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Smartphone Antenna Design Covering 2G~5G Mobile Terminals

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Abstract: The demands of designing compact multi-band antennas to meet the growing requirements of integrating more wireless services in the narrow space of the mobile terminals are increased continuously. In order to meet this need, a multi-band multiple-input multiple-output (MIMO) antenna is proposed for various mobile terminals is this manuscript. The configuration of the antenna element of the 2×2 MIMO design consists of a multi-mode loop radiator with a pair of coupled parasitic structures placed at the upper edge of the smartphone printed circuit board (PCB). The loop antenna is a kind of self-balance antenna can operate at multi frequency bands. The employed substrate is a low-cost FR-4 laminate with an overall size of 75×150×1.6 mm^3. Simple, compact and flexible structure of the antenna makes it easy to manufacture and installation. For S_{11}≤−10 dB, the antenna elements of the MIMO design operate at the frequency ranges of 0.87–0.93 GHz, 1.7–1.8 GHz, 2.05–2.2 GHz, 3.5–6 GHz, and 6.7–7.3 GHz covering DCS, PCS, IMT, UMTS, LTE, and X operation bands. The designed MIMO antenna provides good efficiencies and sufficient gains in different frequency bands. In addition, the calculated TARC, ECC, and DG results of design are sufficient over the operation bands. The obtained results indicate that the proposed antenna can meet the actual demands of future smartphones.

Keywords: Cellular Communications, Loop Antenna, Mobile Antenna, MIMO Systems, SAR

1. Introduction

MIMO technology is the most promising technology to reach the required transfer data rates of cellular communications [1-3]. A MIMO mobile-phone system needs a number of antenna elements which operate concurrently to achieve system diversity gain [4-5]. For smartphone applications, multiband antenna designs covering various bands of mobile terminals such as GSM/LTE, WiFi, GPS etc. are highly required [6-7]. However, designing multi-band antennas in the limited space of the smartphone mainboard is a significant challenge for antenna engineers. Among various MIMO antennas, microstrip antennas such as planar inverted-F antenna (PIFA), loop, slot, monopole and etc. are more applicable to be used in handheld devices due to their compact profile, low cost, easy integration, and manufacturability [8-11].

While PIFA antennas are very popular due to their features such as multi-band and compact size characteristics. However, since PIFAs have high ground plane surface current which makes them sensitive to user interaction [12-14]. In this paper, we present a multiband loop antenna covering different frequencies of the mobile terminals. The proposed antenna in this paper is more suitable for user interaction. The configuration of the design is composed of two multi-band antenna radiators located at top and bottom sides of smartphone PCB. The antenna element consists of a loop radiator and a pair of parasitic resonators. A CPW feeding technique is employed for the antennas [15-16]. It is seen that the proposed antenna occupies small area and depicts good radiation characteristics which make it suitable for wireless devices operating at digital communication system (DCS), personal communication system (PCS), international mobile telecommunications (IMT), universal mobile telecommunications service (UMTS), long-term evolution (LTE), wireless local area network (WLAN), and X-band frequency spectrums. The antenna operation bands cover the frequency bands of 0.87–0.93 GHz, 1.7–1.8 GHz, 2.05–2.2 GHz, 3.5–6 GHz, and 6.7–7.3 GHz. The CST and Antenna Magus are used to investigate the design properties [17-18]. The characteristics of the design are described below.

2. Design Method of the Multi-Band Antenna

The configuration and design parameters of the single-element smartphone antenna are represented in Figure 1. As can be observed, it contains a loop radiator with a height of 5 mm and a pair of L-shaped and rectangular parasitic structures. The antenna is implemented in a cheap FR-4 with details of permittivity=4.4, loss tangent=0.025, and thickness of 1.6 mm.

