Design of multi-band millimeter wave antenna for 5G smartphones

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ABSTRACT

The design of a millimeter wave (mmW) antenna for the 5G mobile applications is presented in this paper. The designed antenna has dimensions of 10×10×0.245 mm^3. This includes the copper ground plane. The resonance of the proposed mmW antenna lies within the range of 33 GHz and 43 GHz. These frequency bands are covering the 5G proposed band in terms of the signal speed, data transmission, and high spectral efficiencies. Computer simulation technology (CST) software is used to simulate the proposed 5G antenna including the characteristics of S-parameters, gain, and radiation pattern. Simulation results show that the return loss at resonant frequencies goes -22 dB, which satisfies the requirements of 5G mobile technology.

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1. INTRODUCTION

Nowadays, there is a rapidly increasing interest to explore emergent wireless communication systems that can meet the growing signal speed requirements, and achieving an acceptable spectral efficiency with high-speed data transmission [1]-[3]. Eventhough some of these system requirements were already fulfilled by using the existed 1G to 4G mobile technologies, however they cannot meet the needs of the future network's generation [4]-[6]. Regardless of the advantages and disadvantages of using this range of frequency bands in wireless communication, the focus here is being about the limitations of 4G technology to effectively address most of the currently-raising communication problems such as the capability of exhibiting multiple band operation and increased bandwidths. In addition to the problems related to poor quality of the service influenced by unreliable poor system connection [7]-[9].

Furthermore, 5G wireless communication networks are emergent basically to overcome the aforementioned issues in today's mobile networks by meeting the continuously increasing demands and rapid interest for future smartphone applications [10]-[12]. It is widely agreed that 5G mobile techniques have the potential to provide extremely high data rates (around 1Gbit per sec) serving a huge number of mobile users simultaneously. Moreover, using a 5G network provides ultra-wide radio coverage area, wide bandwidth, very low latency, and high resolution for cell phones as compared with the previous generations [13], [14]. Furthermore, 5G demonstrates higher security features and energy efficiency compared to previous generations.

Utilizing 5G allows the development of interactive multimedia services in particular virtual reality and autonomous driving. Two rang of frequency bands can be covered by using 5G networks. These include the frequency that is greater than 6 GHz and also the frequencies of the mmW frequency bands [15]-[18].

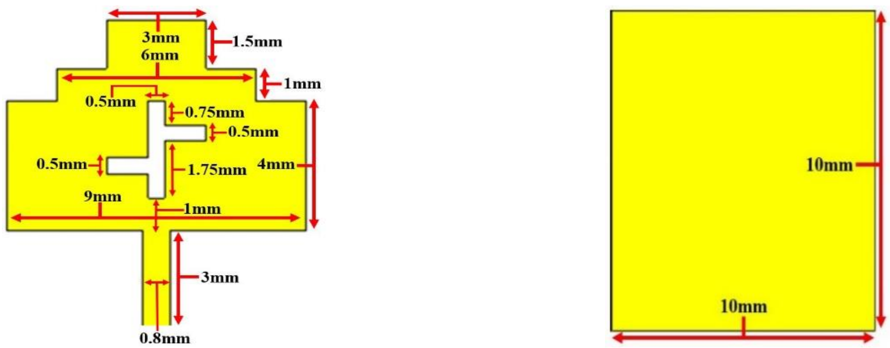
For wireless mobile communication devices, the microstrip-patch antenna can be analyzed and designed with specific characteristics in terms of resonance, bandwidth, beam shape, and width as well as efficiency [19], [20]. This antenna structure has recently been found theoretically and experimentally to provide compact, planar, and multi-resonance properties. Besides that, a microstrip antenna demonstrates lower cost and higher gain compared to other antenna structures [21]-[24].

Recently, the studies of 5G smartphone antenna are increasing day by day, where several works have been interested to investigate different types of patch antennas and their related low and high frequencies. For example, in some recent literature [25], a multi-input and multi-output (MIMO) antenna system has been proposed for 5G applications. It is operated at 31.22-34.17 GHz and 31.79-33.37 GHz bands for 5G applications, where the structure of this design was consist of six elements MIMO antenna. These elements are placed opposite to each other within an area of 30 by 20 mm^2. The isolation of the later design is 17 dB [25]. The proposed antenna, which exhibits compact size and printed on Rogers RT5880 substrate, is designed to outperform other published designs in the literature. Additionally, the suggested antenna shows an acceptable performance in terms of resonance and radiation characteristics. The obtained results are promising and indicate a potential solution for 5G applications.

