DESIGN AND ANALYSIS OF RECTANGULAR SLOT MICROSTRIP PATCH ANTENNA FOR MILLIMETRE-WAVE COMMUNICATION AND ITS SAR EVALUATION

B.V.Naik¹, ², Debojyoti Nath³, Rina Sharma¹,²

¹CSIR-National Physical Laboratory, Dr KS Krishnan Marg, New Delhi-110012, India
²Academy of Innovative and Scientific Research (AcSIR), Ghaziabad-201002, India
³Department of Electronic Sciences, University of Delhi, South Campus, New Delhi, India

ABSTRACT

This paper presents the design and analysis of the compact patch antenna for 5G and future generation millimetre-wave communication system. The proposed design consists of FR4 substrate length, width, and height of 21.37 x 5 x 1.59 mm³, besides two rectangular slots incorporated with a dimension of 0.2 x 2.6 mm² within the patch of 4.22 x 3.46 mm², to enhance the resonance frequency more accurate and one more square slot incorporated in to feed line with the dimension of 0.2 x 0.5 mm². The obtained return losses of the design is -21.25dB with gain and voltage standing wave ratio (VSWR) of 3.90dBi,1.18 by using a lumped port configuration. For the specific absorption rate (SAR) evaluation considered as a human head model in high-frequency structure simulator (HFSS) software, the obtained values are within the standard limit, the design covers the frequency range of 28GHz, this design may capable of 5G and next-generation wireless communication system application.

KEYWORDS

Patch antenna, SAR, Rectangular slot, Human head model

1. INTRODUCTION

There are tremendous changes has been observed in mobile communication since last few decades, the mobile devices and connections are not only getting smarter in their computing capabilities but also evaluating lower generation network connectivity technologies i.e.1G, 2G to higher generation technology (3G, 3.5G, and 4G or LTE) [1,2]. The first generation technology pertained to voice transmission services only were highly incompatible with related services it was introduced in the early 1980s[2], the second-generation wireless cellular mobile technology was planned for voice transmission with digital data transfer and the data transfer rate up to 64 kbps. This technology ahead of 1G services by providing the facilitate short message services (SMS) and lower speed data such as CDMA2000, the second generation technology deploying GSM services, Global system for mobile communication uses digital modulation schemes to improve the voice quality but network offers limited data services and the second generation carriers continued to improve the transmission quality and coverage, also, it began to offer text message services, voicemail, and fax service.

In the 2.5 generation technology introduced General packet radio services (GPRS)[1-3], it
implies packet-switched data capabilities to existing GSM services and also it allows to user can send graphical data as packets, the importance of the packet switching increased with rising of internet and internet protocol (IP). 3rd generation technology based on wideband wireless evolution intends to mobile telephone customer to use audio, graphics, and video application data transfer rate up to 200 kbps. This technology enhances the clarity and speed of the network up to megabits per second, for the Smartphone and mobile modems in laptop computers. Fourth-generation technology brought in Long Term Evaluation (LTE), this technology comes under 3GPP (Third Generation Partnership Project) Standard it fulfils (International Telecommunication Unit) ITU, (International Mobile Telecommunication) IMT -Advanced broadband network, the data transfer rate of the technology up to 1 Gbps and the 4G provides better than TV quality images, video-links. Furthermore, to enhance the data speed, it is predicted that the commercial deployment of fifth-generation (5G) systems will be approximately in the early 2020s [4]. To meet the increasing need for even higher data rates required in future applications (such as wireless broadband connections, massive machine-type communications, and highly reliable networks), the research activities on 5G mobile communication systems have started [5,6]. The microstrip antenna has several advantages compared to conventional microwave antennas some of them are lightweight, low volume and thin profile configurations, which can be made conformal, low fabrication cost, readily amenable to mass production, linear and circular polarizations are possible with simple feed, dual-frequency and dual-polarization antennas can be easily made, no cavity back is required, can be easily integrated with microwave integrated circuits [7].