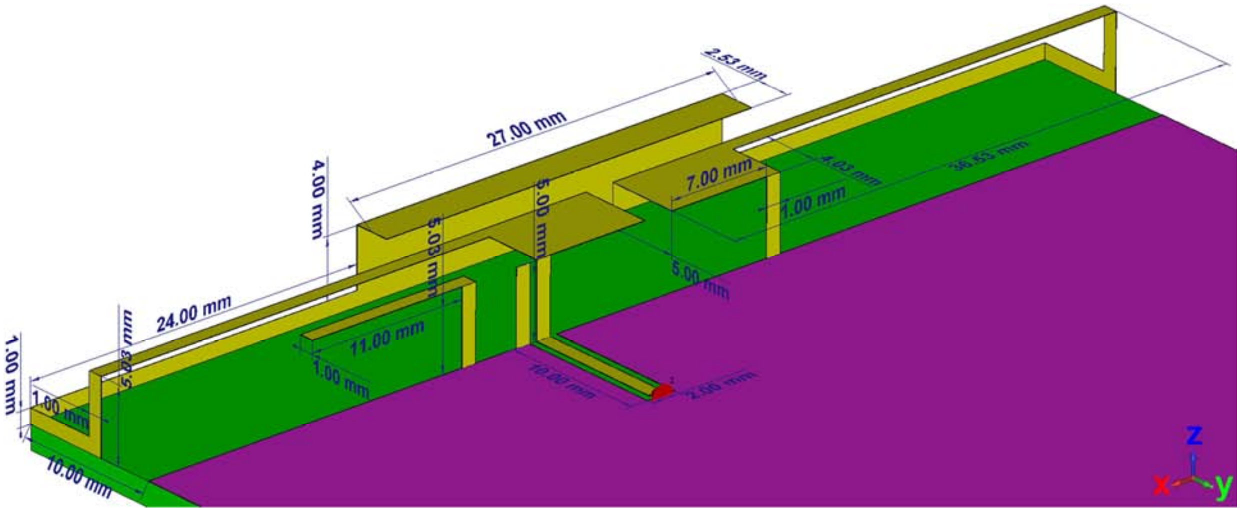


Figure 1. *Transparent view and design details of the antenna.*

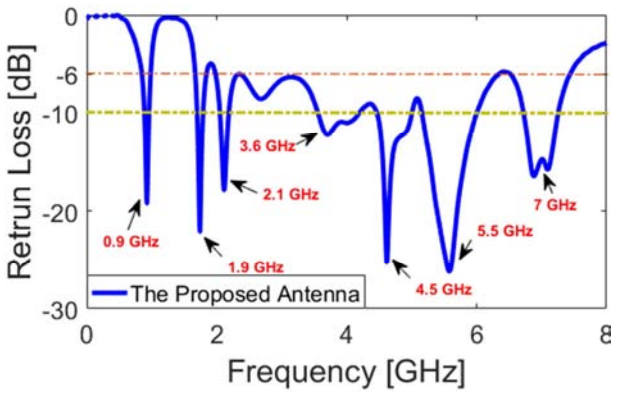


Figure 2. *Return loss (S_{11}) characteristic of the designed antenna.*

The antenna S_{11} result is plotted in Figure 2. As seen, the antenna operation bands cover the frequency bands of 0.87–0.93 GHz, 1.7–1.8 GHz, 2.05–2.2 GHz, 3.5–6 GHz, and 6.7–7.3 GHz. In order to justify the multi-band characteristic of the design, the simulated current densities of the loop antenna at different operation frequencies are illustrated in Figure 3. It should be noted that the maximum scaling for all figures is the same. It can be observed that the Four of the antenna resonances (including 0.9, 1.9, 2.1, and 4.5 GHz) are mainly due to the loop resonator itself and the other two modes are from the employed parasitic structures [19-20].

The radiation efficiency and total efficiency characteristics of the proposed antenna design are represented in Figure 4. As can be observed, the antenna provides sufficient efficiencies over the three operation band. More than 85% radiation efficiency and 75% total efficiency properties are achieved for the antenna at different resonance frequencies. The 3D radiation patterns for the design at different frequencies are displayed in Figure 5.

