Novel Differential-Fed Frequency-Reconfigurable Filtering Patch Antenna for 4G/5G Systems

Yasir I. A. Al-Yasir[1], Naser Ojaroudi Parchin[1], Ahmed Abdulkhaleq[1,2], Embarak M. I. Elfoghi[3], Raed Abd-Alhameed[1]
{Y.I.A.Al-Yasir@bradford.ac.uk}

[1] Faculty of Engineering and Informatics, University of Bradford, Bradford, UK
[2] SARAS Technology, Leeds, UK
[3] College of Electronic Technology, Bani Walid, Libya

Abstract. In this paper, a new high-gain differential-fed microstrip reconfigurable filtering antenna with high common-mode rejection is presented. A pair of probe feeding port is utilized to provide differentially exciting signals. The filtering response is achieved by introducing four symmetrical open-loop ring resonator slots on the top layer surrounding the excitation ports of the patch antenna. The resonators can produce nulls at the high edge of the passband bandwidth with high gain and wide stopband characteristics. The filtering antenna is designed, simulated and optimized using computer simulation technology (CST) software with Rogers TMM3 substrate and a relative dielectric constant of 3.45. Also, the antenna has a single layer substrate with a height of 0.035 of the free space wavelength and operating at 2.6 GHz and 3.5 GHz for 4G and 5G applications, respectively.

Keywords: Microstrip filtering antenna, 4G, 5G, CST, reconfigurable, differentially-fed antenna, Rogers.

1 Introduction

With the fast growth of new wireless communications, fourth-generation (4G) (2.6-2.7 GHz) and fifth-generation (5G) (3.4–3.8 GHz) spectrum have been allocated for many modern microwaves (MW) and radio frequency (RF) components such as antennas and filters [1-16]. Thus, microstrip antennas with filtering performance, high gain, high isolation, high front-to-back ratio (FTBR), stable radiation pattern, good common-mode (CM) rejection level and unidirectional radiation pattern in the planar configuration simultaneously are necessary for 5G applications [17-22]. Recently, dual-polarized and differential-fed techniques have been extensively introduced to improve the performance of the microwave and RF systems [23-25]. Different differential-fed antennas have been reported, such as planar antennas [26-29], magneto-electric dipole antennas [30, 31], 3D-backed antennas [32], and so on. A differential planar antenna presented in [26] is fed by 0^0 and 180^0 signals, providing low cross-polarization, wide bandwidths, and high gain. The presented design has a bandwidth of 13 GHz and resonates at 13.2 GHz for Ku-band wireless applications. Unlike conventional differentially fed microstrip antennas, the designs proposed in [27] and [28] employ a folded plate pair as the differential feeding approach. The proposed antennas have stable realized gains around 8 dB within the operating bandwidth, providing high stability of the radiation patterns with the symmetrical performance for the two resonating modes. A differential-fed planar antenna with a realized gain of 8.2 dBi and a 130 MHz bandwidth is presented in [29]. The designed antenna can serve different applications such as energy harvesting, Radio-frequency identification (RFID) tags and differential/balanced circuits.

In this work, a new differentially fed high gain reconfigurable filtering antenna is designed and simulated. Four half-wavelength open-ring slots are loaded to the radiating patch as resonator filters to provide the filtering characteristics. The filtering antenna is designed on a Rogers TMM3 substrate with a relative dielectric constant of 3.45, loss tangent = 0.002 and thickness h = 3.2 mm, and is simulated and optimized using finite element solver software (CST) simulator. Because of the differentially-driven and strict symmetrical geometry, very good performance including high stability of the radiation pattern characteristics, high isolation, good CM rejection, low-cross polarization level with filtering characteristics are obtained. All of these merits make the presented microstrip antenna suitable for 4G and sub-6GHz 5G communications. Compared with other presented filtering antenna designs, the proposed design has not only high gain and reconfigurable characteristics but also introduces high efficiency and much lower cross-polarization level due to the differentially driven port.