In the existing present wireless communication world antennas are needed to assure some security of the human body from the electromagnetic radiation for that some of the protecting and guiding organization federal communication commission (FCC), European international electro technical commission (IEC) and IEEE 1528 has set the safety limit of 1.6W/kg absorbed by 1-gram tissue and 2W/kg for 10-gram of tissue.

2. DESIGN AND ANALYSIS OF THE PATCH ANTENNA

Geometry consists of FR-4 epoxy substrate dimensions of width, length and height are 5 x 21.37mm x 1.59 mm with an epsilon value and the loss tangent of 4.4, 0.017. The design Fed by a microstrip transmission line, and the ground plane made of conducting material i.e., copper. The patch consists width and length of 4.22 x 3.46 with two rectangular slots dimensions of 0.2 x 2.6 mm², to enhance resonance one more square 0.2 x 0.5 mm² dimension feed slot incorporated to the patch. The considerable height of the patch is smaller than the wavelength of operation, the proposed design resonate frequency is 28 GHz, as per design the detailed dimensions are given in Table 1 with respective the Fig.1

![Figure 1: The geometry of the Rectangular Slot patch antenna](image)
Table 1. Dimensions of the Rectangular slot Microstrip patch antenna

| Parameters                  | Dimensions in (mm) |
|-----------------------------|--------------------|
| Substrate Width             | 5                  |
| Substrate Length            | 21.37              |
| Height of Substrate (h_t)   | 1.59               |
| Patch Length (P_l)          | 3.46               |
| Patch Width (P_w)           | 4.22               |
| Slot Width (W_slot)         | 0.2                |
| Slot Length (L_slot)        | 2.6                |
| Between Slot Distance (w_1) | 2.4                |
| Fedd line (F_{wx l})        | 0.2, 0.5           |
| w_2, w_3                    | 1.58, 1.05         |
| w_4, w_5                    | 0.37, 0.91         |
| w_6                         | 1.19               |
| l_1, l_2                    | 0.65, 0.50         |
| l_3, l_4                    | 2.1, 8.37          |

3. **Measurement Analysis of the Patch Antenna**

To verify the design approaches, the proposed antenna fabricated and measured. The proposed microstrip patch antenna is designed in Ansys High-Frequency Structure Simulator (HFSS). The return losses and voltage standing wave ratio are measured in VNA as shown in Fig. 2 and Near field and the far-field radiation pattern is reported in Fig. 4, as shown in Fig. 2 the simulated and measured return loss plot which shows that resonance frequency of 28 GHz (7%)\(^8\), which is in good agreement with the simulated results having a resonance at 28 GHz (6.7%). The little versions in simulated and measured results are due to the manufacturing allowance and binding of SMA connector using a conductive adhesive, return loss for covering 5G millimetre wave applications \(^9\) is higher than −10dB. The proposed design antenna return loss is -22.21dB, as shown Fig.2, as well as section A and B, describes the effect of incorporated slots and the parametric analysis slot width, length variation with respective slot as shown Fig.3a,b.
A. Effect of Incorporated Slot

Incorporating the additional slots to patch the antenna behaviour has been changing i.e. enhancing the return loss and impedance matching, when there were no additional slots present on rectangle patch the antenna shows a non-resonance behaviour at the desired frequency, with increasing the additional slots on the rectangular patch to enhances the matching condition of the antenna, the patch resonating at 23 GHz to 25GHz to bring the response at the desired frequency at 28GHz. Further, one more slot incorporated on the rectangular patch. the slot width and length variations with respect resonance as given in section B

B. Parametric Analysis

Parametric analysis is one of the important analysis to determine the optimized results at desired resonance, the proposed antenna slot width variation from $W_{\text{slot}} = 0.02$ mm to 0.2 mm, slot length variation is $L_{\text{slot}} = 1$ mm to 2.6 mm from this observation resonance varies with respective return loss it is reported in Fig.3a, b.

