHZ | (B) 75 GHZ | (C) 80 GHZ

FIG. 6. SIMULATED 2-D RADIATION PATTEREN (E AND H-PLANE)OF PROPOSEDMM-WAVE RMP ANTENNA



(A) 71.03 GHZ | (B) 75 GHZ | (C) 80 GHZ

FIG. 7. SIMULATED 3D GAIN PLOTS OF THE PROPOSED MM-WAVE ANTENNA

3.4 Surface Current Distribution:

The radiation efficiency and Gain vs frequency plot of the proposed work are shown in figure 8(a-b) respectively. The maximum radiation efficiency of 92.48% at 79 GHz is observed.

Surface current distribution at frequencies 71.03 GHz, 75 GHz and 80 GHz are depicted in Figs.9(a-c). Table 2 presents the performance of proposed antenna with previous antenna designs.

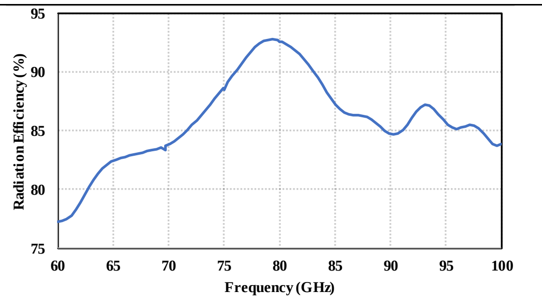


FIG. 8(A). RADIATION EFFICIENCY

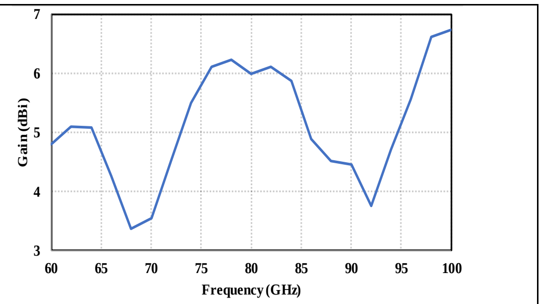
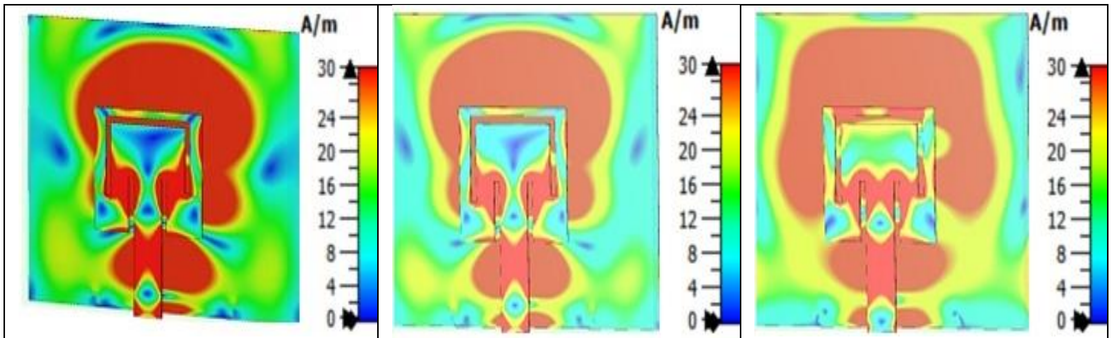


FIG. 8(B). GAINVS FREQUENCY PLOTS OF THE PROPOSED MM-WAVE RMP ANTENNA



(A) 71.03 GHZ | (B) 75 GHZ | (C) 80 GHZ

FIG. 9 . SURFACE CURRENT DISTRIBUTION OF PROPOSED MM-WAVE RMP ANTENNA

TABLE 2. COMPARISON OF OTHERS ANTENNA WITH PROPOSED ANTENNA

Published Antenna	Bandwidth (GHz)	Gain (dB)	Size of Antenna (mm)	Efficiency (%)
Ali et. al. [1]	-	6.60	5x5	73.00
Saini et. al. [16]	4.028	5.48	8x8	70
Jandi et. al. [19]	-	7.50	21x21	62.00
Oyesina et. al. [20]	2.40	5.56	6x6	97.70
Khattak et. al. [21]	1.30	7.60	6x6	85.60
Kaeib et. al. [22]	2.48	6.37	7x7	86.73

