Triple-Band Dual-Polarized Dipole Antenna for 5G Sub-6 GHz Communications

Lixia Yang1 · Hafiz Usman Tahseen2 · Syed Shah Irfan Hussain3 · Wang Hongjin2

Accepted: 21 November 2021 / Published online: 2 December 2021
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract
A triple-band ± 45° dual-polarized dipole antenna is presented in this paper. The proposed antenna covers two n77 bands and one n79 band in 5G NR frequency spectrums with S11, S22 < −15 dB return loss. The profile antenna exhibits the measured impedance bandwidths of 250 MHz, 150 MHz and 350 MHz from the operating bands 3.6–3.85 GHz, 4.05–4.2 GHz and 4.8–5.15 GHz respectively. Antenna is fabricated with four substrates; one radiator, one reflector and two feeding baluns. Antenna is designed and optimized with HFSS simulator and fabricated for experimental verification. Antenna gives a stable radiation pattern of 8.55 dBi high gain with 70° half power beam width (HPBW) that makes it a good candidate for wireless 5G sub-6 GHz and multiband base station applications. Finally, antenna is tested in a realistic application environment to show the utility of the proposed antenna for wireless sub-6 GHz IoT applications.

Keywords Sub-6 GHz · IoT · 5G

1 Introduction

Internet of things (IoT) is expected to be adopted for most of the electronic communication applications in near future. The polarization diversities and frequencies will work at several bands in future. IoT is bringing an advanced digital revolution to our daily life. As a result, there is a huge production of sensors and integrated antennas associated with IoT age. The
IoT technology associated with integrated antennas is expected to make our future communications a very sophisticated and simple. The concept of internet of things (IoT) is known as the extension of internet now. It is a worldwide inter-connected emerging network of different objects associated with sensors, input/output devices, actuators and communication systems. The efficiency of internet of things (IoT) and wireless internet connection are improved with the wireless sensor technology [1].

In fact, antennas are playing a vital role in wireless sensor technology that leads to an emerging future with the development of IoT techniques. The compact and low profile integrated antennas have drawn a large attention in last few years due to multi-band and multi-function features in communication systems [2]. A loop antenna is presented in [3] for an IoT application with the antenna placement at different places. A multi-standard MIMO antenna is proposed in [4] for IoT applications. A loop antenna is proposed in [5] for a biotelemetry application to operate in GSM900, GSM1800 and Bluetooth Low Energy. In the recent years, different antenna modules and antennas has been designed for upcoming multimedia high speed and large data volume challenges. The technological development in different cellular and wireless applications has generated a high speed data rate requirement that leads to a fifth generation (5G) communication system. In present communication systems, dual-polarized antenna has attained a large attraction to reduce multipath fading. For dual-polarized antennas, a significant research is present [6–14]. Many countries are using (IMT-2020) standard 5G networks and services for research and services. The sub-6 GHz frequency spectrum i.e. 3.3–3.6 GHz and 4.8–5.0 GHz in China and 3.4 GHz to 3.8 GHz in Europe has been licensed. The N78 (3.3–3.8 GHz) 5G band has been assigned in many countries. The broadband MIMO antennas with high impedance bandwidths have become a good solution for 5G demands. A dual-polarized printed dipole antenna with 52% impedance bandwidth is presented in [15]. The base station broadband antennas for 2G, 3G and 4G networks are proposed in [16–22]. The comparison of the proposed work with the related ones [23–37] is presented in Table 1.

A low cost, low profile triple band ±45° dual-polarized dipole antenna is proposed for wireless 5G applications. In the first step, an un-slotted printed dipole with ±45° cross pair arrangement antenna is designed. In the next steps, slots are added in the center of each quadrant patch and then at corners. Radiation patterns and reflection coefficient are noted at each stage of electromagnetic analysis to get optimum antenna structure.

The paper is organized as follows: design of the profile antenna with EM analysis lies in Sect. 2. Simulated and experimental results are presented in Sect. 3. The final summary lies in Sect. 4.

