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Design and Investigation of Phased Array LTSA for Future 5G Smartphone

Naser Ojaroudi Parchin[1*], Haleh Jahanbakhsh Basherlou[2], Raed A. Abd-Alhameed[1]

[1]*Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, UK*
[2]*Bradford College, Bradford, BD7 1AY, UK*

***Corresponding Author:** Naser Ojaroudi Parchin, Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, UK, Email: N.OjaroudiParchin@Bradford.ac.uk*

ABSTRACT

This study proposes a linear-tapered slot antenna (LTSA) array with beam steering function and wide impedance bandwidth for use in fifth-generation (5G) smartphone. Its configuration consists of eight compact LTSA elements with end-fire radiation mode are employed at the top portion of smartphone main board. The operation frequency band of the design expands from 20.5 to 24.7 GHz, providing more than 4 GHz bandwidth. The employed substrate is a low-cost N9000 *PTFE substrate with 2.2 permittivity, 0.8 mm thickness and overall size of 60×120×0.8 mm^3. Fundamental characteristics of the designed phased array antenna in terms of S-parameters, radiation beams, efficiencies, beam-steering, and gain levels are investigated and good results have been obtained. In addition, the proposed phased array design has sufficient radiation behavior in the presence of user-hand in data-mode.*

Keywords: *5G, beam-steerable antenna, LTSA, future 5G communications, mobile phone devices.*

INTRODUCTION

One of the main challenges in the future mobile communications is to shift to the higher spectrum (sub mm-wave and mm-wave spectrums) to provide high speed communications permitting transfer of high volumes of uncompressed data [1-4]. Increasing the operation frequency would require new techniques and careful consideration in the design of 5G antennas, especially for handheld devices [5-10].

For 5G mobile-phones, compact antennas can be arranged in a linear array form to be employed at different top/bottom portions of a mobile-phone PCB [11-14]. Compared with other printed microstrip antennas such as monopole, patch, Vivaldi, horn and etc., the linear tapered slot antenna is a good option to be used in the wide-band and point to point communication for wireless systems such as cellular networks [15-20].

The design and performance of mm-wave antenna array with beam-steerable function for 5G mobile broadband communication system has been provided. It is implemented on a cheap *N9000* PTFE substrate and operating in a wide range of 20.5 to 24.7 GHz. The employed radiation elements of the design is a linear tapered slot antenna to have broad band performance. The configuration of the proposed design is composed LTSA radiators with microstrip feeding technique in a 1×8 linear form on top portion of the mobile-phone PCB. The proposed phased array exhibits more than 4 GHz bandwidth for S_{11}≤-10 dB. It also provides good beam steering characteristics and high gain radiation beams with end-fire mode at different scanning angles. The EM simulation software CST Microwave Studio was used for the simulation [21]. The design details and fundamental radiation properties of the single-element antenna and its phased array are elaborated below.

SINGLE-ELEMENT LTSA

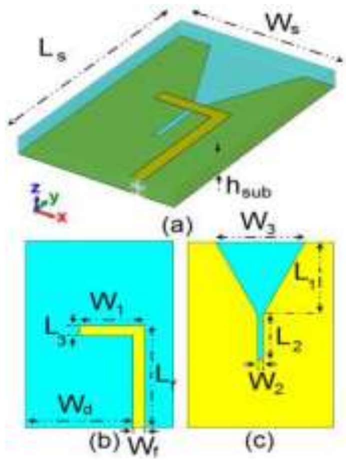

Fig1. *The element LTSA, (a) 3D view, (b) top layer, and (c) ground plane.*

The configuration of the single element LTSA as shown in Fig. 1 consists of a microstrip to slot-line and a linear tapered slot. The microstrip to slot-line consists of an open-circuited microstrip line and a short-circuited slot-line [22]. It has a low-profile with a dimension of $W_S \times L_S$. The values of the design parameters are listed in Table I.