In this paper, a slotted mmW antenna is designed to occupy a compact area of 10×10 mm^2 exhibiting multiple resonances. The proposed design in this work covers the range of mmW frequency bands of 33-43 GHz in one single antenna design. Simulations have been achieved by computer simulation technology (CST) software. The design and simulation results are shown in the following sections. The rest of the paper will be organized as follows: section 2 will present the antenna structure showing the full dimensions. In section 3, the simulation results such as return loss and radiation pattern (2D and 3D) will be illustrated and discussed. Finally, section 4 concludes the main idea and results of this paper.

2. DESIGN AND CHARACTERISTICS OF THE SLOTTED ANTENNA

The structure along with the geometrical dimensions for the proposed slotted antenna is illustrated in Figures 1(a) and (b). The slotted antenna is printed on a relatively thin substrate with a dielectric constant of 4.1 and a loss tangent of 0.02, where the copper layer has a thickness of 18 µm. The ground plane was placed to cover the entire backside of the structure as shown in Figure 1(b). The patch consists of a mirrored staircase to increase the probability of the antenna to exhibit adjacent multiple resonances. Furthermore, a vertical slot intersected by two horizontal lines as shown in Figure 1(a) has been placed at the middle of the antenna structure in order to enhance the impedance matching with the assumed reference impedance of the port (i.e., 50 Ω). The overall dimension of the antenna is 10×10 mm^2 as shown in Figure 1(b) which is light weight and compact as well as the structure has no fine details making it easy to manufacture, measure, and imbed within the antenna circuitry.



(a) (b)

Figure 1. The proposed slotted antenna; (a) front and (b) back

3. SIMULATION RESULTS

The reflection coefficient of the designed mmW slotted antenna shows an acceptable resonance within the frequency range of 30 to 45 GHz as illustrated shown in Figure 2. It is clearly noticed that the proposed mmW 5G antenna exhibits three major resonances around 33 GHz, 34.5 GHz, and 41.1 GHz, which are preferred and required in 5G applications. These frequencies meet the return loss values that are around -28,

-24, and -22 dB, respectively. Besides this, the frequency bandwidth for this range of frequencies were 0.7, 0.54, and 2.09 GHz, respectively. The antenna exhibits wide bandwidth at the 40 GHz band with acceptable bandwidth at lower frequencies, which makes it compatible with the 5G application especially at frequencies above 40 GHz.

Figures 3(a)-(d) illustrates the two-dimensional (2D) radiation pattern for these ranges of frequencies, showing the direction of the null. The antenna radiation pattern has its main beam at around 0 for the 30 GHz frequency band, whereas for the 40 GHz frequency band the radiation pattern has more major lobes at different directions with minimal backward radiation. Therefore, we note that the angle of the broadcast direction is 50.0 degree, the broadcast width angle is 53.0 degree, and the main lobe magnitude is 19.8 dBV at 41.1 GHz as shown in Figure 3(a). In addition, we note that the angle of the broadcast direction is 12.0 degree, the broadcast width angle is 41.8 degree, and the main lobe magnitude is 17.3 dBV at 42.4 GHz as shown in Figure 3(b). Moreover, we note that the angle of the broadcast direction is 4.0 degree, the broadcast width angle is 44.3 degree, and the main lobe magnitude is 23.3 dBV at 33 GHz as shown in Figure 3(c). Furthermore, we note that the angle of the broadcast direction is 1.0 degree, the broadcast width angle is 65.3 degree, and the main lobe magnitude is 20.6 dBV at 34.5 GHz as shown in Figure 3(d). For this, based on the values of these parameters, the best results provided by the antenna are at the frequency of 41.1 GHz.