2 Triple-Band Dual-Polarized Antenna

2.1 Antenna Design

The antenna geometry is shown in Fig. 1. The profile antenna consists of one reflector, one radiator and two baluns. The radiator has a 0.8 mm thick RT5880 substrate printed on the top. The RT5880 substrate has dielectric constant and loss tangent 2.2 and 0.0004 respectively. The reflector has RT5880 substrate with 0.8 mm thickness printed at bottom. Baluns are erected perpendicularly between radiator and reflector.

The main radiator of the proposed antenna has two dipoles with ±45° cross pair arrangement as shown in Fig. 1a. Radiator is a 32 × 36 mm² printed substrate mounted
on both baluns at 23.8 mm height. The patch is divided into four equal quadrants on the substrate. Each quadrant has $15.5 \times 17.5 \text{ mm}^2$ dimension and is connected with the other in a ±45° cross pair dipole arrangement. Balun shorts each dipole with ground separately. The two center lines slots divide the main radiator patch into four equal quadrants. The quarter circle slot is placed at each corner of the main radiator. The quarter circle has 2.8 mm radius. Each quadrant has an E-shaped slot at the center. The whole radiator arrangement demonstrates ±45° dual-polarized cross pair dipoles that are shorted with the ground via baluns.

Geometric configuration of baluns is shown in Fig. 1c and d. Each balun has a micro strip patch at one side and L-probe feed line on the other side on a FR4 dielectric substrate. Both baluns are erected perpendicularly in a ±45° cross arrangement. Balun1 is mounted on balun2. The open slots on both baluns make adjustment of balun1 on balun2. Both baluns have bumps at upper and lower edges. Radiator is mounted on the upper bumps of the baluns and the lower bumps are inserted in the reflector bores. Micro strip patches on both baluns short radiator with the ground through balun bumps. The feed line on the other side of each balun is shorted with the inner conductor of port/coaxial cable.

The outer conductor of coaxial cable/port is connected to the ground. The feed lines on both baluns have different dimensions but the micro strip patches and relevant bumps have same dimensions as shown in Fig. 1c and d. The reflector is a 120 × 120 mm² RT5880 dielectric substrate with ground patch at bottom. This ground is connected with the outer conductors of both ports port1 and port2 as shown in Fig. 1b. Hence a ±45° dual-polarized cross pair dipole antenna structure is developed by connecting each feed line to a separate port and each dipole to the ground.

### Table 1 Comparison with related works

| Refs. | Height (mm) | Gain (dB) | Bandwidth S11, S22 < 10 dB | HPBW |
|-------|-------------|-----------|----------------------------|------|
| [23]  | 19.2        | 8.7       | 2.45–3.7 GHz               | NA   |
| [24]  | 13.8        | 3.91–10.2 | 2.96–11 GHz                | 57°  |
| [25]  | 3.2         | 10.2 dB   | 3.65–3.81 GHz              | 52°  |
| [26]  | 33          | 9 dB      | 3.4–3.8 GHz                | 11°, 44° |
| [27]  | 12.8        | 8.1 dB    | 3.14–3.81 GHz              | 64°  |
| [28]  | 5.3         | 8.5 dB    | 3.3–3.6 GHz                | 69.7° |
| [29]  | 6.81        | 8.2 dB    | 3.17–3.77 GHz              | 65°  |
| [30]  | 7.2         | 9.5       | 3.15–4.05                  | 72°  |
| [31]  | 13.1        | 8.9       | 3.3–3.8                    | 56°–65° |
| [32]  | 1.6         | NA        | 3.44–3.52                  | NA   |
| [33]  | 18.8        | 7.3       | 3.3–3.6                    | 68°  |
| [34]  | 1.5         | 8.5       | 3.45–3.55                  | 34°  |
| [35]  | 12.2        | 8.5       | 3.3–3.8                    | 65°  |
| [36]  | 11.8        | 8.1       | 3.14–3.8                   | 64°  |
| [37]  | 14          | 5.3       | 3.2–3.9                    | 88°  |
| This work | 24.3 | 8.55 dB | 3.6–3.85, 4.05–4.2, 4.8–5.15 GHz (S11, S22 < 15 dB) | 70°  |
Fig. 1 Geometric configuration of the proposed antenna; (a) Top view, (b) Side view, (c, d) Baluns
2.2 EM Analysis