Table1. *Dimensions of the Design Parameters*

Parameter	W_{sub}	L_{sub}	h_{sub}	W_S	L_S	W
Value (mm)	60	120	0.5	6.5	9.75	52
Parameter	L	W_1	L_1	W_2	L_2	W_3
Value (mm)	9.75	2.85	3.8	0.25	2.35	4
Parameter	L_3	W_f	L_f	W_d	d	d_1
Value (mm)	0.5	0.5	5.25	4.75	6.5	5.25

The motive behind the proposed design is to obtain compact end-fire antenna radiator supporting a wide frequency spectrum with a possibility to be integrated in a smartphone main board [23-25]. Figure 2 plots the simulated reflection coefficient (S_{11}) of the LTSA. As can be seen, the antenna covers the frequency range of 20.5 to 25 GHz and exhibits more than 4GHz impedance bandwidth. The 3D radiation patterns of the antenna at 22 and 23 GHz (resonance ferquenices) are plotted in Fig. 3. The obtained results show that the antenna provides excellent radiation behaviour in both of the operation frequencies. It is seen that the designed LTSA has good end-fire radiation mode with acceptable realized gain values.

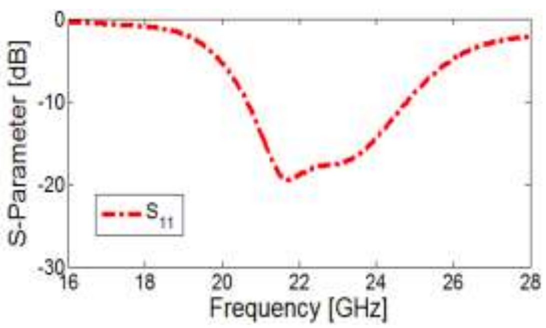

Fig2. *S_{11} characteristic of the LTSA*

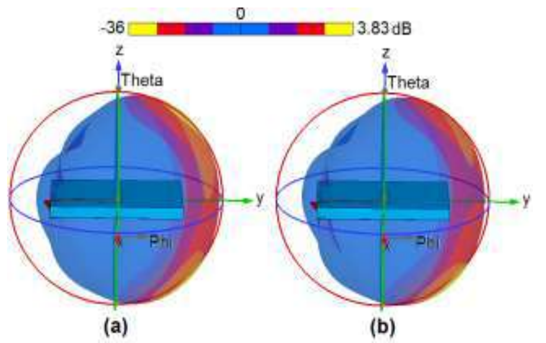

Fig3. *Simulated 3D radiation patterns at (a) 22 GHz, and (b) 23 GHz.*

The simulated current densities of the LTSA element at 22 and 23 GHz are illustrated in Fig. 4. It can be observed, at 22 and 23 GHz the maximum current distribution with high densities are dominant around of the microstrip to slot-line and a linear tapered slot with different directions of surface currents [26-28]. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the antenna resonator. The simulated maximum gain, radiation and total efficiencies of the LTSA antenna design over its operation band are illustrated in Fig. 5. As seen, the antenna provides sufficient maximum gain characteristics (almost constant around 4 dBi). In addition, the proposed antenna achieves more than 90% radiation efficiency over the operation band. Furthermore, as seen, the designed antenna provides good total efficiency above 80% with a maximum value of 95% at the resonance frequencies (22 and 23 GHz).

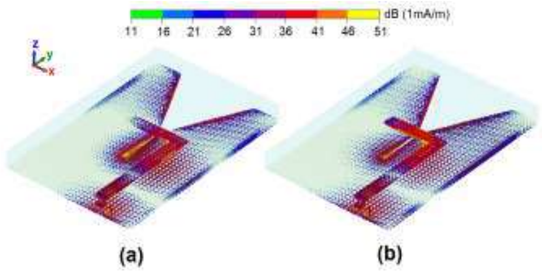

Fig4. *The surface current density of the LTSA element at, (a) 22 GHz, and (c) 23 GHz*

