

# 60 GHz Multi-Sector Antenna Array with Switchable Radiation-Beams for Small Cell 5G Networks

N. Ojaroudi Parchin, H. Jahanbakhsh Basherlou, Y. Al-Yasir, A. M. Abdulkhaleq, R. A. Abd-Alhameed, P. S. Excell

**Abstract**—A compact design of multi-sector patch antenna array for 60 GHz applications is presented and discussed in details. The proposed design combines five  $1 \times 8$  linear patch antenna arrays, referred to as sectors, in a multi-sector configuration. The coaxial-fed radiation elements of the multi-sector array are designed on 0.2 mm Rogers RT5880 dielectrics. The array operates in the frequency range of 58-62 GHz and provides switchable directional/omnidirectional radiation beams with high gain and high directivity characteristics. The designed multi-sector array exhibits good performances and could be used in the fifth generation (5G) cellular networks.

**Keywords**—MM-wave communications, multi-sector array, patch antenna, small cell networks.

## I. INTRODUCTION

THE multi-sector antenna array is a type of microwave antennas with sector-shaped radiation sections and could be used for specific operational needs such as mobile communications [1]-[5]. Its main advantage is that the antenna beams can be reconfigured to cover everywhere and can provide high gains for stationary and/or moving stations. Since MM-Wave communications have a harder time traveling through the obstacles, a sort of relay team for signal transmitting is needed [6]-[12]. By using this technique, as illustrated in Fig. 1, the smartphones can be switched to a new mini base station to keep the connections all the time.

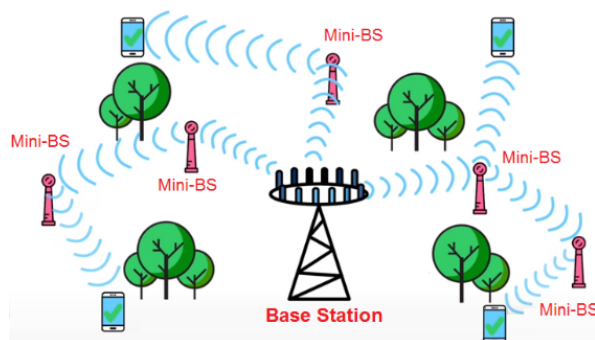


Fig. 1 Small cell network for 5G communications

Different kinds of antennas could be used as the radiation elements of the multi-sector antennas [13]-[18]. The printed

Naser Ojaroudi Parchin is with the Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, UK (e-mail: N.OjaroudiParchin@Bradford.ac.uk).

Haleh Jahanbakhsh Basherlou is with the Bradford College, Bradford, West Yorkshire, BD7 1AY, UK.

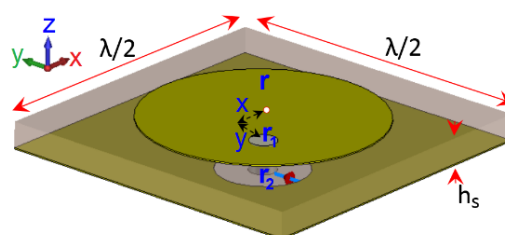
Peter S. Excell is with the Engineering Division, Glyndwr University, Wrexham LL11 2AW, UK.

patch antenna is very popular in arrays due to their attractive characteristics such as compact-size, high gain, and etc. [19]-[25].

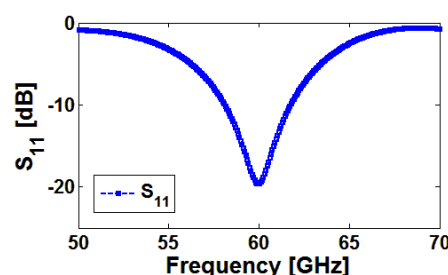
The main objective of this study is to demonstrate a very compact design of multi-sector patch antenna array for future cellular applications. The multi-sector antenna array is designed to use in mm-Wave 5G wireless networks [26]-[30]. The design is composed of five  $1 \times 8$  linear arrays arranged in a conformal form. The antenna provides 4 GHz bandwidth with high-gain and switchable directional/omnidirectional patterns. Fundamental properties of the multi-sector array have been studied and good results are achieved.