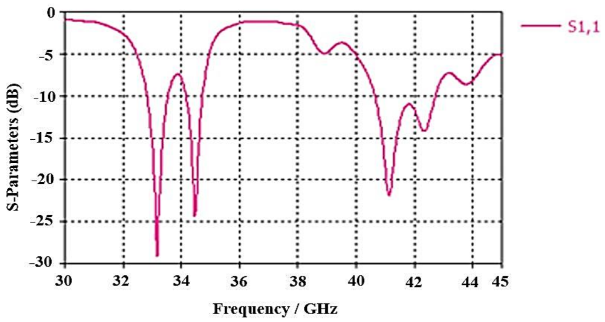
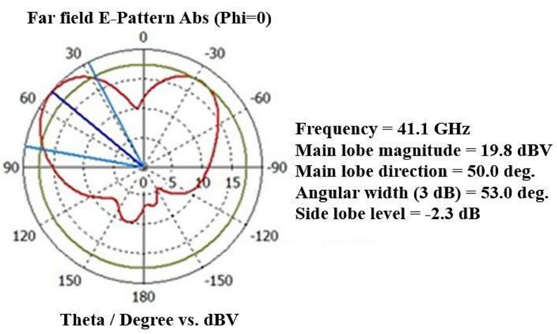
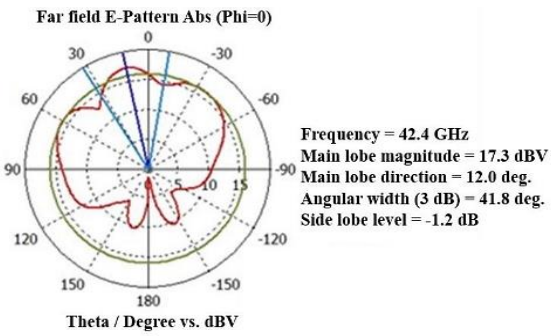


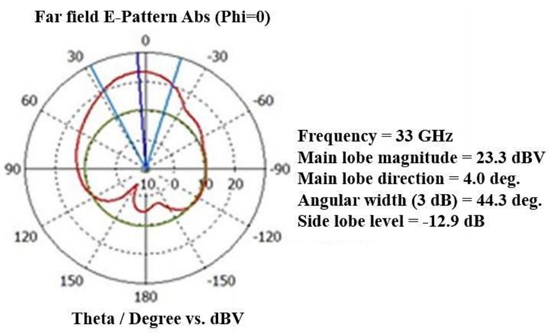
Figure 2. The multiband behavior of the simulated antenna is shown by the S-parameter graph



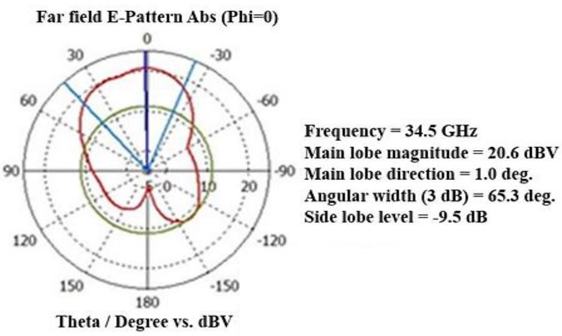
(a)



(b)



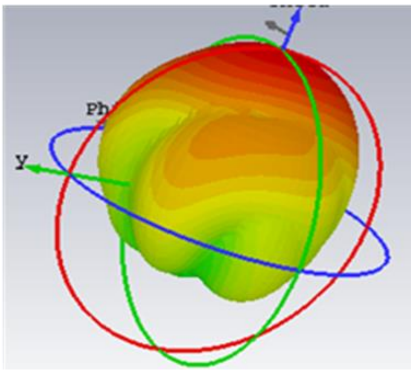
(a)



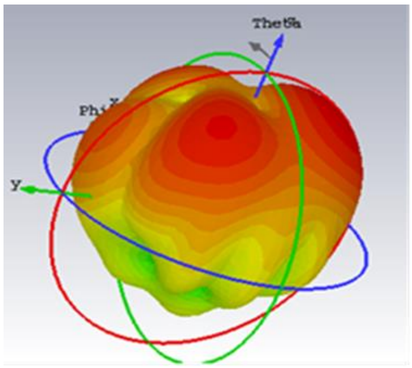
(b)

Figure 3. 2D pattern of the proposed mmW antenna at frequency; (a) 41.1 GHz, (b) 42.4 GHz, (c) 33 GHz, and (d) 34.5 GHz

The three-dimensional radiation (3D) pattern at resonant frequencies is shown in Figures 4(a) and (b). It is clearly seen that the proposed antenna has approximate omnidirectional behavior, which meets one of the requirements of this application. The recorded gain and efficiency for the designed antenna were 8.3 dB and 85% at 32.5 GHz, whereas the values were 6.45 dB and 89% at 41.5 GHz, respectively.