Proposed Work	26.76	6.11 (dBi)	4x5	92.00

4. CONCLUSION

A single band of U-Shaped slot rectangular Microstrip patch antenna is designed in this paper. The proposed antenna is designed for future mm-wave 5G communication and used for above 60 GHz frequency band. Rogers TMM4 as a substrate are used of thickness 0.508mm with a relative permittivity of 4.5. The centered frequency of single-band antenna is 71.03 GHz having return loss of -55.9 dB and a bandwidth of 26.76 GHz in the range of 63.28-90GHz. The gain at 71.03GHz, 75GHzand 80 GHz are 4.04dBi d,5.99dBiand 5.99 dBi, respectively.The VSWR value of this antenna is 1.005 which is less than 2dB. The radiation efficiency of this antenna are 92% at 79 GHz. The proposed antenna possesses wider bandwidth which is useful for mm-wave 5G communication. Radiation characteritics can further be improved by applying different techniques reported in literature like array techniques, MIMO (Multiple-Input and Multiple-Output) configuration and frequency selective surfaces, beam steering, metamaterials etc.

The prototype of the antenna will be fabricated and tested in measurement facility in order to validate the simulation results. In addition a feeding network will be designed for the array antennas to make the design simpler to fabricate and operate.

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REFERENCES

[1] Ali, M.M.M., and Sebak, A.-R., "Dual Band (28/38 GHz) CPW Slot Directive Antenna for Future5G Cellular Applications", IEEE International Symposium on Antennas and Propagation, pp. 399-400, 2016.

[2] Chauhan, B., Vijay, S., and Gupta, S., "Millimeter-Wave Mobile Communications Microstrip Antenna for 5G-A Future Antenna", International Journal of Computer Applications, Volume 99, No. 19, pp. 15-18, 2014.

[3] Km, K., Singh, A., Aneesh, M., and Ansari, J.A., "Novel Design of Microstrip Antenna with Improved Bandwidth", International Journal of Microwave Science and Technology, 2014.

[4] Hedayati, M.K., Abdipour, A., Shirazi, R.S., John, M., Ammann, M.J., and Staszewski, R.B., "A 38 GHz On-Chip Antenna in 28-nm CMOS Using Artificial Magnetic Conductor for 5G Wireless Systems", IEEE 4th International Conference on Millimeter-Wave and Terahertz Technologies, pp. 29-32, 2016.

[5] Anab, M., Khattak, M.I., Owais, S.M., Khattak, A.A., and Sultan, A., "Design and Analysis of Millimeter Wave Dielectric Resonator Antenna for 5G Wireless Communication Systems", Progress In Electromagnetics Research, Volume 98, pp. 239-255, 2020.

[6] Harini, V., Sairam, M.V.S. and Madhu, R., "Performance Analysis of Pentagon Shaped Millimeter Wave Antenna for 5G Femto cells Applications", IEEE International Conference on Smart Systems and Inventive Technology, pp. 284-287, 2019.

[7] Soliman, Md.M., Hakim, M.L., Uddin, M.J., Faisal, M.M.A.,and Rahaman, A., "Optimization of Design Parameters of Microstrip Patch Antenna at 28 GHz and 38 GHz for 5G Applications", IEEE International Conference on Telecommunications and Photonics, pp. 1-4, 2019.

[8] Ullah, R., Ullah, S., Umar, S.M., Ullah, R., and Kamal, B., "Design and Modeling of a 28/38/60/70/80 GHz Antenna for Fifth Generation (5G) Mobile and Millimeter Wave (mmW) Applications", IEEE International Conference on Electrical, Communication, and Computer Engineering, pp. 1-7, 2019.

[9] Sunthari, M., and Veeramani, R., "Multiband Microstrip Patch Antenna for 5G Wireless Applications Using MIMO Techniques", IEEE 1st International Conference on Recent Advances in Aerospace Engineering, pp. 1-5, 2017.

[10] Misbah, O.M.A., Zayid, A.M.E., and Samra, E.H.A.,. "Design and Analysis of Millimeter Wave Microstrip Patch Antenna for 5G Applications", International Conference on Technical Sciences, Volume 6, pp. 4, 2019.

[11] Rabbani, M.S., and Ghafouri-Shiraz, H., "Simple Methods for Enhancing Bandwidth of a Rectangular Microstrip Patch Antenna" IET 2nd Annual Active and Passive RF Devices Seminar, pp. 1-4, 2014.