## II. 60 GHz PATCH ANTENNA

Fig. 2 (a) illustrates the schematic of the single element 60 GHz circular patch antenna.



(a)



(b)

Fig. 2 (a) 60 GHz patch antenna and (b) its reflection coefficient

It is designed on a Rogers RT5880 dielectric with an overall dimension of  $\lambda/2 \times \lambda/2 \times h_s = 2.5 \times 2.5 \times 0.2 \text{ mm}^3$ . As illustrated, the antenna has been fed by bringing the inner conductor of a coaxial cable through the substrate and connecting it to the circular patch surface. The parameter values of the antennas are as follow:  $r = 0.92 \text{ mm}$ ,  $r_1 = 0.1 \text{ mm}$ ,  $r_2 = 0.35 \text{ mm}$ ,  $x = 0.35 \text{ mm}$ . Fig. 2 (b) shows the reflection-coefficient ( $S_{11}$ ) of the coaxial-fed antenna versus frequency. It can be observed that the antenna has a good response around 60 GHz with 4

GHz bandwidth [31]-[35].

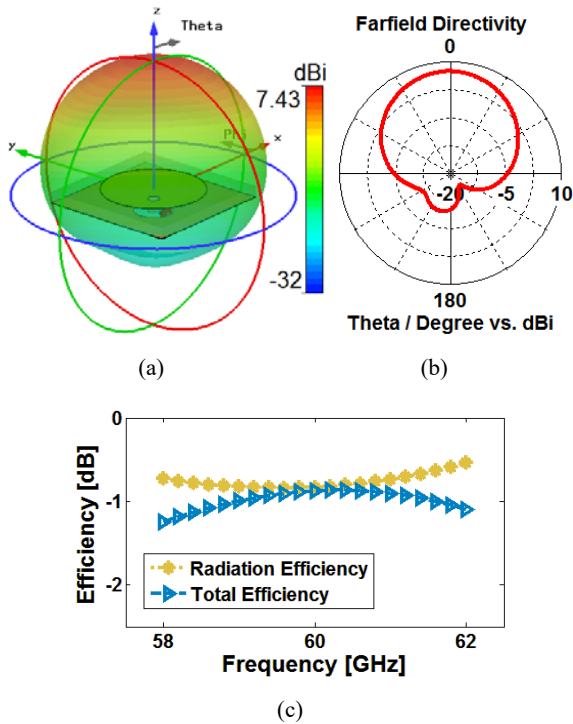


Fig. 3 (a) 3D (b) 2D radiation patterns at 60 GHz, and (c) the antenna efficiencies

The simulated 3-D and 2-D radiation patterns of the antenna are depicted in Fig. 3(a) and Fig. 3(b). The designed antenna has 7.43 dBi directivity with low back-lobes at 60 GHz. Simulated antenna efficiencies in the frequency range of 58 GHz to 62 GHz are shown in Fig. 3 (c). More than -1 dB (80%) and -1.25 dB (70%) radiation and total efficiencies are obtained for the designed single-element coaxial-fed antenna [36]-[38].