As shown in Fig. 3a describes the variation of slots width with constant length of 2.6mm when increasing slot width values from 0.02mm to 0.2mm the resonance frequency shifts towards the desired response whenever increasing the further value of 0.2mm we acquired resonance at 28 GHz, as well as in the Fig.3b demonstrates the slot width keeping constant at 0.2mm, meanwhile slot length varies at 1mm to 2.6mm, from the 1mm to 2.2mm the resonance range from 27 to 30 GHz unmatching condition hence there is no desired response so that whenever increasing the further value of 2.6mm the resonance response and impedance matching was enhanced at 28 GHz.

![Figure 3(a): slot width varies with constant slot length](image-url)

Figure 3(a) : slot width varies with constant slot length
Figure 3(b): slot length varies with a constant slot width

Figure 4(a): Measured and Simulated Radiation pattern

From the above plot, it describes antenna gain versus angle of phi in spherical coordinate from 0 to 360, this values on the perimeter of the circle while the values inside the circle such as -14dB to 0dB are radiation intensity values (gain), so we can observe that at phi =0 degrees simulated gain is approx. 3.9dBi and the measured value is approx.3dBi, both values should be quite similar at 28 GHz frequency.
As shown figure 4b demonstrate that the values on the perimeter of the circle are angle values from 0 to 360 degree for phi, while the values inside the circle such as -20 dB, -15 dB, -10 dB, -5 dB, 0 dB, and 5 dB are the radiation intensity values (gain), the measured value is approx. 3.5 dBi and simulated value approx. 3.9 dBi at phi=0 degree, the high gain compact microstrip patch antenna reported in [29], both values are rather similar at 28GHz resonance, but phi at 75 degree radiation intensity of simulated value is -20 dB and the measured value is approx. -17.5 dB at phi 60 degree, same way phi at 300 degrees simulated value is -20 dB and the measured value is approx. -16.5 dB, from this observation both, are not identical but quite similar.

![Figure 5: A fabricated prototype of the proposed antenna](image)

![Figure 6: a prototype of the radiation pattern measurement setup](image)
From the above figure, 6 reports measurement prototype of the radiation pattern, from the RF signal generator selected frequency of 28 GHz with 0 dB power and it fed up to waveguide adapter, it acts as a transmitter and the second end connected microstrip antenna to the 40 GHz R&S FSV40 signal and spectrum analyzer. In the antenna under test waveguide to coaxial adapter keeping constant microstrip antenna position changing with respective distance and phi, theta 0 to 360-degree rotation from 1 meter to 7-meter range. This experiment was done in an indoor environment with a noise level below -70 dBm (direct antenna gain method)

C. Specific Absorption Rate (SAR) Analysis

SAR is the unit of measurement for the RF energy absorbed by any biological tissue (human body) when we use wireless devices, SAR values are measured in W/kg. In this analysis, human head modal has been stimulated in HFSS software at the 28GHz, fed by monopole antenna with proposed design [24] as per IEEE 1528

$$SAR = \frac{\sigma E^2}{M} \quad (1)$$

Where $\sigma$ is the conductivity of the tissue, $E$ is the electric field, $M$ is the mass density of the tissue.

![Figure 7(a): Simulated SAR of the proposed antenna with 1 gram biological tissue](image1)

As per IEEE/ANSI C63.19 standard, SAR safer limit value should be 1.6 W/kg for any 1g biological tissue, in the above figure describes SAR value with the limited about 0.5<1.6W/kg

![Figure 7(b): Simulated SAR of the proposed antenna with 10-gram biological tissue](image2)
As per the IEEE 1528 standard safer limit of SAR is 2W/kg for any 10g biological tissue, in the above figure demonstrates that the max value of SAR is within the limit of 0.9<2W/kg.