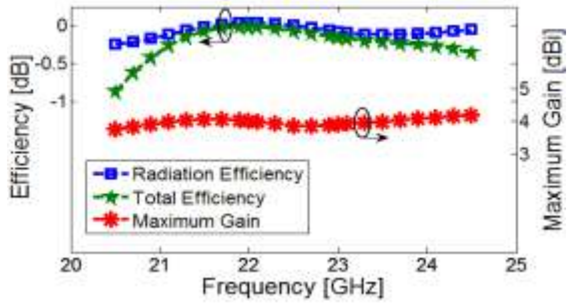

Fig5. *Fundamental radiation characteristics of the LTSA element*

CHARACTERISTICS OF THE PROPOSED ARRAY

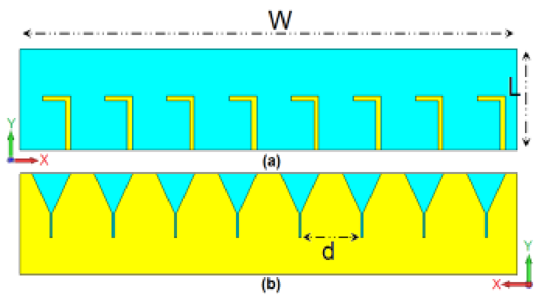

Fig6. *top bottom views of the LTSA array*

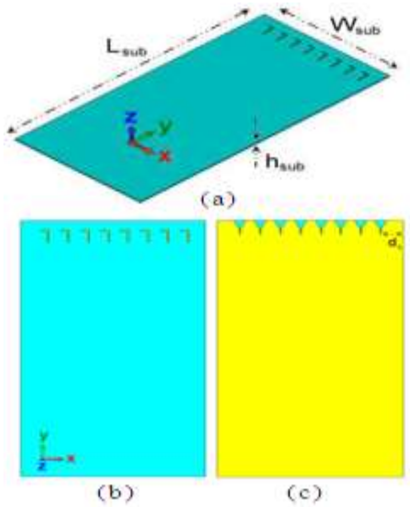

Fig7. *Geometry of the 5G smartphone antenna design, (a) 3D view, (b) top and (c) bottom layers.*

Figure 6 shows the configuration of the array with eight elements of LTSAs. Its configuration contains eight elements of LTSA in a linear array form which has been placed at the upper edge of the smartphone PCB with an overall dimension of 60×120×0.8 mm^3. Another set of the array can be employed in bottom portion of the smartphone PCB to cover the required radiation coverage [29-30]. The simulated S-parameter results of the proposed smartphone antenna array are depicted in Fig. 8. It can be seen that the designed 5G antenna array offers good S-parameters with low mutual coupling characteristic and similar reflection coeficicnt of the single element LTSA. As illustrtaed more than 4 GHz impedance bandwidth and better than -15 dB mutual coupling are achived for the proposed LTSA array design.

The simulated current distributions of the LTSA array design at 22 and 23 GHz are illustrtaed in Fig. 8. As can be cleasly seen, all currents with high debsities have concentrated on the upper portion of the samrtphone mainboard and the current flows are mainly distrubited around the LTSA radiators. It can be concluded that the big-size ground plane has insignificant impact to reduce the radiation-power of the end-fire arrays.