2 Design and Configuration of the proposed reconfigurable filtering antenna

Fig. 1 shows the geometry of the proposed differentially driven microstrip filtering antenna. The proposed filtering antenna composites of circular dick radiating patch with a diameter (D=30mm) and pair of differential feeding probes. Adding slots with different shapes to the radiating patch can affect the surface current densities or excite specific frequency modes. Therefore, the antenna size can be reduced with improved performance.

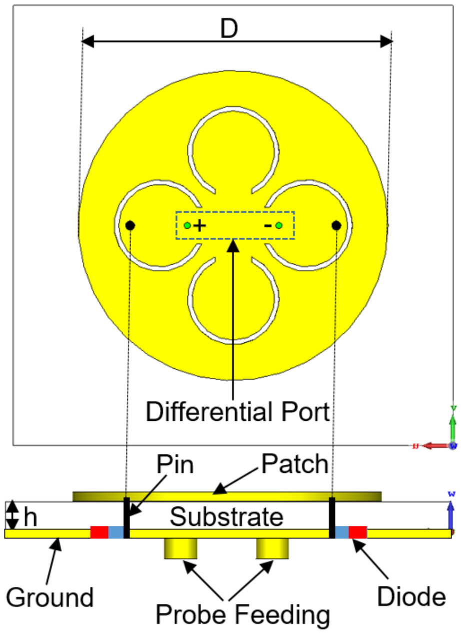
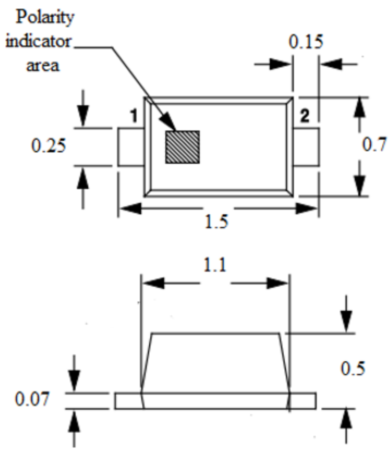


Fig. 1. Top- and side-view of the proposed antenna.

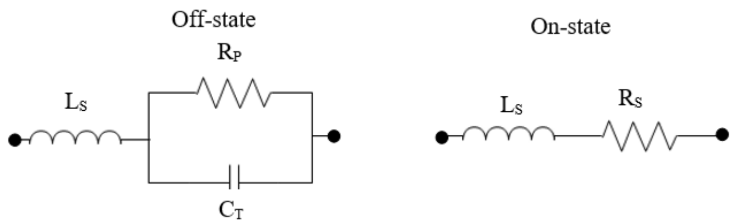
In our paper, the slots are loaded on the antennas to provide a broadside radiation-pattern nulls at the upper edge of the in-band antenna frequency response, providing filtering response with wide stopband rejection. The presented antenna consists of four open-loop ring slots, which are loaded on the top layer of the radiating patch. The total length of each slot is about half the wavelength of the resonant frequency. To achieve the reconfigurability property, two PIN diodes are placed on the ground layer to control the current distribution and, therefore, providing two resonance frequencies for 4G and 5G spectrums.

Just to prove the design concept, practical PIN diodes, SMP1320-079 from Skyworks Solutions Inc, were used with a size of 1.5 x 0.7 mm^2, as the switches. In computer simulation technology, CST microwave studio, these diodes are modeled with a lumped element network which gives 0.9 Ω as the resistance value of the PIN diode in the ON state and 0.3 pF as the capacitance value in the OFF state.

In the OFF state, a PIN diode is modeled as a series capacitance with a parasitic inductance as shown in Fig. 2. In the ON state, a PIN diode is represented to a series resistance with a parasitic inductance. A parasitic inductance results from the packaging effect. The circuit parameters are provided from the manufacturer's data where LS = 0.7 nH, CT = 0.3 pF and RS = 0.9 Ω. Since the value of Rp is higher than the reactance of CT, it can be neglected in the equivalent circuit.



(a)



(b)

Fig. 2. SMP1320 SC-79 PIN diode: (a) package dimension drawing (in mm), and(b) RF equivalent circuit models.

The SMP1320 series of plastic packaged, surface mountable PIN diodes is designed for use in high volume switch applications from 10 MHz to more than 10 GHz. The low current performance of these diodes (0.9 Ω maximum at 10 mA and 2 Ω typical at 1 mA) makes the SMP1320 series particularly suited to battery operated circuits. Package dimension for The SMP1320 SC-79 from Skyworks Solutions Inc and its equivalent circuit are shown in Fig. 2.