4. CONCLUSION

This paper portrays the rectangular slot microstrip patch antenna design and analysis has been investigated, various parameters in the design of the antenna are optimized and optimum design is reported. The proposed antenna return loss is -21.25 dB The VSWR of the antenna is 1.18 with 7% bandwidth. The intended antenna structure delineated a gain of 3.90 dBi and SAR investigated results for 1g,10g biological tissue limits are within standard range so, this antenna may find its suitability in future 5G-6G millimetre wave application.

ACKNOWLEDGEMENT

Authors would like to thank Dr S. K. Dubey for the lab facility, Dr D. K. Aswal, Director CSIR-National Physical Laboratory, for their constant motivation and support throughout this work, and CSIR-HRDG.

REFERENCES

[1] I J Bahl and P. Bhartia, Microstrip Antenna, Artech House Dedham, MA(USA) 1980.
[2] Shukla, Sapna, et al. "Comparative Study of 1G, 2G, 3G, and 4G." J. Eng. Comput. Appl. Sci, vol.4, pp.55-63, 2003.
[3] Pereira V, Sousa T. Evolution of Mobile Communications: from 1G to 4G. Department of Informatics Engineering of the University of Coimbra, Portugal, vol.4, pp. 20-0,2004.
[4] T.S. Rappaport, et al., “Millimeter-wave mobile communications for 5G cellular: It will work!” IEEE Access, vol.5 pp. 335-349, 2013.
[5] Amit Kumar, Dr Yunfei Liu, Dr Jyotsna Sengupta, Divya, “Evolution of Mobile Wireless Communication Networks1G to 4G”, International Journal of Electronics & Communication Technology, IJECT, vol.12, pp.68-72, 2010.
[6] J. G. Andrews, S.Buzzi, W. Choi, S. V. Hanly, A. Lozano A. C. K., Soong, and J. C. Zhang, “What will 5G be?” IEEE J. Sel. Area of Communication, vol.6, pp. 1065–1082, 2011.
[7] Rappaport TS, Gutierrez F, Ben-Dor E, Murdock JN, Qiao Y, Tamir JI. Broadband millimeter-wave propagation measurements and models using adaptive-beam antennas for outdoor urban cellular communications. IEEE transactions on antennas and propagation, vol.4 2013, pp.1850-9,2013.
[8] S. Raja Gopal, Sh. Abu-Surra, Zh. Pi and F. Khan, “Antenna array design for multi-GbpsmmWave mobile broadband communication”, Proc. IEEE GLOBECOM’2011, Houston, Texas, pp.1-6, 2011.
[9] R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, Microstrip antenna design Handbook, Boston: Artech House, 2001.
[10] Desai A, Upadhyaya T, Patel R. Compact wideband transparent antenna for 5G communication systems. Microwave and Optical Technology Letters, vol.3, pp.781-6,2019.
[11] Tighezza M, Rahim SKA, Islam MT. Flexible wideband antenna for 5G applications. Microwave Opt Technology Lett., pp.38-44, 2011.
[12] El Mubarak Elbaid HA, Abdul Rahim SK, Hamdi M, Castel X AbedianKasgari M. A transparent and flexible polymer-fabric tissue UWB antenna for future wireless networks. IEEE Antennas Wireless Propagation Lett. pp. 1333-1336,2017
[13] Xie W, Wu Y, Wang J, Cui L, Liu Y. A semicircular metamaterial-loaded monopole filtering antenna with high selectivity and harmonics suppression.2017 International Applied Computational Electromagnetics Society Symposium (ACES), pp. 1-2,2017
[14] Dahri MH, Kamarudin MR, Jamaluddin MH, Inam M, Selvaraju R. Broadband Resonant Elements for 5G Reflectarray Antenna Design. Telkomnika, vol. 6, pp. 793,2017.
[15] Munger D, Durai Kannan S. Microstrip Patch Antenna at 28 GHz for 5G Applications. Journal of Science Technology Engineering and Management-Advanced Research & Innovation., vol.1, pp.20-22, 2018.

[16] El_Mashade MB, Hegazy EA. Design and Analysis of 28GHz Rectangular Microstrip Patch Array Antenna.WSEASTransactions on Communications, pp.1-9, 2018.