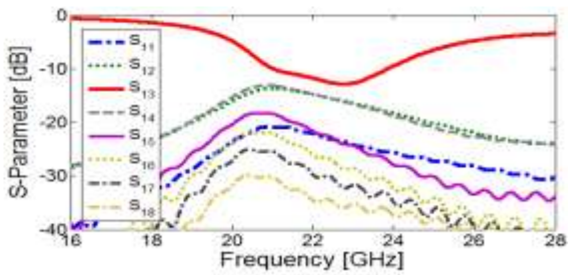

Fig8. *Simulated S-parameters of the proposed 5G mobile-phone antenna.*

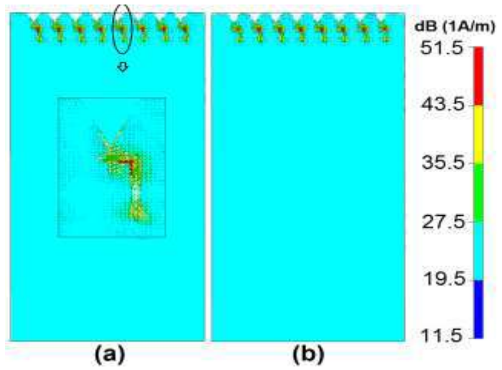

Fig9. *Current distribution at (a) 22 GHz and (b) 23 GHz.*

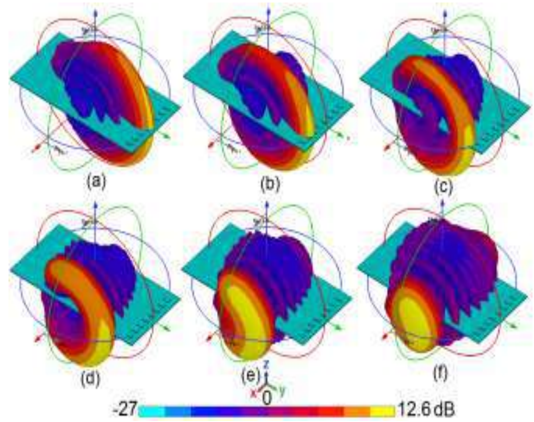

Fig10. *Radiation beams of the LTSA array at 22 GHz for scanning angle of (a) 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 70°.*

In order to demonstrate the sufficient performance of the proposed phased array over its operation bands, the 3D radiation beams for different scanning angles at 22 GHz and 23 GHz are represented in Fig. 10 and 11, respectivily. It is seen that the array exhibits good beam-steering function in the scanning range of 0~70 degree. In addition, as shown, the employed LTSA provide high-gain and end-fire beams which make it more appropriate for use in handheld devices.

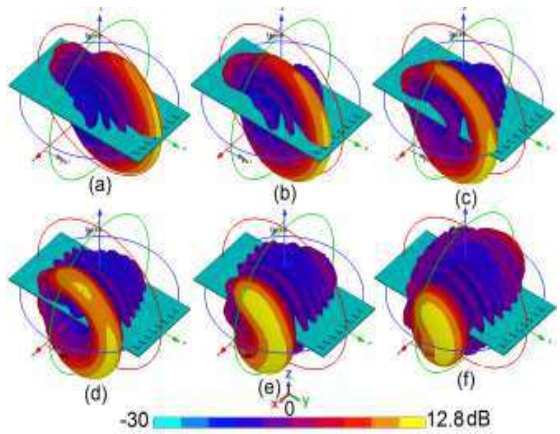

Fig10. *Radiation patters of the antenna at 23 GHz for different scanning angles, (a) 0°, (b) 15°, (c) 30°, (d) 45°, (e) 60°, and (f) 70°.*

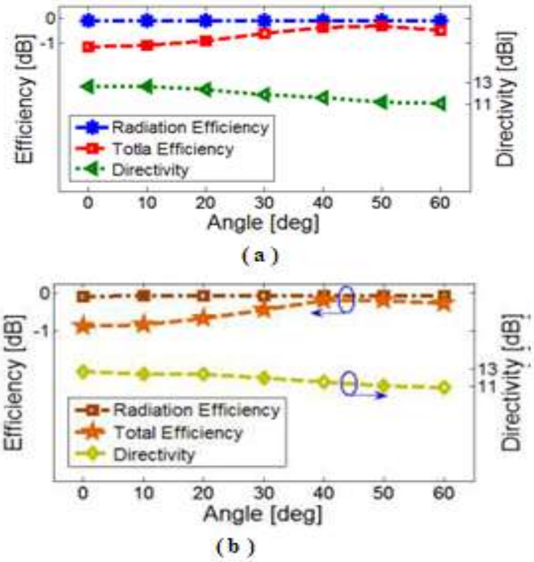

Fig11. Simulated durectivity and efficienies of the LTSA array beams for different angles at (a) 22 GHz, (b) 23 GHz.