(a)



(b)

Figure 4. 3D radiation pattern of the proposed mmW antenna; (a) 32.5 and (b) 41.5 GHz

4. CONCLUSION

A Multiband compact mmW antenna for 5G mobile technology was suggested in this paper. The proposed antenna was aimed to cover the range of frequencies 33/34.5/41.1/42.4 GHz. The obtained results showed that the suggested antenna's satisfactory performance in terms of S-parameters, radiation characteristics, and gain. The proposed antenna indicates the suitability of this design for the 5G mobile network. Furthermore, the achieved wide frequency bandwidth of each operating frequency supports a higher data rate that is one of the most important requirements of 5G applications. More antenna elements can be combined together to form a MIMO antenna, which significantly helps in achieving improved performance with reasonable isolation between antenna ports.

REFERENCES

[1] M. G. Kachhavay and A. P. Thakare, “5G technology-evolution and revolution,” *International Journal of Computer Science and Mobile Computing (IJCSMC)*, vol. 3, no. 3, pp. 1080-1087, Mar. 2014, doi: 10.1109/ICISCT47635.2019.9011957.

[2] M. D. Hill, D. B. Cruickshank, and I. A. MacFarlane, “Perspective on ceramic materials for 5G wireless communication systems," *Applied Physics Letters*, vol. 118, no. 12, p. 120501, Mar. 2021, doi: 10.1063/ 5.0036058.

[3] W. Yongpeng, X. Gao, S. Zhou, W. Yang, Y. Polyanskiy, and G. Caire, “Massive access for future wireless communication systems," *IEEE Wireless Communications*, vol. 27, no. 4, pp. 148-156, Aug. 2020, doi: 10.1109/ MWC.001.1900494.

[4] K. S. Muttair, O. A. Sh Al-Ani, and M. F. Mosleh, “Outdoor Millimeter-Wave Propagation Simulation Model for 5G Band Frequencies,” 2^{nd} *International Conference on Electrical, Communication, Computer, Power and Control Engineering (IEEE)*, Feb. 2019, pp. 40-45, doi: 10.1109/ICECCPCE46549.2019.203745.

[5] A. Dujaili, M. Jawad, and B. A. Salih, “A Review of Mobile Technologies from 1G to the 5G and a Comparison between Them," *Solid State Technology*, vol. 64, no. 2, pp. 2805-2823, Feb. 2021.

[6] H. Mahmud, “Cellular mobile technologies (1G to 5G) and massive MIMO,” *Int. J. Sci. Res*, vol. 8, no. 7, pp. 929-937, Jul. 2019, doi: 10.21275/ART20199494.

[7] K. S. Muttair, O. A. S. Al-Ani, and M. F. Mosleh, “Performance Comparison of Multi-band Frequencies for Outdoor Communication,” *Applied Computing to Support Industry: Innovation and Technology. Communications in Computer and Information Science (Springer)*, vol. 1174, pp. 476-487, Sep. 2020, doi: 10.1007/978-3-030-38752-5_37.

[8] H. Jie, C. Wang, H. Chang, J. Sun, and X. Gao, “Multi-frequency multi-scenario millimeter wave MIMO channel measurements and modeling for B5G wireless communication systems,” *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 9, pp. 2010-2025, Sept. 2020, doi: 10.1109/JSAC.2020.3000839.

[9] P. Riki, A. Desai, T. Upadhyaya, T. K. Nguyen, H. Kaushal, and V. Dhasarathan, “Meandered low profile multiband antenna for wireless communication applications,” *Wireless Networks*, vol. 27, no. 1, pp. 1-12, Jul. 2021, doi: 10.1007/s11276-020-02437-6.

[10] N. Yang, L. Wang, G. Geraci, M. Elkashlan, J. Yuan, and M. D. Renzo, “Safeguarding 5G wireless communication networks using physical layer security,” *IEEE Communications Magazine*, vol. 53, no. 4, pp. 20-27, Apr. 2015, doi: 10.1109/MCOM.2015.7081071.

[11] K. S. Muttair, O. A. Shareef Al-Ani, and M. F. Mosleh “Outdoor to Indoor Wireless Propagation Simulation Model for 5G Band Frequencies," *The Fourth Postgraduate Engineering Conference, IOP Publishing*, vol. 745, no. 1, pp. 012034, Feb. 2020, https://iopscience.iop.org/article/10.1088/1757-899X/745/1/012034.