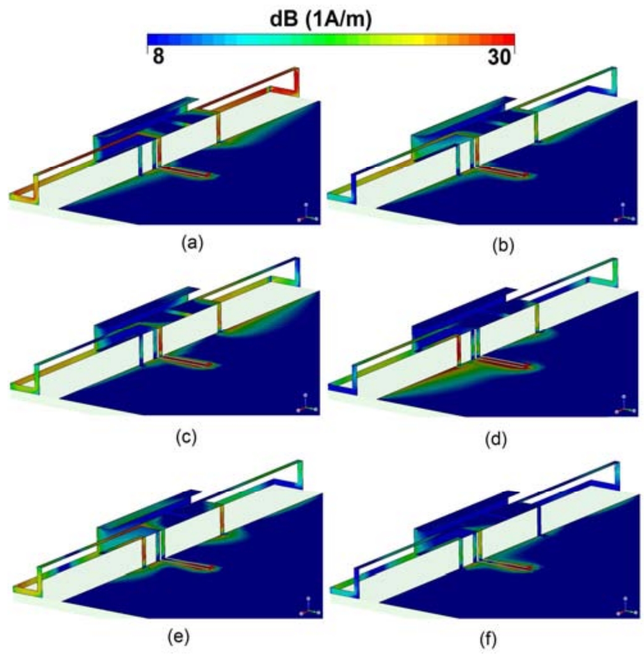


Figure 3. *Current distributions at (a) 0.9 GHz, (b) 1.9 GHz, (c) 2.1 GHz, (d) 4.5 GHz, (e) 5.5 GHz, and (f) 7 GHz.*