The numerical simulations and optimization of the profile antenna are performed on HFSS. The slotted radiator develops a dual band s-parameter while the L-probe feed line achieves a better 50 Ω matching with a wide band feature. Based on the cited work and literature review, an un-slotted radiator with cross pair dipoles mounted on feeding baluns is designed for a dual-polarized radiation pattern in the first step. It exhibits 8.55 dBi gain and impedance bandwidth 3.6–4.1 GHz with S11, S22 < −15 dB as shown in Figs. 2 and 3. In the 2nd step E-shaped and corner circle slots are added to get a multi-band feature. The antenna exhibits 8.55dBi gain with impedance bandwidth 3.6–3.85 GHz, 4.05–4.20 GHz and 4.8–5.1 GHz with S11, S22 < −15 dB as shown in Figs. 2 and 3. So, a triple band dual-polarized feature is achieved with a ±45° dual-polarized cross pair dipole arrangement along with the feeding baluns and reflector. A uniform stable radiation pattern is observed with no evident drop when slots are added to get multi-band feature as shown in Fig. 2. Figure 3 shows the reflection coefficient of the profile antenna with slotted and un-slotted
radiator. It is observed that the un-slotted radiator structure gives a single band while the slotted radiator configuration exhibits triple band with the same uniform radiation pattern.

3 Simulation and Experimental Results

Based on optimization and above EM analysis with both dipole configurations, a triple band dual-polarized dipole antenna is proposed for 5G wireless applications. The profile antenna is fabricated and measured as shown in Fig. 4. Experimental results were taken in anechoic chamber using vector network analyzer. The reflection coefficient of the proposed antenna is shown in Fig. 5.

It is observed that the antenna gives impedance bandwidth 3.6–3.85 GHz, 4.05–4.20 GHz and 4.8–5.15 GHz. The simulated and measured radiation patterns of the proposed antenna at 3.6 GHz center frequency in E and H planes are shown in Figs. 6 and 7. The −45° polarized radiation pattern is omitted due to the similarity in results. The simulated and measured radiation patterns are very consistent and uniform in E and H planes. The radiation patterns at various frequencies within the proposed bands are shown in Fig. 8. It is observed that the profile antenna gives a uniform and stable radiation pattern over the entire band. The profile antenna gives 8.55 ± 0.6dBi gain over the entire band.

Fig. 4 Proposed fabricated antenna (a) and (b)
Both simulated and measured results are in a good agreement and a small discrepancy is due to the fabrication and insertion loss. The half power beam width (HPBW) of the proposed antenna is 70°. Furthermore, the comparison of the proposed antenna with reference papers of related works is presented in Table 1. For IoT applications, the profile antenna was tested in a realistic environment. The port1 was connected to a 5 GHz supported core I5 DELL laptop through a USB port connector as shown in Fig. 9. It was observed that the profile antenna got connected with Wi-Fi WLAN (Wi-Fi 4(802.11n)) at 5 GHz and support browsing as shown in Fig. 9.
4 Conclusion

In IoT applications, there is an advantage of applying an antenna as a wireless sensor technology. In this paper, a triple band $\pm 45^\circ$ dual-polarized dipole antenna is proposed for 5G wireless applications. Antenna covers 3.6–3.85 GHz, 4.05–4.20 GHz and 4.8–5.15 GHz measured bands and exhibits 8.55 dBi high gain with 70° half power beam width (HPBW). Antenna supports WLAN (Wi-Fi 4(802.11n)) when tested for an IoT application in a realistic environment at 5 GHz. The measured results confirm the validity of the proposed antenna design that makes it a good candidate for 5G sub-6 GHz wireless applications. The antenna performance and comparison with related works makes it eligible for massive MIMO antenna array for multi-band 5G base station applications.
Funding This paper is supported by National Science Foundation of China (Nos. 62071003, 41874174, 61901004, 61801194), the Opening Foundation of National Key Laboratory of Electromagnetic Environment (No. 201802003), The fund for key Laboratory of Electromagnetic scattering (No. 61424090107), Natural Science Foundation of Anhui Province (2008085MF186).