3 Reconfigurable filtering antenna performance

Reconfigurable filtering antenna characteristics in terms of reflection coefficients and peak realized gain for both diodes configurations (ON and OFF) are presented in Figs. 3 and 4, respectively. The obtained performance illustrates that the filtering antenna resonances at 2.6 GHz and 3.5 GHz with peak realized gain 5dB and 7.5dB at OFF and ON configurations, respectively, with impedance bandwidth 100 MHz. Also, Figs. 5 and 6 show the radiation patter characteristics for the proposed reconfigurable filtering antenna at diodes-OFF and diodes-ON configurations, respectively. At diodes-OFF configuration (Fig. 5), the operating frequency 3.6 GHz and main lob magnitude 8.13 dBi. The angular width (3 dB) 73.5^0 and side lobe level -23.8 dB. From the other hand, at diodes-ON configuration (Fig. 6), the operating frequency 2.65 GHz and main lob magnitude 7 dBi. The angular width (3 dB) 86 and side lobe level -17 dB. Fig. 7 shows the 3D simulation results for directivities which correspond to the cases of diode switching in both ON and OFF states.

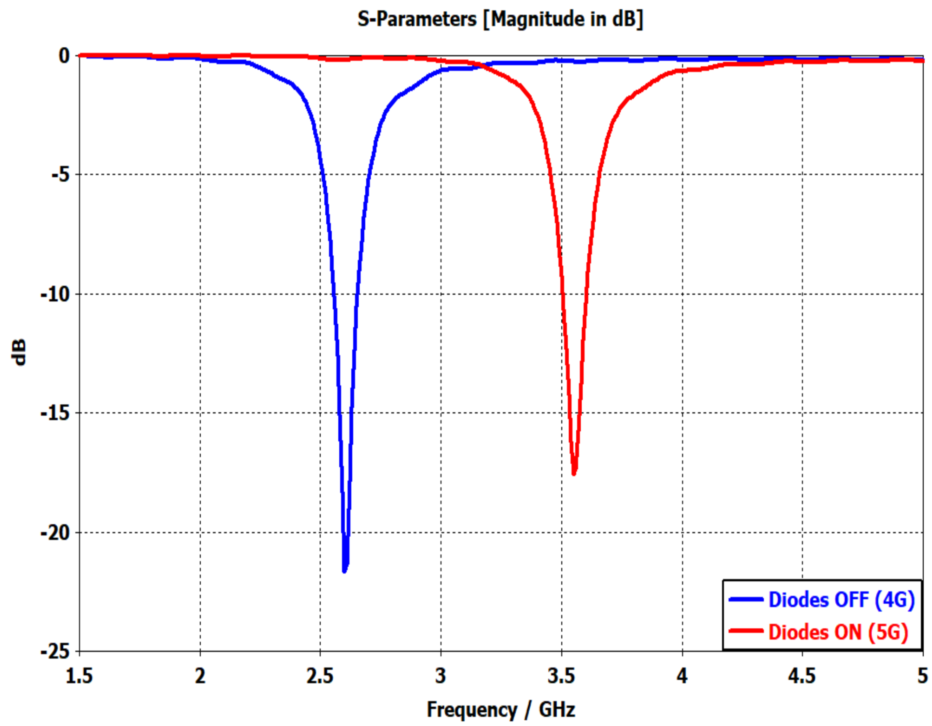


Fig. 3. S-parameter results of the proposed reconfigurable filtering antenna.