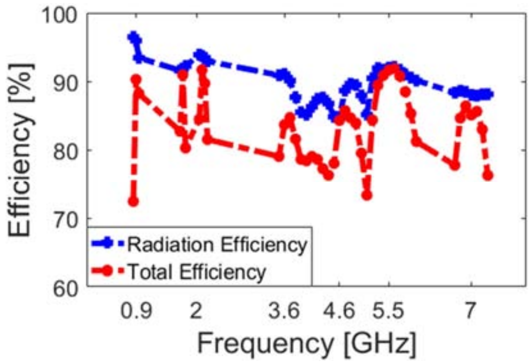


Figure 4. *Radiation and total efficiencies of the design.*

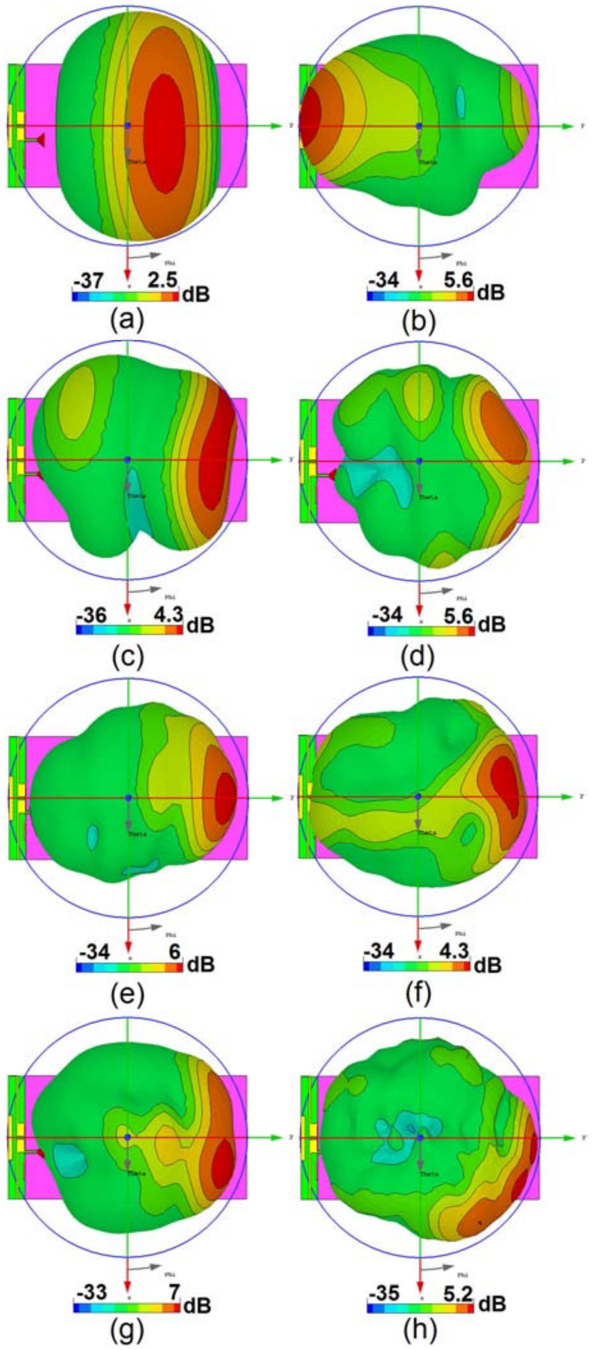


Figure 5. *Radiation patterns at (a) 0.9 GHz, (b) 1.9 GHz, (c) 2.1 GHz, (d) 3.6 GHz, (e) 4 GHz, and (f) 4.5 GHz, (h) 5.5 GHz, and (h) 7 GHz.*

It can be observed that the smartphone antenna design can offer sufficient gain vale for each radiator. As illustrated, the gain levels of the design vary from 2.5 to more than 5.5 dBi. In addition, the antenna provides sufficient radiation coverage at top and bottom sides of the smartphone mainboard [21-24].

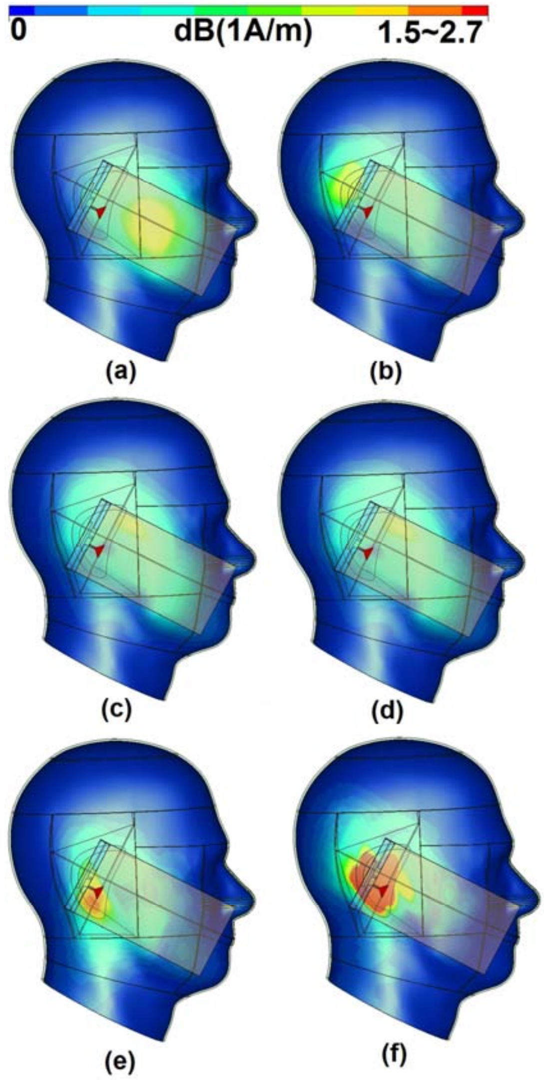
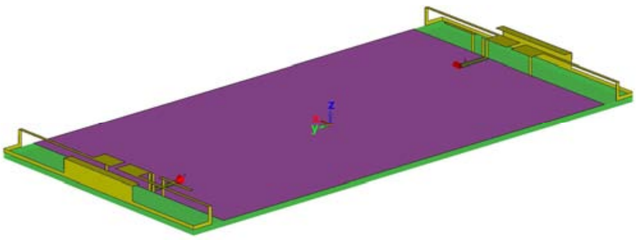


Figure 6. *SAR study of the designed antenna at (a) 0.9 GHz, (b) 1.9 GHz, (c) 2.1 GHz, (d) 3.6 GHz, (e) 4 GHz, and (f) 5.5 GHz.*