### III. 1×8 LINEAR ANTENNA ARRAY

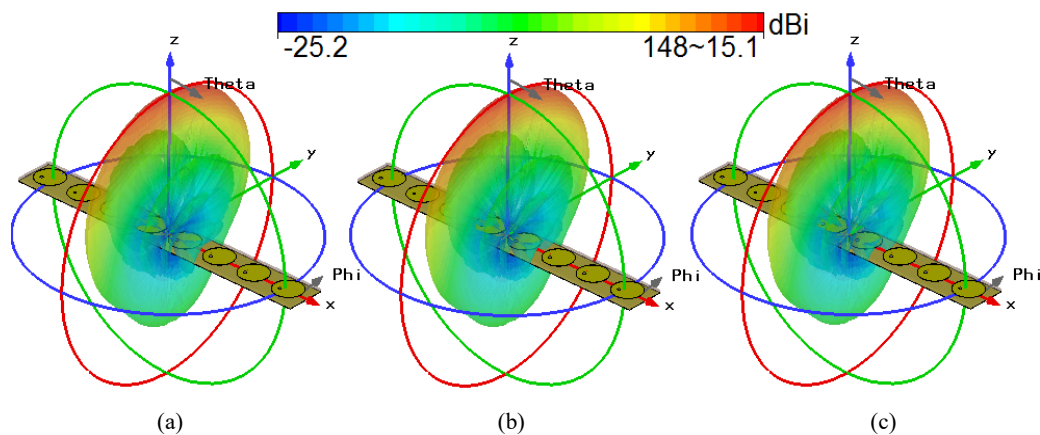


Fig. 5 3D views of the array radiation beams at (a) 59 GHz, (b) 60 GHz, and (c) 61 GHz

### IV. THE PROPOSED MULTI-SECTOR ANTENNA ARRAY

The schematic of the multi-sector array is illustrated in Fig.

Using eight elements of the 60 GHz patch antenna, a 1×8 linear array is designed as illustrated in Fig. 4 (a). The antenna elements have been arranged with a distance of  $d = \lambda/2 = 2.5$  mm. The overall dimension of the array is  $2.5 \times 20$  mm<sup>2</sup>. Fig. 4 (b) depicts the simulated S parameter results. As shown, the array has a good frequency response with a maximum -18 dB mutual coupling characteristics at 60 GHz.

3-D view of the array antenna beams (0°) at different frequencies of the antenna operation range (59 GHz, 60 GHz, and 61 GHz, respectively) are shown in Fig. 5: the designed antenna array has good radiation beams versus its operation frequency. It provides high-directivity/directional beams with low back/side lobes [39]-[42].

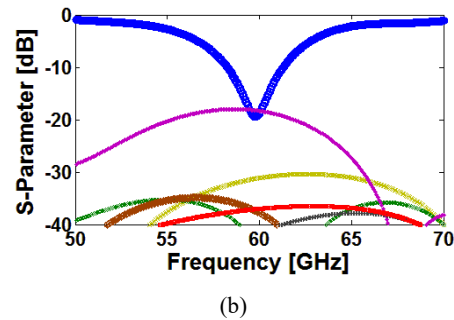
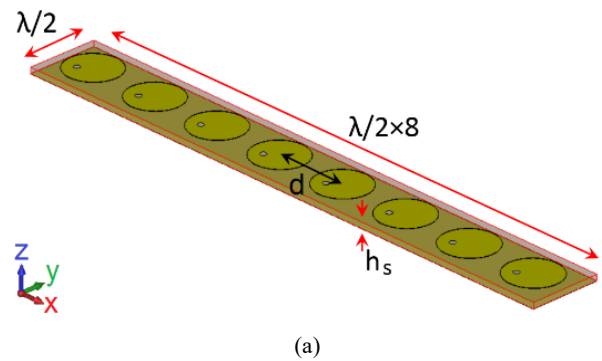


Fig. 4 (a) Structure of the linear array and (b) the array S parameter results

6. The design is composed of five 1×8 linear patch antenna arrays, referred to as sectors, in a multi-sector configuration.

The overall dimension of the antenna is  $8\lambda/2 \times L = 20 \times 4.5 \text{ mm}^2$ . Simulated  $S_{11}$  characteristics of the employed linear arrays as sectors are represented in Fig. 7. As shown, the sectors have good frequency responses around 60 GHz. Fig. 8 illustrates the directivity characteristics of the single element and the linear array at 60 GHz: symmetrical radiation patterns with low side lobes are achieved.