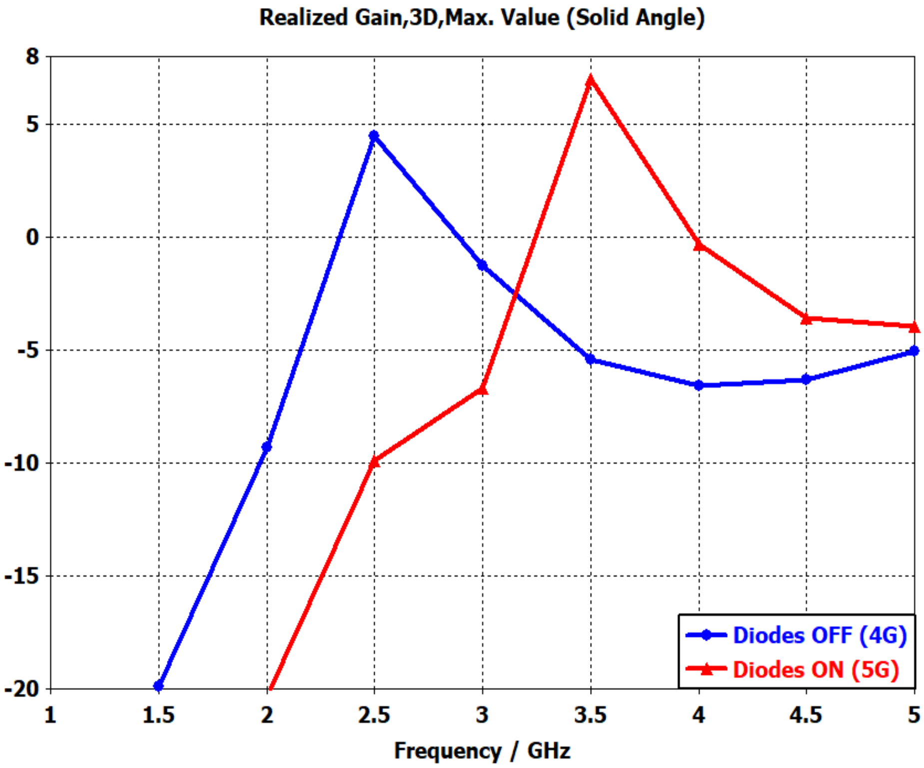


Fig. 4. Realized gain results of the proposed reconfigurable filtering antenna.

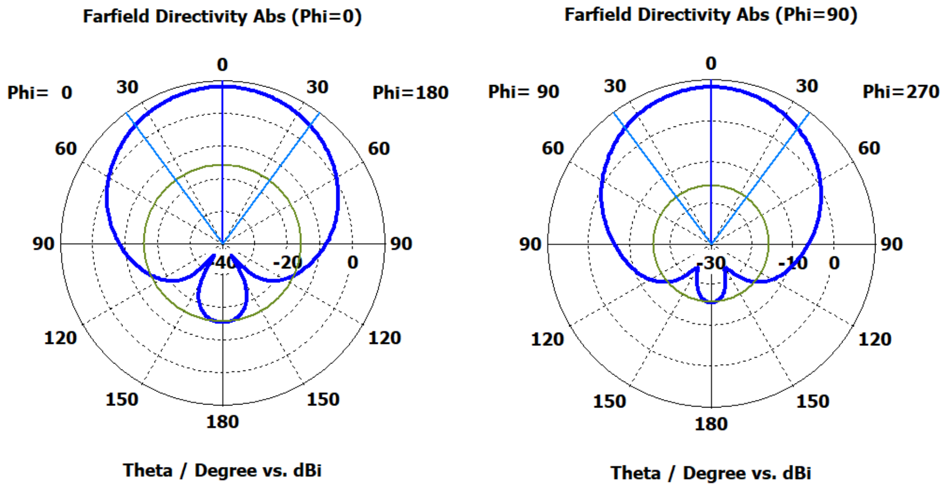


Fig. 5. 2-D Radiation pattern characteristics at diodes-OFF configuration.