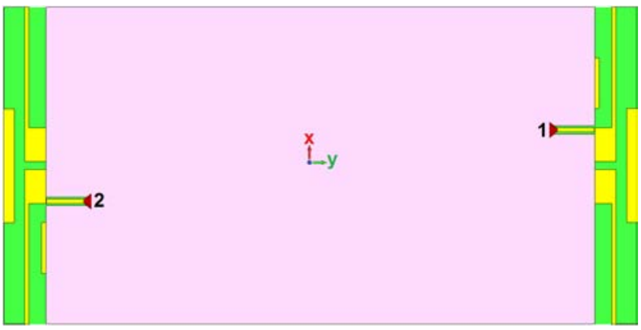
The Specific absorption rate (SAR) function of the multi-band loop antenna element with user-head at different operation frequencies is investigated and the obtained results are illustrated in Figure 6. As can be observed, the proposed smartphone antenna design exhibits sufficient SAR values at different operation frequency bands [25-26]. The maximum SAR value of the designed antenna is for upper frequencies including 3.6 and 5.5 GHz.

3. Results and Discussion of 2×2 MIMO Design

The configuration of the designed MIMO smartphone antenna is illustrated in Figure 7. As shown, it is composed of two-loop radiators that have been deployed at top and bottom sides of the mainboard. Figure 8 shows the S parameters (including S_{11} and S_{21}) of the designed smartphone antenna. As illustrated, the antenna exhibits good S parameters at operation bands covering the same spectrums of the single-element antenna design described in Section II. In addition, the proposed MIMO design provides sufficient mutual coupling between tow antenna elements, especially at the upper-frequency bands.



(a)



(b)

Figure 7. *(a) Side and (b) top views of 2×2 MIMO smartphone design.*

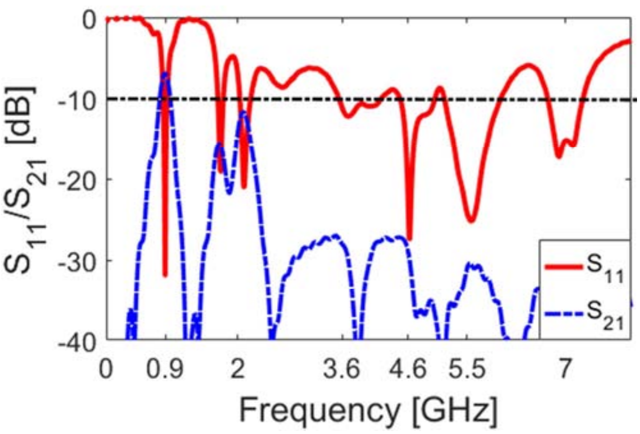


Figure 8. *S-parameters of the 2×2 MIMO smartphone design.*

The radiation patterns of the MIMO design for both antenna elements at different frequencies are illustrated in Figure 9. As shown, the MIMO antenna design can provide good radiation patterns with sufficient gain vales for each radiator. It is seen that 2.7 -5.7 dBi gain characteristic is obtained for the antenna elements.