[12] W. Zhang, Z. Weng, and L. Wang, “Design of a dual-band MIMO antenna for 5G smartphone application,” *International Workshop on Antenna Technology (iWAT)*, pp. 1-3, Jun. 2018, doi: 10.1109/IWAT.2018.8379211.

[13] O. A. S. Al-Ani, K. S. Muttair, and M. F. Mosleh, "Outdoor transmitter localization using multiscale algorithm," *International Journal of Simulation Systems, Science & Technology (United Kingdom)*, pp. 3.1-3.7, Mar. 2019, doi: 10.5013/IJSSST.a.20.S1.03.
[14] W. A. Awan, N. Hussain, S. Naqvi, and A. Iqbal, "A miniaturized wideband and multi-band on-demand reconfigurable antenna for compact and portable devices," *AEU-International Journal of Electronics and Communications*, vol. 122, p. 153266, Jul. 2020, doi: 10.1016/j.aeue.2020.153266.
[15] O. O. Fagbohun, "Comparative studies on 3G, 4G and 5G wireless technology," *IOSR Journal of Electronics and Communication Engineering*, vol. 9, no. 3, pp. 88-94, Apr. 2014, doi: 10.9790/2834-0925133139.
[16] G. Abhishek, A. Gupta, and S. Gupta, "5G: the future mobile wireless technology by 2020," *International Journal of Engineering Research & Technology*, vol. 2, no. 9, Sep. 2013.
[17] S. J. Yang, Y. M. Pan, L. Y. Shi, and X. Y. Zhang, "Millimeter-Wave Dual-Polarized Filtering Antenna for 5G Application," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 7, pp. 5114-5121, Jul. 2020, doi: 10.1109/TAP.2020.2975534.
[18] M. Anab, M. I. Khattak, S. M. Owais, A. A. Khattak, and A. Sultan, "Design and Analysis of Millimeter Wave Dielectric Resonator Antenna for 5G Wireless Communication Systems," *Progress In Electromagnetics Research*, vol. 98, pp. 239-255, Jan. 2020, doi: 10.2528/PIERC19102404.
[19] K. S. Muttair, A. Z. G. Zahid, O. A. Al-Ani, A. M. Q. Al-Asadi, and M. F. Mosleh, "A New Design of mm-Wave MIMO Antenna with High Isolation for 5G Applications," *International Journal of Microwave and Optical Technology*, vol. 16, no. 4, pp. 370-379, Jul. 2021, https://ijmot.com/VOL-16-NO-4.aspx
[20] V. Prakasam, K. A. LaxmiKanth, and P. Srinivasu, "Design and simulation of circular microstrip patch antenna with line feed wireless communication application," *In 2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS)*, pp. 279-284. IEEE, Jun. 2020, doi: 10.1109/ICICCS48265.2020.9121162.
[21] P. Sharma, "5G Mobile Wireless Technology," *International Journal of Research*, vol. 1, no. 9, pp. 71-75, Oct. 2014.
[22] M. Zahid, S. Shoaib, and M. Rizwan, "Design of MIMO antenna system for 5G indoor wireless terminals," *International Conference on Engineering and Emerging Technologies (ICEET)*, pp. 1-4, May 2019, doi: 10.1109/CEET1.2019.8711818.
[23] M. Stanley, Y. Huang, T. Loh, Q. Xu, H. Wang, and H. Zhou, "A high gain steerable millimeter-wave antenna array for 5G smartphone applications," 11^{th} *European Conference on Antennas and Propagation (EUCAP)*, pp. 1311-1314, May 2017, doi: 10.23919/EuCAP.2017.7928542.
[24] W. Ali, S. Das, H. Medkour, and S. Lakrit, "Planar dual-band 27/39 GHz millimeter-wave MIMO antenna for 5G applications," *Microsystem Technologies*, vol. 27, pp. 283-292, Jan. 2020, doi: 10.1007/s00542-020-04951-1.
[25] S. F. Jilani, Q. H. Abassi, and A. Alomainy, "Millimeter-Wave Compact and High-Performance Two-Dimensional Grid Array for 5G Applications," *In 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, pp. 25-26, Jul. 2019, doi: 10.1109/APUSNCURSINRSM.2019.8889123.

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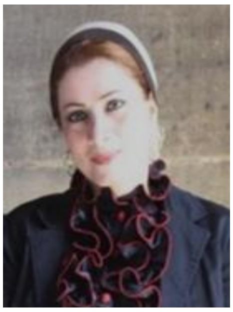

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