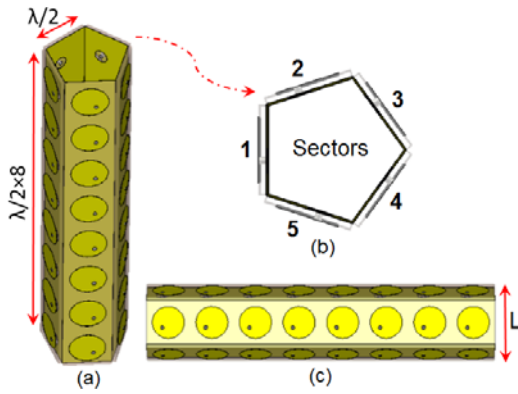


Fig. 6 (a) Side, (b) top, and (c) front views of the multi-sector design

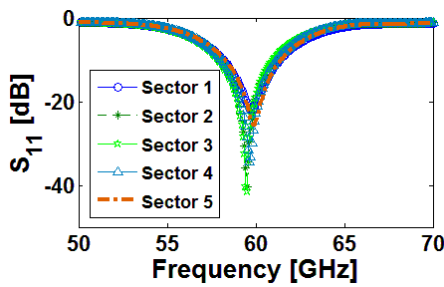


Fig. 7  $S_{11}$  results of the antenna array sectors

The 2D-polar radiation beams of the proposed multi-sector patch antenna array fed singly at different frequencies (59 GHz, 60 GHz, and 61 GHz) have been illustrated in Fig. 9. As can be observed, each sector of the proposed array can cover a different area of the required radiation coverage [43]-[45]. Apart from the directional beams of the multi-sector array, as shown in Fig. 10, the proposed design can also provide omnidirectional radiation patterns with sufficient directivity

values everywhere when it is fed singly (all the ports are excited simultaneously).

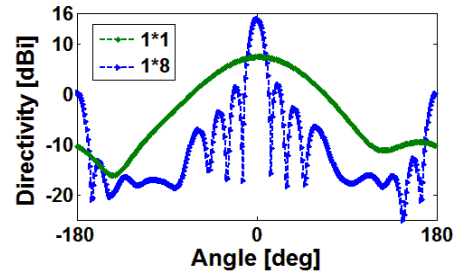


Fig. 8 Directivities of the single element and each secto

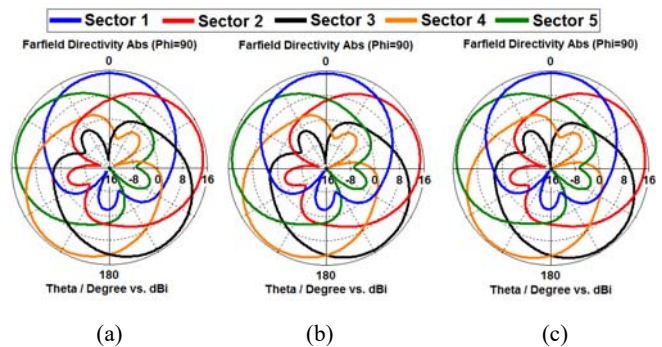
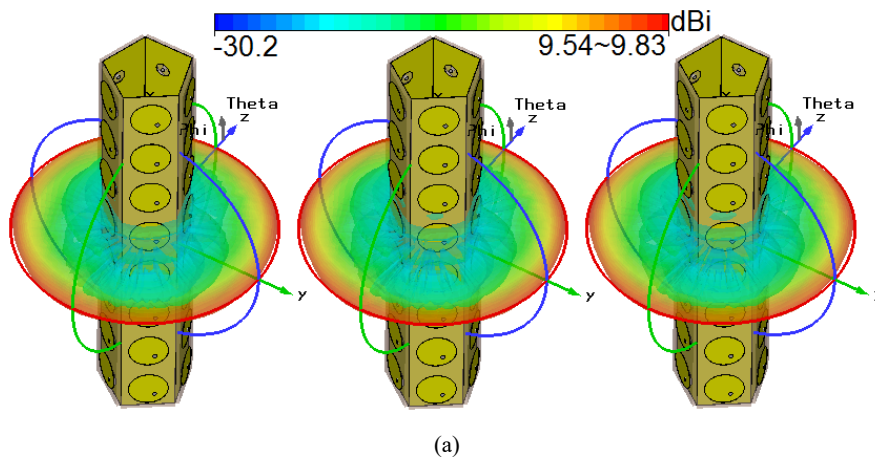