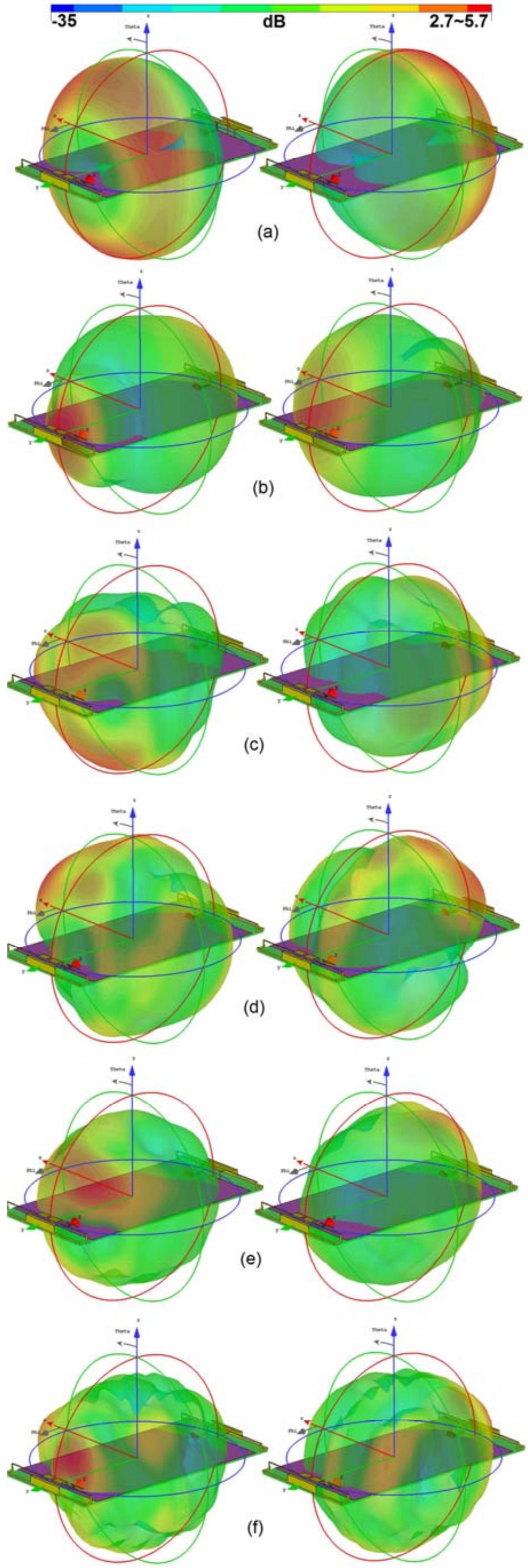


Figure 9. *Radiation patterns of the MIMO design at (a) 0.9 GHz, (b) 1.9 GHz, (c) 2.1 GHz, (d) 4.6 GHz, (e) 5.5 GHz, and (f) 7 GHz.*

Total active reflection coefficient (TARC) and envelope correlation coefficient (ECC) characteristics are two important parameters to be considered in MIMO antennas [27-28]. The ECC and TARC of two elements can be calculated from the S-parameters using the formula described as:

$$ECC = \frac{|S_{mm}^{*}S_{nm}+S_{mn}^{*}S_{nn}|^2}{(1-|S_{mm}|^2-|S_{mn}|^2)(1-|S_{nm}|^2-|S_{nn}|^2)^*} \quad (1)$$

$$TARC = -\sqrt{\frac{(S_{mm}+S_{mn})^2+(S_{nm}+S_{nn})^2}{2}} \quad (2)$$

As evident from figures 10 and 11, the calculated ECC results are very low entire the operation bands (less than 0.02). It can be also observed that the TARC value of the design is less than -10 dB. Another important parameter for MIMO performance of the MIMO antenna is diversity gain (DG) which can be calculated using the following relation:

$$DG = 10\sqrt{(1-ECC)^2} \quad (3)$$

The diversity gain function of the designed antenna over its operation band is illustrated in Figure 12. As can be clearly seen, more than 9.85 dB over the operating frequency bands is obtained for the MIMO design.