The simulated fundamental properties of the LTSA array beams including the directivity, radiation and total efficiencies over the scanning angles at two different frequencies are illustrated in Fig. 11. As can be observed the LTSA array design exhibits sufficient and similar properties with 11-13 dBi directivities and more than -0.25 dB (95%) and -1 dB (80%) radiation and total efficiencies, respectively. Figures 12 (a) and (b) illustrtates the beam-steering function of the designed 5G smartphone antenna with 2D-cartesian realized and almost constant gain values at 22 and 23 GHz, respectively. It is seen sufficient radiation beams with low sidelobes and high relized gains are obianed at different angles.

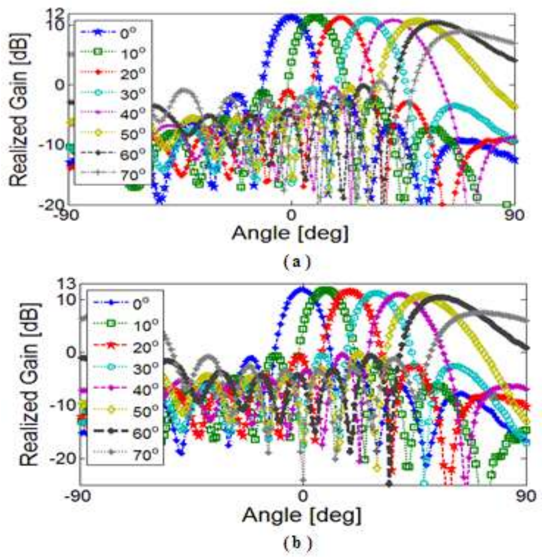

Fig12. *Realized gain characteristics of the radiation beams at scaning range of -60~ 60 degree at (a) 22 GHz, (b) 23 GHz.*

Characteristics of the Proposed Array

The User's hand usually has a negative effect on the characteristic of smartphone antennas [31-35]. This section studied the fundamental characteristics of the propose LTSA antenna array in the presence of the user-hand in Data-mode. The placement of the antenna with the user-hand in top and bottom positions illustrated in Fig. 13. . Figure 13 illustrates the radiation beams of the smartphone antenna array at different scanning angels (including 0°, 20°, 40°, and 60°).

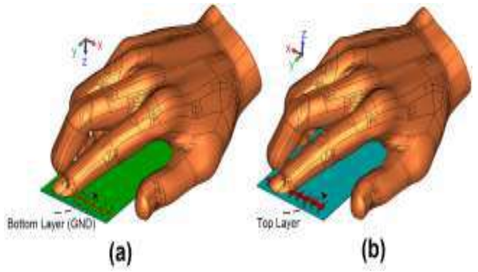

Fig13. *5G antenna placements in data mode, (a) bottom and (b) top position.*

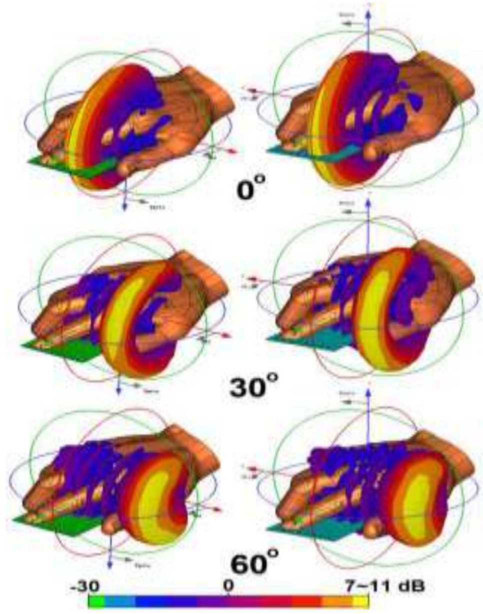

Fig13. *3D radiation beams in Data-mode for (a) bottom and (b) top positions.*

It can be seen that the LTSA array design provides good radiation beams with sufficient gain levels and end-fire radiation mode at different angles. However, as expected, the performance of the array has been reduced slightly. Table II summarizes the impact of user's hand on the performance of the proposed antenna. It can be observed that the proposed antenna has good performance in data mode. The maximum losses of antenna parameters in terms of antenna gain, radiation efficiency, and total efficiency are about 4.5 dB, 30%, and 45%, respectively.