Declarations

Conflict of interest All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version. This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

References

1. Shahidul Islam, M., Islam, M. T., Almutairi, A. F., Beng, G. K., Misran, N., & Amin, N. (2019). Monitoring of the human body signal through the Internet of things (IoT) based LoRa wireless network system. Applied Sciences, 9(9), 1884.
2. Alomainy, A., Hao, Y., & Pasveer, F. (2007). Numerical and experimental evaluation of a compact sensor antenna for healthcare devices. IEEE Transactions on Biomedical Circuits and Systems, 1(4), 242–249.
3. Koga, Y., & Kai, M. (2018). A transparent double folded loop antenna for IoT applications. In 2018 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC) (pp. 762–765). https://doi.org/10.1109/APWC.2018.8503801.
4. Jha, K. R., Bukhari, B., Singh, C., Mishra, G., & Sharma, S. K. (2018). Compact planar multistandard MIMO antenna for IoT applications. IEEE Transactions on Antennas and Propagation, 66(7), 3327–3336.
5. Damis, H. A., Khalid, N., Mirzavand, R., Chung, H.-J., & Mousavi, P. (2018). Investigation of epidermal loop antennas for biotelemetry IoT applications. IEEE Access, 6, 15806–15815.
6. Zhou, S. G., Tan, P. K., & Chio, T. H. (2012). Low-profile, wideband dual-polarized antenna with high isolation and low cross polarization. IEEE Antennas and Wireless Propagation Letters, 11, 1032–1035.
7. Li, B., Yin, Y. Z., Hu, W., Ding, Y., & Zhao, Y. (2012). Wideband dual-polarized patch antenna with low cross polarization and high isolation. IEEE Antennas and Wireless Propagation Letters, 11, 427–430.
8. Wu, B. Q., & Luk, K. M. (2009). A broadband dual-polarized magneto-electric dipole antenna with simple feeds. IEEE Antennas and Wireless Propagation Letters, 8, 60–63.
9. Xue, Q., Liao, S. W., & Xu, J. H. (2013). A differentially-driven dual-polarized magneto-electric dipole antenna. IEEE Transactions on Antennas and Propagation, 61(1), 425–430.
10. Siu, L., Wong, H., & Luk, K. M. (2009). A dual-polarized magneto-electric dipole with dielectric loading. IEEE Transactions on Antennas and Propagation, 57(3), 616–623.
11. Chu, Q. X., & Luo, Y. (2013). A broadband unidirectional multi-dipole antenna with very stable beamwidth. IEEE Transactions on Antennas and Propagation, 61(5), 2847–2852.
12. Luo, Y., & Chu, Q. X. (2015). Oriental crown-shaped differentially fed dual-polarized multidipole antenna. IEEE Transactions on Antennas and Propagation, 63(11), 4678–4684.
13. Chu, Q. X., Wen, D. L., & Luo, Y. (2015). A broadband ±45° dual-polarized antenna with y-shaped feeding lines. IEEE Transactions on Antennas and Propagation, 63(2), 483–490.
14. Cui, Y. H., Li, R. L., & Fu, H. Z. (2014). A broadband dual-polarized planar antenna for 2G/3G/4G/LTE base stations. IEEE Transactions on Antennas and Propagation, 62(9), 4836–4840.
15. Cui, G., Zhou, S.-G., Zhao, G., & Gong, S.-X. (2016). A compact dual-band dual-polarized antenna with high isolation for wideband base station applications. IEEE Transactions on Antennas and Propagation, 62, 4392–4395.
16. Huang, H., Liu, Y., & Gong, S. X. (2017). A dual-broadband, dual-polarized base station antenna for 2G/3G/4G applications. IEEE Antennas and Wireless Propagation Letters, 16, 1111–1114.
17. Liu, X., He, S., Zhou, H., Xie, J., & Wang, H. (2006). A novel low-profile, dual-band, dual-polarization broadband array antenna for 2G/3G base station. In 2006 Presented at the IET International Conference on Wireless, Mobile, Multimedia Networks (pp. 1–4).
18. Li, B. A., Yin, Y. Z., Hu, W., Ding, Y., & Zhao, Y. (2012). Wideband dualpolarized patch antenna with low cross polarization and high isolation. IEEE Antennas and Wireless Propagation Letters, 11, 427–430.
19. Cui, G., Zhou, S.-G., Zhao, G., & Gong, S.-X. (2016). A compact dual-band dual-polarized antenna for base station application. Progress in Electromagnetics Research C, 64, 61–70.