Fig. 9 2D views of the individual fed arrays at (a) 59 GHz, (b) 60 GHz, and (c) 61 GHz

## V. CONCLUSION

This manuscript presented the design and characteristic analysis of a very compact multi-sector patch antenna array for 5G cellular applications. The design contains five linear patch antenna arrays, referred to as sectors, to form a multi-sector antenna array. The radiation elements of the arrays are designed to operate at 60 GHz with 4 GHz impedance bandwidth. Fundamental properties of the design are discussed and sufficient results are achieved. The multi-sector array design has a compact size and is suitable to be used in 5G cellular networks.



(a)

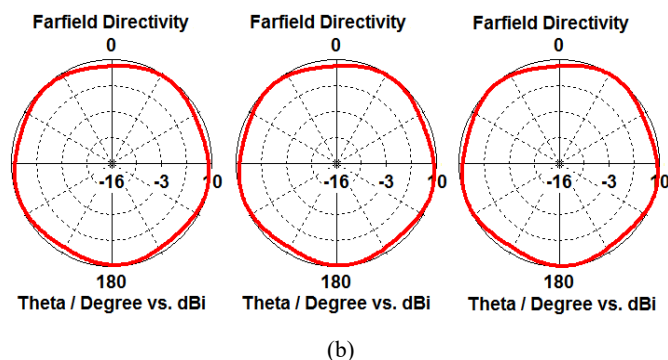


Fig. 10 (a) 3-D and (b) 2-D radiation beams of the single-fed array at 59, 60, and 61 GHz, respectively

#### ACKNOWLEDGMENT

This work is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement H2020-MSCA-ITN-2016 SECRET-722424.

#### REFERENCES

[1] T. Seki, T. Hori, "Cylindrical multi-sector antenna with self-selecting switching circuit", *IEICE 2000 Int. Symp. Antennas Propag.*, pp.1175–1178, 2000.

[2] N. Ojaroudiparchin, M. Shen, S. Zhang, and G. F. Pedersen, "A switchable 3D-coverage phased array antenna package for 5G mobile terminals," *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 1747–1750, 2016.

[3] Y. Simba, M. Yamamoto, T. Nojima, K. Itoh, "Planar-type sectored antenna based on slot Yagi-Uda array", *IEE Proceedings Microwaves, Antennas and Propagation*, pp.347-353, 2005.

[4] Y. Al-Yasir, et al., "New radiation pattern-reconfigurable 60-GHz antenna for 5G communications," *Modern Printed Circuit Antennas, IntechOpen*, 2019.

[5] N. O. Parchin, R. A. Abd-Alhameed, "A compact Vivaldi antenna array for 5G channel sounding applications," *EuCAP*, London, UK, 2018.

[6] H. Ebrahimiyan, et al., "Distributed diode single-balanced mixer using defected and protruded structures for Doppler radar applications," *ACES Journal*, vol. 28, no. 6, pp. 528-534, 2013.

[7] Y. Al-Yasir, et al., "New pattern reconfigurable circular disk antenna using two PIN diodes for WiMax/WiFi (IEEE 802.11a) applications," *IEEE Proceeding of International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD) 2019*, Lausanne, Switzerland, 2019.

[8] Y. Al-Yasir, et al., "A New Polarization-Reconfigurable Antenna for 5G Wireless Communications," *BroadNets'2018*, Faro, Portugal.