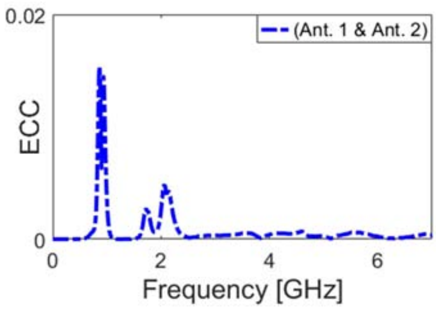


Figure 10. *ECC function of the MIMO design.*

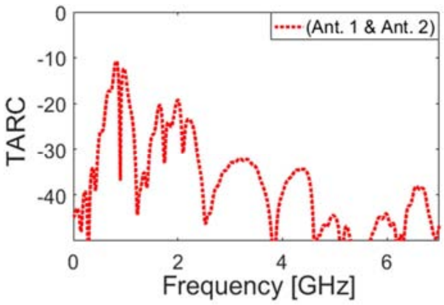


Figure 11. *TARC characteristic of the MIMO design.*

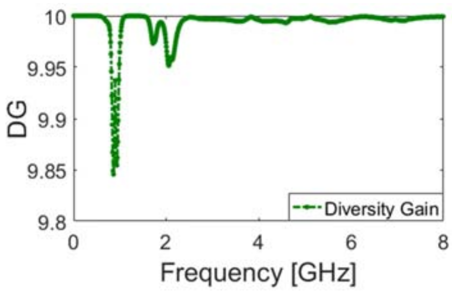


Figure 12. *DG result of the MIMO design.*

In general, the human-hand has a negative impact on the characteristics of the antenna design [29-30]. The efficiency characteristics of the antenna for two user-hand scenarios for top and back layers of the smartphone mainboard are studied, as seen in Figure 13. As can be observed from the results in Figure 14, the MIMO design and its radiation elements provide sufficient efficiencies (25%-65%).

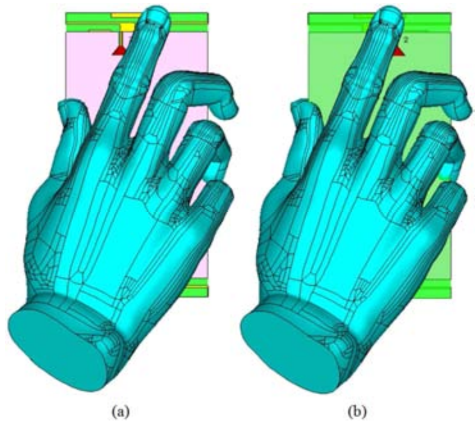


Figure 13. *Antenna placements in data mode, (a) top and (b) bottom Layers.*

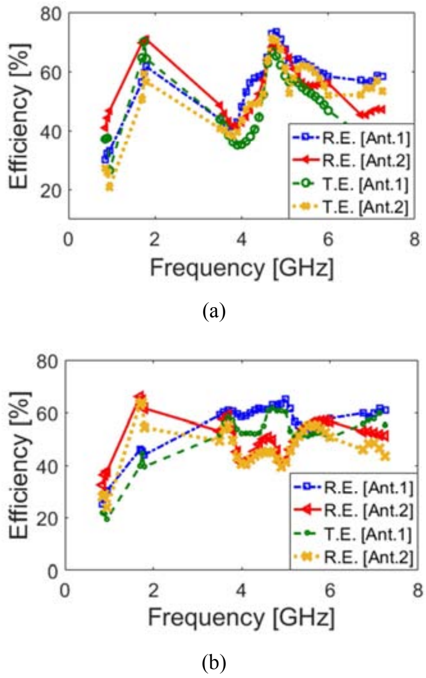


Figure 14. *Efficiency results of the MIMO design for (a) top-layer and (b) bottom-layer scenarios in data mode.*

4. Conclusion

In this paper, a double smartphone antenna design is introduced for various mobile communications. Its configuration structure is composed of two-loop radiators with pairs of parasitic structures. The antenna operates at different frequency bands including 0.87–0.93 GHz, 1.7–1.8 GHz, 2.05–2.2 GHz, 3.5–6 GHz, and 6.7–7.3 GHz. Fundamental radiation characteristics and MIMO performance of the antenna are discussed. The proposed

MIMO antenna design offers sufficient characterizes and can be used in handheld devices.

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References

[1] M. Jensen, J. Wallace, "A review of antennas and propagation for MIMO wireless communications," *IEEE Trans. Antennas Propag.,* vol. 52, pp. 2810–2824, 2004.

[2] Z. Zhang, "*Antenna Design for Mobile Devices*," Hoboken, NJ, USA: Wiley-IEEE Press, 2011.

[3] 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.

[4] 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.

[5] N. O. Parchin *et al.*, "*Microwave/RF components for 5G front-end systems*," Avid Science, pp. 1-200, 2019.

[6] N. Ojaroudi and N. Ghadimi, "Design of CPW-fed slot antenna for MIMO system applications," *Microw. Opt. Technol. Lett.*, vol. 56, pp. 1278- 1281, 2014.

[7] Z. Liang, Y. Li, and Y. Long, "Multiband monopole mobile phone antenna with circular polarization for GNSS application," *IEEE Trans. Antennas propag,* vol. 62, pp. 1910–1917, 2014.