[17] Darboe O, Konditi DB, Manene F. A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications, pp.854-857, 2019.

[18] Hong, Wonbin, Kwanghun Baek, Youngju Lee, and Yoon Geon Kim. "Design and analysis of a low-profile 28 GHz beam-steering antenna solution for future 5G cellular applications." In 2014 IEEE MTT-S International Microwave Symposium (IMS2014), vol. 6, pp.1-4, 2014.

[19] Ojaroudiparchin, Naser, Ming Shen, and Gert Froiland Petersen. "A 28 GHz FR-4 compatible phased array antenna for 5G mobile phone applications." 2015 International symposium on Antennas and propagation (ISAP), vol.11, pp.1-4, 2015.

[20] Hong W, Baek KH, Goudelev A. Multilayer antenna package for IEEE 802.11 ad employing ultra-low-cost FR4. IEEE Transactions on Antennas and Propagation, vol.8, pp.5932-8, 2012.

[21] Parment F, Ghiotto A, Vuong TP, Duchamp JM, Wu K. Air-filled substrate integrated waveguide for low-loss and high power-handling millimetre-wave substrate integrated circuits. IEEE Transactions on Microwave Theory and Techniques, vol.3, pp.1228-38, 2015

[22] Hong W, Baek KH, Ko S. Millimeter-wave 5G antennas for smartphones: Overview and experimental demonstration. IEEE Transactions on Antennas and Propagation. Vol.8, pp.6250-61, 2017.

[23] Parchin, NaserOjaroudi, et al. "Orthogonally dual-polarised MIMO antenna array with pattern diversity for use in 5G smartphones.” IET Microwaves, Antennas & Propagation 2020.

[24] Lak, A. and Oraizi, H., 2013. Evaluation of SAR distribution in six-layer human head model. International Journal of Antennas and Propagation, 2013.

[25] Rashad NM, Khalaf AA. Modified Design and Fabrication of a broadband Millimeter-Wave Ankh-Key Antenna for 5G and Next Generations Applications. In2020 International Conference on Innovative Trends in Communication and Computer Engineering (ITCE), IEEE., pp. 322-325, 2020

[26] Zhang S, Chen X, Kishk AA, Ying Z, Kühn S. Guest Editorial: Special Cluster on 5G/6G Enabling Antenna Systems and Associated Testing Technologies. IEEE Antennas and Wireless Propagation Letters., vol. 19(11), pp.1916-9, 2020

[27] Duan BY. Evolution and innovation of antenna systems for beyond 5G and 6G., 2020.

[28] Belot D, González Jiménez JL, Mercier E, Dore JB. Spectrum Above 90 GHz for Wireless Connectivity: Opportunities and Challenges for 6G. Microwave Journal., vol.63(9), 2020.

[29] AlyAbout-Dahab, Mohamed, Hussein Hamed Mahmoud Ghouz, and Ahmed ZakariamAhmed Zaki. "High gain compact microstrip patch antenna for X-band applications.” International Journal of Antennas (JANT) Vol 2, 2016.

AUTHORS

Mr Bhukya Venkanna Naik received his B.Tech.(Electronics and Communication Engineering) from the Jawaharlal Nehru Technological University, Hyderabad. He worked as a Hardware Design Engineer in Electronics Corporation of India Limited Hyderabad. Currently, he is member of IEEE MTT-S, Antenna and Propagation Society Member since 2017, and working toward the PhD degree in RF and Microwave Engineering at the Academy of Scientific and Innovative Research (AcSIR), CSIR-NPL, New Delhi, India

Dr Rina Sharma received M.Sc. in physics from DAV College Muzaffarnagar, Meerut University in 1983. she obtained M.Tech, PhD in Solid-State Physics from IIT Delhi. Currently, She is Sr. Principal Scientist and Head HRD, Co-Ordinator of AcSIR at CSIR National Physical Laboratory, New Delhi, India.