[9] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Multi-layer 5G mobile phone antenna for multi-user MIMO communications," *Telecommunications Forum (TELFOR 2015)*, November 2015, Serbia.

[10] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Beam-steerable microstrip-fed bow-tie antenna array for fifth generation cellular communications," *EuCAP 2016*, Switzerland, 2016.

[11] M. M. abdollahi, et al., "Octave-band monopole antenna with a horseshoe ground plane," *ACES Journal*, vol. 30, pp. 773-778, July 2015

[12] I. T.E. Elfergani et al., "Antenna fundamentals for legacy mobile applications and beyond," Springer Nature, pp. 1-659, 2017.

[13] G. Kumar, K. P. Ray, "Broadband Microstrip Antennas", Artech House Inc. Norwood MA, 2003.

[14] S. Rajagopal, S. Abu-Surra, Z. Pi and F. Khan, "Antenna array design for multi-gbps mmwave mobile broadband communication," *Proc. IEEE GLOBECOM'2011*, Houston, Texas, USA, pp.1-6, 2011.

[15] J. Zolghadr, et al., "UWB slot antenna with band-notched property with time domain modeling based on genetic algorithm optimization," *ACES Journal*, vol. 31, pp. 926-932, 2016.

[16] M. Bahmani, et al., "A compact UWB slot antenna with reconfigurable band-notched function for multimode applications," *ACES Journal*, vol. 13, no. 1, pp. 975-980, 2016.

[17] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "MM-wave dielectric

resonator antenna (DRA) with wide bandwidth for the future wireless networks," *International Conference on Microwaves, Radar and Wireless Communications (MIKON)*, Poland May 2016.

[18] N. O. Parchin, et al., "Frequency reconfigurable antenna array for mm-Wave 5G mobile handsets," *BroadNets*, Faro, Portugal, 19–20 September 2018.

[19] N. O. Parchin et al., "A substrate-insensitive antenna array with broad bandwidth and high efficiency for 5G mobile terminals," *IEEE Photonics & Electromagnetics Research Symposium (PIERS)*, Xiamen, China, 2019.

[20] J. Mazloum, et al., "Compact oscillator feedback active integrated antenna by using interdigital coupling strip for WiMAX applications," *ACES Journal*, vol. 28, no. 9, pp. 844-850, 2013.

[21] N. Ojaroudiparchin, et al., "Design of Vivaldi antenna array with end-fire beam steering function for 5G mobile terminals," *23rd Telecommunications Forum*, Belgrade, Serbia, Nov. 2015, pp. 587–590.

[22] J. Mazloum, et al., "Bandwidth enhancement of small slot antenna with a variable band-stop function," *Wireless Personal Communications, (Springer)*, vol. 95, pp. 1147-1158, 2017.

[23] J. Mondal, S. K. Ray, "Design smart antenna by microstrip patch antenna array", *International Journal of Engineering and Technology*, pp.675-682, 2011.

[24] N. Ojaroudiparchin, M. Shen, G. F. Pedersen. "A compact design of planar array antenna with fractal elements for future generation applications", *Applied Computational Electromagnetics Society (ACES) Journal*, pp. 789-796, 2016.

[25] H. Akbarzadeh, et al., "Utilization of protruded strip resonators to design a compact UWB antenna with WiMAX and WLAN notch bands," *ACES Journal*, vol. 31, pp. 159-163, 2016.

[26] T. Yilmaz, E. Fadel, O. B. Akan, "Employing 60 GHz ISM band for 5G wireless communications", *IEEE International Black Sea Conference on Communications and Networking*, 2014.

[27] N. Ojaroudi, "Circular microstrip antenna with dual band-stop performance for ultra-wideband systems," *Microw. Opt. Technol. Lett.*, vol. 56, pp. 2095-2098, 2014.