Table1. *Total Losses of the Antenna Parameters in Data Mode*

Antenna Parameters	22 GHz		23 GHz	
	Position (a)	Position (b)	Position (a)	Position (b)
Total Efficiency	5~17%	20~40%	8~20%	20~45%
Radiation Efficiency	5~15%	25~30%	8~25%	15~30%
Realized Gain	0.5~1.5 dB	2~4.5 dB	0.5~2 dB	3~4.5 dB

CONCLUSION

This work deals with a design of phased array with more than 4 GHz bandwidth characteristic and high-gain/end-fire radiation beams for mm-wave 5G applications. Eight LTSA elements have been used for form a uniform linear array on the upper portion of the smartphone main board. Simulated results of the antenna fundamental characteristics have been investigated. According to the obtained results, the proposed LTSA array exhibits good features and can be used in 5G handheld devices.

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REFERENCES

[1] A. Osseiran, *et al.*, "Scenarios for 5G mobile and wireless communications: the vision of the METIS project," *IEEE Commun. Mag.*, vol. 52, pp.26-35, 2014.

[2] N. O. Parchin *et al.*, Microwave/RF components for 5G front-end Systems, *Avid Science*, 2019.

[3] Y. Wang, *et al.*, "5G mobile: Spectrum broadening to higher-frequency bands to support high data rates," *IEEE Vehicular Technology Magazine*, vol. 9, pp. 39-46, 2014.

[4] N. O. Parchin *et al.*, "Eight-element dual-polarized MIMO slot antenna system for 5G smartphone applications," *IEEE Access*, vol. 9, pp.15612-15622, 2019.

[5] W. Roh *et al.*, "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: Theoretical feasibility and prototype results," *IEEE Commun. Mag.*, vol. 52, pp. 106–113, 2014.

[6] N. O. Parchin, et al., "MM-wave phased array quasi-yagi antenna for the upcoming 5G cellular communications," *Applied Sciences*, vol. 9, pp. 1-14, 2019.

[7] N. Amitay, V. Galindo, C. P. Wu, "*Theory and analysis of phased array antennas*," Wiley-Interscience, New York, 1972.

[8] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Investigation on the performance of low-profile insensitive antenna with improved radiation characteristics for the future 5G applications," *Microw. Opt. Technol. Lett.*, vol. 58, pp. 2148-2158, 2016.

[9] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "End-fire phased array 5G antenna design using leaf-shaped bow-tie elements for 28/38 GHz MIMO applications," *International Conference on Ubiquitous Wireless Broadband (ICUWB 2016)*, Nanjing, China, Oct. 16-19, 2016.

[10] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "A 28 GHz FR-4 compatible phased array antenna for 5G mobile phone applications," *International Symposium on Antennas and Propagation* (*ISAP 2015)*, November 2015, Australia.

[11] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Design of Vivaldi antenna array with end-fire beam steering function for 5G mobile terminals," *Telecommunications Forum (TELFOR 2015)*, November 2015, Serbia.

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

[13] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "8 × 8 planar phased array antenna with high efficiency and insensitivity properties for 5G mobile base stations," *in Proc. 10th Eur. Conf. Antennas Propag.*, Davos, Switzerland, 2016, pp. 1–5.

[14] W. Hong, *et al.*, "Design and analysis of a low-profile 28 GHz beam steering antenna solution for future 5G cellular applications," *IEEE international microwave symposium*, June 2014, Florida, 2014.

[15] N. O. Parchin *et al.*, "Design of low cost FR4 wide-band antenna arrays for future 5G mobile communications," *ISAP2019*, Xian, China, October 2019.