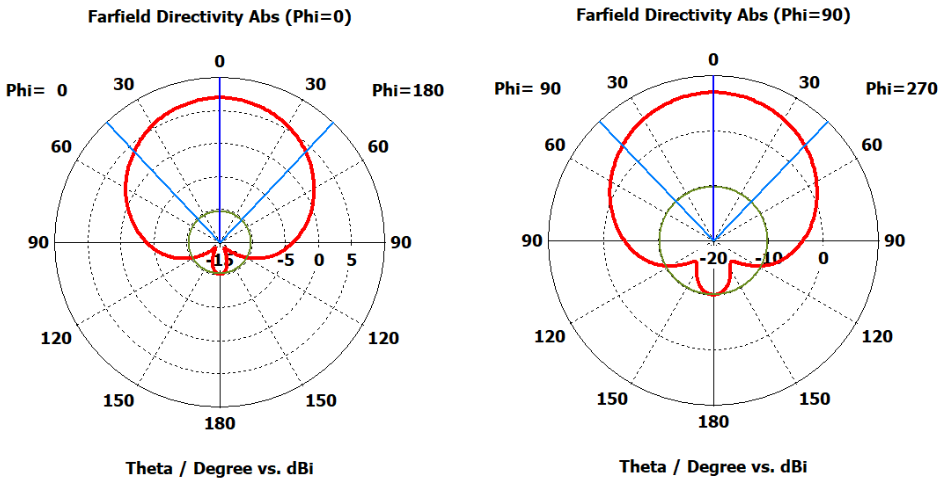


Fig. 6. 2-D Radiation pattern characteristics at diodes-ON configuration.

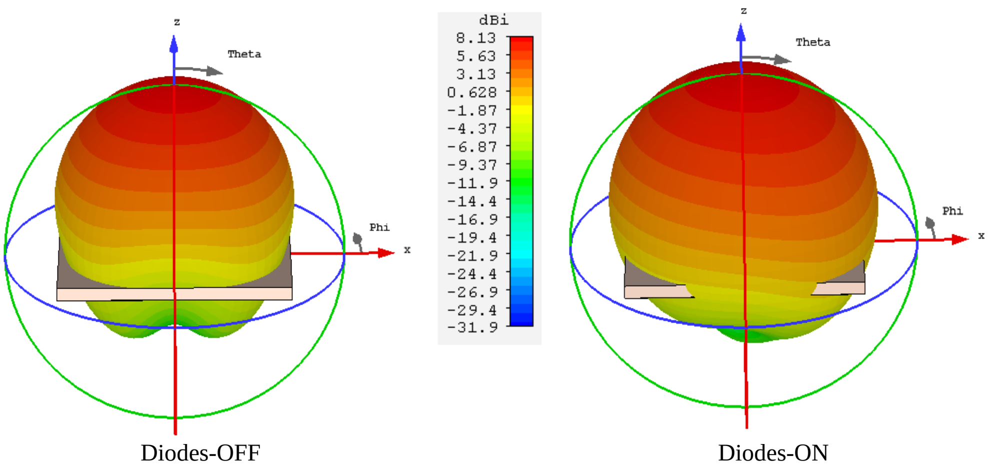


Fig. 7. 3-D Radiation pattern characteristics of the proposed filtering antenna.

4 Conclusion

A new differential-fed reconfigurable microstrip filtering antenna with high gain and high common-mode rejection is presented for 4G and 5G applications. In addition to the reconfigurability property, the performance has exhibited a few attractive features of our presented reconfigurable filtering antenna, that is, high gain, high efficiency, as well as much lower cross-polarization level due to the differentially-driven ports, and complete symmetry of the configuration. The resonators can produce nulls at the high edge of the passband bandwidth with high gain and wide stopband characteristics. The proposed reconfigurable filtering antenna height 0.035 λg and operating at the 4G and sub-6 GHz 5G spectrum. The designed filtering antenna is simulated and optimized using the CST simulator.

Acknowledgments. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement H2020-MSCA-ITN-2016 SECRET-722424.

References

[1] A. Hussaini, "Green Flexible RF for 5G," in Fundamentals of 5G Mobile Networks, J. Rodriguez, Ed.: John Wiley and Sons, 2015, pp. 241–272.

[2] Yasir I.A. Al-Yasir, Hasanain A.H. Al-Behadili, Baha A. Sawadi, Naser Ojaroudi Parchin, Ahmed M. Abdulkhaleq, Abdulkareem S. Abdullah and Raed A. Abd-Alhameed (September 26th 2019). New Radiation Pattern-Reconfigurable 60-GHz Antenna for 5G Communications, IntechOpen, Available from: https://www.intechopen.com/online-first/new-radiation-pattern-reconfigurable-60-ghz-antenna-for-5g-communications.