[12] Chen, W., Wu, K.-L., Bi, Z.-Q., and Litva, J., "Accurate Characterization of Planar Printed Antennas Using Finite-Difference Time-Domain Method", IEEE Transactions on Antennas and Propagation, Volume 40, No. 5, pp. 526-534, 1992.

[13] Ehab, D., and Qasem, N., "Design and Optimization of Rectangular Microstrip Patch Array Antenna Using Frequency Selective Surfaces for 60 GHz", International Journal of Applied Engineering Research, Volume 11, No. 7, pp. 4679-4687, 2016.

[14] Sonia, S., Tripathi, C.C., and Rishi, R., "Impedance Matching Techniques for Microstrip Patch Antenna", Indian Journal of Science and Technology, Volume 10, No. 28, pp. 1-16, 2017.

[15] Efri, S., and Marani, T., "Design of Multiband MIMO Antenna for 5G Millimeter wave Application", IOP Conference Series: Materials Science and Engineering, Volume 852, No. 1, pp. 012154, 2020.

[16] Jyoti, S., and Agarwal, S.K., "Design a Single Band Microstrip Patch Antenna at 60 GHz Millimeter Wave for 5G Application", IEEE International Conference on Computer, Communications and Electronics, pp. 227-230, 2017.

[17] Wonbin, H., Baek, K.-H., and Ko, S., "Millimeter-Wave 5G Antennas for Smartphones: Overview and Experimental Demonstration", IEEE Transactions on Antennas and Propagation, Volume 65, No. 12, pp. 6250-6261, 2017.

[18] Marwa, S.H., Zaki, A.I., Radwa, K.H., and Omar, M.M.M., "A Novel Dual-Band (38/60 GHz) Patch Antenna for 5G Mobile Handsets", Sensors, Volume 20, No. 9, pp. 2541, 2020.

[19] Yassine, J., Gharnati, F., and Said, A.O., "Design of a Compact Dual Bands Patch Antenna for 5G Applications", IEEE International Conference on Wireless Technologies, Embedded and Intelligent Systems, pp. 1-4, 2017.

[20] Adedotunl, O.K., Anosike, I.E., and John, B., "Design and Optimization of a Square Patch Antenna for Millimeter Wave Applications", International Journal of Science and Research, Volume 6, No. 4, pp. 2192-2194, 20017.

[21] Khattak, M.I., Sohail, A., Khan, U., Barki, Z., and Witjaksono, G., "Elliptical Slot Circular Patch Antenna Array with Dual Band Behaviour for Future 5G Mobile Communication Networks", Progress in Electromagnetics Research, Volume 89, pp. 133-147, 2019.

[22] Kaeib, A.F., Shebani, N.M., and Zarek, A.R., "Design and Analysis of a Slotted Microstrip Antenna for 5G Communication Networks at 28 GHz", IEEE 19thInternational Conference on Sciences and Techniques of Automatic Control and Computer Engineering, pp. 648-653, 2019.

[23]. Waqar Hussain M.irfan Khattak Mushtaq A.K.Khattak and Muhammad Anab Multiband Microstrip Patch Antenna for 5G Wireless Communication International Journal of Engineering Works Vol. 7 Issue 01 PP. 15-21 January 2020.

[24] Muhammad Anab, Muhammad Irfan Khattak, Syed Muhammad Owais, Abbas Ali Khattak, and Asif Sultan, “Design and Analysis of Millimeter Wave Dielectric Resonator Antenna for 5G Wireless Communication Systems,” Progress In Electromagnetics Research C, Vol. 98, 239-255, 2020.

[25] Imran, D., Farooqi, M. M., Khattak, M. I., Ullah, Z., Khan, M. I., Khattak, M. A., & Dar, H. (2018, February). Millimeter wave microstrip patch antenna for 5G mobile communication. In 2018 International Conference on Engineering and Emerging Technologies (ICEET) (pp. 1-6). IEEE.

[26] Aziz, Muhammad Afiq Abdul, Norhudah Seman, and Tien Han Chua. "Microstrip antenna design with partial ground at frequencies above 20 GHz

for 5G telecommunication systems." Indonesian Journal of Electrical Engineering and Computer Science (IJEECS) 15, no. 3 (2019): 1466-1473.