[16] Z. Briqech, J. Robitaille, K. Bishyk, K. Abdo, D. Bhogal, and A. Sebak, ''High gain antipodal tapered slot antenna With sine-shaped corrugation and Fermi profile substrate slotted cut-out for MMW 5G,'' *in Proc. Global Symp. Millim.-Waves (GSMM)*, May 2015, pp. 1–3

[17] N. O. Parchin, M. Shen, and G. F. Pedersen, ''Small-size tapered slot antenna (TSA) design for use in 5G phased array applications,'' *Appl. Comput. Electromagn. Soc. J.*, vol. 32, no. 3, pp. 193–202, 2017.

[18] N. O. Parchin *et al.*, "Reconfigurable Phased Array 5G Smartphone Antenna for Cognitive Cellular Networks," *23rd Telecommunications Forum*, TELFOR 2019, 25–27 November, 2019, Belgrade, Serbia.

[19] N. Ojaroudi Parchin, R. A. Abdalhameed "A compact Vivaldi antenna array for 5G channel sounding applications," *EuCAP 2018*, London, UK, 2018.

[20] N. Ojaroudi Parchin *et al.*, "Frequency Reconfigurable Antenna Array for MM-Wave 5G Mobile Handsets," *BroadNets'2018*, Faro, Portugal.

[21] *CST Microwave Studio*, ver. 2017, CST, Framingham, MA, USA, 2018.

[22] K. S. Yngvesson, T. L. Korzeniowski, Y.-S. Kim, E. L. Kollberg, and J. F. Johansson, ''The tapered slot antenna-a new integrated element for millimeter-wave applications,'' *IEEE Trans. Microw. Theory Techn.*, vol. 37, no. 2, pp. 365–374, Feb. 1989.

[23] N. O. Parchin, "Low-profile air-filled antenna for next generation wireless systems," *Wireless Personal Communications*, vol. 97, pp. 3293–3300, 2018.

[24] N. O. Parchin, *et al.*, "A Design of Beam-Steerable Antenna Array for Use in Future Mobile Handsets," *ICSASWL 2020: International Conference on Smart Antenna Systems and Wireless LANs*, London, UK, 2020.

[25] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Design of Vivaldi antenna array with end-fire beam steering function for 5G mobile terminals", 23rd Telecommunications Forum Telfor (TELFOR), Belgrade, Serbia, 24–26 November 2015, pp. 587–590.

[26] R. A. Alhalabi and G. M. Rebeiz, "High-gain yagi-uda antennas for millimeter-wave switched-beam systems," *IEEE Trans. Antennas and Propagat.*, vol. 57, pp.36-72, Nov, 2009.

[27] 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.

[28] N. Ojaroudi, H. Ojaroudi and N. Ghadimi, "Quadband planar inverted-f antenna (PIFA) for wireless communication systems," Progress In Electromagnetics Research Letters, vol. 45, pp. 51- 56, 2014.

[29] N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Investigation on the performance of low-profile insensitive antenna with improved radiation characteristics for the future 5G applications," Microw. Opt. Technol. Lett., vol. 58, pp. 2148-2158, 2016.

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

[31] N. O. Parchin *et al.*, "Phased array antenna design for mm-wave 5G mobile terminals," Book Chapter, *Top 5 Contributions in Computer Networks and Engineering*, Avid Science, 2019.

[32] N. O. Parchin *et al.*, "Multi-band MIMO antenna design with user-impact investigation for 4G and 5G mobile terminals, *Sensors*, vol. 19, pp. 1-16, 2019.

[33] N. O. Parchin, *et al.*, "Mobile-phone antenna array with diamond-ring slot elements for 5G massive MIMO system," *Electronics*, vol. 9, pp. 1-14, 2019.

[34] N. O. Parchin, M. Shen, and G. F. Pedersen, "Small-size tapered slot antenna (TSA) design for use in 5G phased array applications," *Applied Computational Electromagnetics Society (ACES) Journal*, 2017.

[35] I. Syrytsin *et al.*, "Performance investigation of a mobile terminal phased array with user effects at 3.5 GHz for LTE advanced," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 1847–1850, 2017.

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