[3] Y. Al-Yasir et al., "Compact tunable microstrip filter with wide-stopband restriction and wide tuning range for 4g and 5g applications," The IET's Antennas and Propagation Conference, 2019, pp. 1-6.

[4] Y. I. Abdulraheem, A. S. Abdullah, H. J. Mohammed, B. A. Mohammed, and R. A. Abd-Alhameed, "Design of Radiation PatternReconfigurable 60-GHz Antenna for 5G Applications," Journal of Telecommunications, vol. 52, no. 4, pp. 1-5, 2014.

[5] Y. Liu, S. Wang, N. Li, J. Wang and J. Zhao, "A compact dual-band dual-polarized antenna with filtering structures for sub-6 GHz base station applications," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 10, pp. 1764-1768, Oct. 2018.

[6] H. J. Mohammed et al., "Evaluation of genetic algorithms, particle swarm optimisation, and firefly algorithms in antenna design," 2016 13th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Lisbon, 2016, pp. 1-4.

[7] Y. I. A. Al-Yasir and R. Abd-Alhameed, "New multi-standard dualwideband and quad-wideband asymmetric step impedance resonator filters with wide stop band restriction," International Journal of RF and Microwave Computer-Aided Engineering, vol. 29, no. 8, p. 1-17, 2019.

[8] Y. Al-Yasir, Y. Tu, N. Ojaroudi Parchin, I. Elfergani, R. Abd Alhameed, J. Rodriguez, J. Noras, "Mixed-coupling multi-function quintwideband asymmetric stepped impedance resonator filt" Microw. And Opt. Tech. Lett. Vol. 61, no. 5, pp. 1181-1184, Jan. 2019.

[9] X. Gu, S. Nikhil N, L. Guo, S. Hemour and K. Wu, "Diplexer-based fully passive harmonic transponder for sub-6-GHZ 5G-compatible iot applications," IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 5, pp. 1675-1687, May 2019.

[10] Y. I. A. AI-Yasir, N. Ojaroudi Parchin, A. Alabdullah, W. Mshwat, A. Ullah and R. Abd-Alhameed, "New Pattern Reconfigurable Circular Disk Antenna Using Two PIN Diodes for WiMax/WiFi (IEEE 802.11a) Applications," 2019 16th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Lausanne, Switzerland, 2019, pp. 53-56.

[11] Y. I. A. Al-Yasir, N. O. Parchin, A. Alabdallah, A. M. Abdulkhaleq, R. A. Abd-Alhameed and J. M. Noras, "Design of Bandpass Tunable Filter for Green Flexible RF for 5G," 2019 IEEE 2nd 5G World Forum (5GWF), Dresden, Germany, 2019, pp. 194-198.

[12] Y. I. A. Al-Yasir et al., "Design, Simulation and Implementation of Very Compact Open-loop Trisection BPF for 5G Communications," 2019 IEEE 2nd 5G World Forum (5GWF), Dresden, Germany, 2019, pp. 189-193.

[13] Y. Al-Yasir, N. Ojaroudi Parchin, R. Abd-Alhameed, A. Abdulkhaleq and J. Noras, "Recent Progress in the Design of 4G/5G Reconfigurable Filters" Electronics, vol. 8, no. 1, Jan. 2019.

[14] Y. Al-Yasir, A. S. Abdullah, N. Ojaroudi Parchin, R. A. Abd-Alhameed, and J. M. Noras, "A New Polarization-Reconfigurable Antenna for 5G Applications," Electronics, vol. 7, no. 11, p. 293, 2018.

[15] Al-Yasir Y.I.A. et al. (2019) A New Polarization-Reconfigurable Antenna for 5G Wireless Communications. In: Sucasas V., Mantas G., Althunibat S. (eds) Broadband Communications, Networks, and Systems. BROADNETS 2018. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 263. Springer, Cham.

[16] Y. I. A. Al-Yasir et al., " A Differential-Fed Dual-Polarized High-Gain Filtering Antenna Based on SIW Technology for 5G Applications," 2020 13th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, 2020, pp. 1-5.