20. He, Y., Pan, Z., Cheng, X., He, Y., Qiao, J., & Tentzeris, M. M. (2015). A novel dual-band, dual-polarized, miniaturized and low-profile base station antenna. IEEE Transactions on Antennas and Propagation, 63(12), 5399–5408.
21. Oh, T., Lim, Y. G., Chae, C. B., & Lee, Y. (2015). Dual-Polarization slot antenna with high cross-polarization discrimination for indoor small-cell MIMO systems. IEEE Antennas and Wireless Propagation Letters, 14, 374–377.
22. Luo, Y., Liu, Y., & Wen, D. L. (2016). A ±45° dual-polarized base-station antenna with enhanced cross-polarization discrimination via addition of four parasitic elements placed in a square contour. IEEE Transactions on Antennas and Propagation, 64, 1514–1519.
23. Xie, J. J., Yin, Y. Z., Wang, J. H., & Liu, X. L. (2013). Wideband dual polarized electromagnetic fed patch antenna with high isolation and low cross-polarization. Electronics Letters, 49(3), 171–173.
24. Zhu, F., Gao, S., Ho, A. T. S., Abd-Alhameed, R. A., See, C. H., Brown, T. W. C., Li, J., Wei, G., & Xu, J. (2014). Ultra-wideband dual-polarized patch antenna with four capacitively coupled feeds. IEEE Transactions on Antennas and Propagation, 62(5), 2440–2449.
25. Gao, Y., Ma, R., Wang, Y., Zhang, Q., & Parini, C. (2016). Stacked patch antenna with dual-polarization and low mutual coupling for massive MIMO. IEEE Transactions on Antennas and Propagation, 64(10), 4454–4449.
26. Hua, C., Li, R., Wang, Y., & Lu, Y. (2018). Dual-polarized filtering antenna with printed Jerusalem-cross radiator. IEEE Access, 6, 9000–9005.
27. Liu, Y., Wang, S., Wang, X., & Jia, Y. (2019). A differentially fed dualpolarized slot antenna with high isolation and low profile for base station application. IEEE Antennas Wireless Propagation Letters, 18(2), 303–307.
28. Huang, H., Li, X., & Liu, Y. (2019). A low-profile, dual-polarized patch antenna for 5G MIMO application. IEEE Transactions on Antennas and Propagation, 67(2), 1275–1279.
29. Wen, L.-H., Gao, S., Luo, Q., Yang, Q., Hu, W., & Yin, Y. (2019). A low-cost differentially driven dual-polarized patch antenna by using openloop resonators. IEEE Transactions on Antennas and Propagation, 67(4), 2745–2750.
30. Zhang, Z.-Y., & Wu, K.-L. (2019). Double torsion coil feeding structure for patch antennas. IEEE Transactions on Antennas and Propagation, 67(6), 3688–3694.
31. Ciydem, M., & Miran, E. A. (2020). Dual-polarization wideband Sub-6 GHz suspended patch antenna for 5G base station. IEEE Antennas and Wireless Propagation Letters, 19(7), 1142–1146. https://doi.org/10.1109/LAWP.2020.2991967
32. Deng, C., Yektakhah, B., & Sarabandi, K. (2019). Series-fed dual-polarized single-layer linear patch array with high polarization purity. *IEEE Antennas and Wireless Propagation Letters, 18*(9), 1746–1750. https://doi.org/10.1109/LAWP.2019.2929226
33. Huang, H., Li, X., & Liu, Y. (2018). 5G MIMO antenna based on vector synthetic mechanism. *IEEE Antennas and Wireless Propagation Letters, 17*(6), 1052–1055. https://doi.org/10.1109/LAWP.2018.2830807
34. Al-Tarifi, M. A., Sharawi, M. S., & Shamim, A. (2018). Massive MIMO antenna system for 5G base stations with directive ports and switched beam steering capabilities. *IET Microwaves Antennas and Propagation, 12*, 1709–1718.
35. Alieldin, A., Huang, Y., Stanley, M., Joseph, S. D., & Lei, D. (2018). A 5G MIMO antenna for broadcast and traffic communication topologies based on pseudo inverse synthesis. *IEEE Access, 6*, 65935–65944. https://doi.org/10.1109/ACCESS.2018.2878639
36. Liu, Y., Wang, S., Wang, X., & Jia, Y. (2019). A differentially fed dual-polarized slot antenna with high isolation and low profile for base station application. *IEEE Antennas and Wireless Propagation Letters, 18*(2), 303–307. https://doi.org/10.1109/LAWP.2018.2889645
37. Li, M., Chen, X., Zhang, A., & Kishk, A. A. (2019). Dual-polarized broadband base station antenna backed with dielectric cavity for 5G communications. *IEEE Antennas and Wireless Propagation Letters, 18*(10), 2051–2055. https://doi.org/10.1109/LAWP.2019.2937201