[8] 62. N. Ojaroudi, M. Ojaroudi, and H. Ebarhimian, "Band-notched UWB microstrip slot antenna with enhanced bandwidth by using a pair of C-Shaped slots," Microw. Opt. Technol. Lett., vol. 54, pp. 515–518, 2012.

[9] Y. L. Ban, J. H. Chen, S. Yang, J. Li, and Y. J. Wu, "Low-profile printed octa-band LTE/WWAN mobile phone antenna using embedded parallel resonant structure," *IEEE Trans. Antennas propag*, vol. 61, pp. 3889–3894, 2013.

[10] N. Ojaroudi, "New design of multi-band PIFA for wireless communication systems," 19th International Symposium on Antenna and propagation, ISAP 2014, Kaohsiung, Taiwan, Dec. 2-5, 2014.

[11] M. S. Sharawi, "*Printed MIMO antenna engineering*," 2014, Norwood, MA, USA: Artech House.

[12] N. O. Parchin *et al.,* "Modified PIFA array design with improved bandwidth and isolation for 5G mobile handsets, IEEE 5G World Forum (WF-5G), Dresden, Germany, 2019.

[13] N. Ojaroudi, *et al.*, "An omnidirectional PIFA for downlink and uplink satellite applications in C-band," *Microwave and Optical Technology Letters*, vol. 56, pp. 2684-2686, 2014.

[14] N. Ojaroudi, H. Ojaroudi, and N. Ghadimi, "Quad-Band Planar Inverted-F Antenna (PIFA) for Wireless Communication Systems," *Progress In Electromagnetics Research Letters*, vol. 45, pp. 51-56, 2014.

[15] A. Kamalvand, *et al.*, "Omni-directional/multi-resonance CPW-fed small slot antenna for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 28, pp. 829-835, September 2013.

[16] N. Ojaroudi and N. Ghadimi, "Dual-band CPW-fed slot antenna for LTE and WiBro applications," *Microw. Opt. Technol. Lett.*, vol. 56, pp. 1013- 1015, 2014.

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

[18] *Antenna Magus,* ver. 2017, USA, 2017.

[19] N. Ojaroudi, "Design of small reconfigurable microstrip antenna for UWB-CR applications," 19th International Symposium on Antenna and propagation, ISAP 2014, Kaohsiung, Taiwan, Dec. 2-5, 2014.

[20] 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.

[21] N. Ojaroudi, M. Ojaroudi, and Sh. Amiri, "Enhanced bandwidth of small square monopole antenna by using inverted Ushaped slot and conductor-backed plane," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, 685– 690, August 2012.

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

[23] N. Parchin, *et al.*, "UWB mm-Wave Antenna Array with Quasi Omnidirectional Beams for 5G Handheld Devices", ICUWB, October 2016, Nanjing, China.

[24] 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.

[25] R. Hussain, A. T. Alreshaid, S. K. Podilchak, M. S. Sharawi, "Compact 4G MIMO antenna integrated with a 5G array for current and future mobile handsets," *IET Microw. Antennas Propag.*, vol. 11, pp. 271–279, 2017.

[26] Q. Chen, H. Lin, J. Wang, L. Ge,; Y. Li, T. Pei, "Single ring slot based antennas for metal-rimmed 4G/5G smartphones," *IEEE Trans. Antennas Propag.* 2019, vol. 67, pp. 1476–1487, doi: 10.1109/TAP.2018.2883686.

[27] Y. Ojaroudi, N. Ojaroudi, and N. Ghadimi, "Circularly polarized microstrip slot antenna with a pair of spur-shaped slits for WLAN applications," *Microw. Opt. Technol. Lett.,* vol. 57, pp. 756–759, 2015.

[28] 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.

[29] N. O. Parchin *et al.,* "8×8 MIMO antenna system with coupled-fed elements for 5G handsets," IET Conference of Antennas and Propagation, Birmingham, UK, 2019.

[30] 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), Belgrade, Serbia, 24–26 November 2015, pp. 587–590.