[17] C. Wang, J. Bian, J. Sun, W. Zhang and M. Zhang, "A survey of 5G channel measurements and models," IEEE Communications Surveys & Tutorials, vol. 20, no. 4, pp. 3142-3168, Fourth quarter 2018.

[18] S. J. Yang, Y. M. Pan, Y. Zhang, Y. Gao and X. Y. Zhang, "Low-profile dual-polarized filtering magneto-electric dipole antenna for 5G applications," IEEE Transactions on Antennas and Propagation, vol. 67, no. 10, pp. 6235-6243, Oct. 2019.

[19] T. Alam, S. R. Thummaluru and R. K. Chaudhary, "Integration of MIMO and cognitive radio for sub-6 GHz 5G applications," IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 10, pp. 2021-2025, Oct. 2019.

[20] M. E. Yassin, H. A. Mohamed, E. A. F. Abdallah and H. S. El-Hennawy, "Single-fed 4G/5G multiband 2.4/5.5/28 GHz antenna," IET Microwaves, Antennas & Propagation, vol. 13, no. 3, pp. 286-290, 27 Feb. 2019.

[21] Y. I. A. Al-Yasir et al., "Design of multi-standard single/tri/quint-wideband asymmetric stepped-impedance resonator filters with adjustable TZs," IET Microwaves, Antennas & Propagation, vol. 13, no. 10, pp. 1637-1645, 14 Aug. 2019.

[22] Y. Al-Yasir, R. A. Abd-Alhameed, J. M. Noras, A. M. Abdulkhaleq and N. O. Parchin, "Design of very compact combline band-pass filter for 5G applications," The Loughborough Antennas & Propagation Conference (LAPC 2018), Loughborough, 2018, pp. 1-4.

[23] Z. Nie, H. Zhai, L. Liu, J. Li, D. Hu and J. Shi, "A dual-polarized frequency-reconfigurable low-profile antenna with harmonic suppression for 5G application," IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 6, pp. 1228-1232, June 2019.

[24] T. Hong, Z. Zhao, W. Jiang, S. Xia, Y. Liu and S. Gong, "Dual-band SIW cavity-backed slot array using TM_{020} and TM_{120} modes for 5G applications," IEEE Transactions on Antennas and Propagation, vol. 67, no. 5, pp. 3490-3495, May 2019.

[25] Y. I. A. Al-Yasir et al, "Design, simulation and implementation of very compact dual-band microstrip bandpass filter for 4G and 5G applications," 2019 16th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Lausanne, Switzerland, 2019, pp. 41-44.

[26] H. Jin, K. Chin, W. Che, C. Chang, H. Li and Q. Xue, "Differential-fed patch antenna arrays with low cross-polarization and wide bandwidths," IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 1069-1072, 2014.

[27] C. K. Chin, Q. Xue and H. Wong, "Broadband patch antenna with a folded plate pair as a differential feeding scheme," IEEE Transactions on Antennas and Propagation, vol. 55, no. 9, pp. 2461-2467, Sept. 2007.

[28] C. h. k. Chin, Q. Xue, H. Wong and X. y. Zhang, "Broadband patch antenna with low cross-polarisation," Electronics Letters, vol. 43, no. 3, pp. 137-138, 1 Feb. 2007.

[29] M. Arrawatia, M. S. Baghini and G. Kumar, "Differential microstrip antenna for rf energy harvesting," IEEE Transactions on Antennas and Propagation, vol. 63, no. 4, pp. 1581-1588, April 2015.

[30] Q. Xue, S. W. Liao and J. H. Xu, "A Differentially-driven dual-polarized magneto-electric dipole antenna," IEEE Transactions on Antennas and Propagation, vol. 61, no. 1, pp. 425-430, Jan. 2013.

[31] Y. Luo and Q.-X. Chu, “Oriental crown-shaped differentially fed dualpolarized multidipole antenna,” IEEE Trans. Antennas Propag., vol. 63, no. 11, pp. 4678–4685, Nov. 2015.

[32] C. R. White and G. M. Rebeiz, “A differential dual-polarized cavity backed microstrip patch antenna with independent frequency tuning,” IEEE Trans. Antennas Propag., vol. 58, no. 11, pp. 3490–3498, Nov. 2010.