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

**Lixia Yang** (Member, IEEE) received the M.S. and Ph.D. degrees in radio science from Xidian University, Xi’an, China, in 2003 and 2007, respectively. From 2010 to 2011, he was a Post-Doctoral Fellow with the ElectroScience Laboratory, The Ohio State University, Columbus, OH, USA. From 2015 to 2016, he was also a Visiting Scholar with the Space Laboratory, School of Physics, The University of Texas at Dallas, Richardson, TX, USA. From 2016 to 2018, he was a Professor and the Head of the Department of Communication Engineering, Jiangsu University, Zhenjiang, China. Since 2019, he has been a Distinguished Professor with the School of Electronic and Information, Anhui University, Hefei, China. He has authored one book and over 100 journal articles. He has been in charge of and undertaken more than 20 projects. His research interests include electromagnetic wave propagation and scattering in complex media and objects, computational electromagnetics, inverse scattering, and antenna analysis and design. Prof. Yang is a Senior Member of the Chinese Institute of Electronics (CIE) and a Fellow of the Electronics Institute of Jiangsu Province, China.

**Hafiz Usman Tahseen** was born in 1983 in Pakistan. He completed his graduation and then Masters in Electronic Engineering from University of Engineering and technology Lahore, Pakistan. He has 12 years of field experience in his relevant research field. He further started his PhD in September 2018 from Jiangsu University China. He is now with the School of Computer Science and Communication Engineering, Jiangsu University China. He has already published different journal and conference papers in his relevant field of wireless communications.
Mr. Syed Shah Irfan Hussain was born in Karachi, Pakistan on 22nd March, 1978. He received a Baccalaureate of Science in Electrical Engineering from the University of Engineering & Technology (UET), Lahore in 2001. He completed his Master of Sciences in Computer Science (MSCS) from the National University of Computer and Emerging Sciences (NUCES) in 2004. Mr. Hussain also received a Master of Sciences in Computer Engineering (MSCE) degree from the Lahore University of Management Sciences (LUMS) in 2005. Being a PhD student at the Electrical Engineering Department, UET since 2005, he initiated his career in this department as a Lab Engineer and then became a Lecturer in 2006. He also completed B.A Arabic from Allama Iqbal Open University (AIOU) in 2007. He spent a year (2008-2009) of his PhD studies at the School of Electronic Engineering & Computer Science, Queen Mary and Westfield College, University of London (QMUL). He became an Assistant Professor in 2011 and since then he is serving UET at this post. He obtained his PhD in Electrical Engineering from UET Lahore, Pakistan in 2013. He is also serving as Director Wireless Communications laboratory since 2014 and Deputy Director EMC/Communication testing since 2016.

Wang Hongjin is a faculty member in the School of Computer Science and Communication Engineering at Jiangsu University. She teaches and conducts research in the field of signal processing and wireless communication. The courses she teaches are Signal and System, Digital Signal Processing, Modern Digital Signal Processing, Microwave Circuits, and Mobile Communication. Form 1988 to 1991, Studied in the Department of Electronic Information Systems at Dalian Maritime University and received her Master’s degree in July 1991. From 1984 to 1988, she studied in the Department of Electronic Engineering at Dalian Maritime University, and received her B.E. degree in July 1988.