[28] N. Ojaroudiparchin, M. Shen, G. F. Pedersen, "8×8 planar phased array antenna with high efficiency and insensitivity properties for 5G mobile base stations", *EuCAP 2016*, Switzerland, 2016.

[29] T. Seki, N. Honma, K. Nishikawa, K. Tsunekawa, "A 60-GHz multilayer parasitic microstrip array antenna on LTCC substrate for system-on-package", *IEEE Microwave and Wireless Components Letters*, pp. 339-341, 2005.

[30] N. Ojaroudiparchin, M. Shen, G. F. Pedersen, "Low-cost planar mm-Wave phased array antenna for use in mobile satellite (MSAT) platforms", *Telecommunications Forum*, Serbia, pp. 528-531, 2015.

[31] N. Ojaroudi, "Design of microstrip antenna for 2.4/5.8 GHz RFID applications," *German Microwave Conference, GeMic 2014*, RWTH Aachen University, Germany, March 10-12, 2014.

[32] A. Musavand, et al., "A compact UWB slot antenna with reconfigurable band-notched function for multimode applications," *Appl Comp Electromagn Soc J*, vol. 31, pp. 14-18, 2016.

[33] B. H. Siahkal-Mahalle, et al., "A new design of small square monopole antenna with enhanced bandwidth by using cross-shaped slot and conductor-backed plane," *Microwave Opt Technol Lett*, vol. 54, pp. 2656–2659, 2012.

[34] N. Ojaroudi, et al., "Enhanced bandwidth of small square monopole antenna by using inverted U-shaped slot and conductor-backed plane,"



- Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, No. 8, 685–690, August 2012.
- [35] A. Valizade, “Band-notch slot antenna with enhanced bandwidth by using  $\Omega$ -shaped strips protruded inside rectangular slots for UWB applications”, *Appl. Comput. Electromagn. Soc. (ACES) J.*, vol. 27, pp. 816–822, 2012.
- [36] N. Ojaroudi, “A novel design of microstrip antenna with reconfigurable band rejection for cognitive radio applications,” *Microw. Opt. Technol. Lett.*, vol. 56, 2998–3003, 2014.
- [37] N. Ojaroudi, “A modified compact microstrip-fed slot antenna with desired WLAN band-notched characteristic,” *American Journal of Computation, Communication and Control*, vol. 1, pp. 56-60, 2014.
- [38] N. Ojaroudiparchin, *et al.*, “Wide-scan phased array antenna fed by coax-to-microstriplines for 5G cell phones,” *MIKON Conference*, Krakow, Poland, May 2016.
- [39] W. Hong, *et al.*, “mmWave phased-array with hemispheric coverage for 5th generation cellular handsets,” *EuCAP*, pp. 714-716, 2014.
- [40] N. Ojaroudiparchin, *et al.*, “End-fire phased array 5G antenna design using leaf-shaped bow-tie elements for 28/38 GHz MIMO applications,” *ICUWB 2016*, Nanjing, China, Oct. 16-19, 2016.
- [41] A. Ullah, *et al.*, “Coplanar waveguide antenna with defected ground structure for 5G millimeter wave communications,” *IEEE MENACOMM'19*, Bahrain, 2019.
- [42] Q. Chen, *et al.*, “Design considerations for millimeter wave antennas within a chip package,” *IEEE International Workshop on Anti-counterfeiting, Security, Identification*, Xiamen, pp. 13-17, 2007.
- [43] Y. Ojaroudi, *et al.*, “A novel 5.5/7.5 GHz dual band-stop antenna with modified ground plane for UWB communications” *Wireless Personal Communications*, vol. 81, pp. 319-332, 2015.
- [44] N. O. Parchin, “Low-profile air-filled antenna for next generation wireless systems,” *Wireless Personal Communications*, vol. 97, pp. 3293–3300, 2017.
- [45] N. O. Parchin *et al.*, “Dual-polarized MIMO antenna array design using miniaturized self-complementary structures for 5G smartphone applications,” *EuCAP Conference*, 2019.