Wideband miniaturized 8-element Sub-6 GHz MIMO antenna system for mobile handset applications

Shu-Min Liao¹, Bo-Jun Zhang², Zhe Chen¹,³, Chong-Zhi Han¹, Fan Zhang³, and Tao Yuan¹

Abstract An 8-port MIMO antenna system covering the band of 3-6 GHz for the 5G MIMO mobile handset applications is proposed. The antenna element consists of an open-slot antenna and a T-shaped feeding strip. Also, an L-shaped strip is adopted to improve the impedance bandwidth and achieve miniaturization simultaneously. The measured results show that wide impedance bandwidth, high isolation (> 11 dB), high efficiency (> 40%) and lower ECC (<0.1) are realized. Finally, the hand-grip effects are investigated by simulation to verify its capability for the industrial applications.

Key words: 5G mobile handset applications, miniaturization, multiple-input multiple-output (MIMO), slot antenna, wideband

Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

As declared, the fifth-generation (5G) communication system will be established and utilized in the year of 2020 or later, and the data rate of 5G system is expected to be 100 times faster than that of 4G with lower latency. However, the faster data rate cannot be achieved by only single antenna. Hence, MIMO antenna system has been taken into consideration. The multi-antenna system can improve data throughput and resist multipath fading [1]. Therefore, several multiple-input multiple-output (MIMO) antenna systems for smartphone have been reported in [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. For instance, a 2 × 2 heptaband antenna system located at the bottom edge of the terminal is demonstrated for WWAN/LTE application [7]. Also, another 2 × 2 WWAN/LTE antenna system operating at the bands of 690 MHz-980 MHz and 1630 MHz-2740 MHz is designed for 5.7-inch mobile handset [8]. To better improve the data throughput, more antenna elements are necessary for the handset MIMO antenna system. Therefore, the 4-element antenna system proposed in [9] can be applied for the 4 × 4 MIMO system covering the 1880–2690 MHz band. Moreover, the 4 × 4 MIMO antenna system presented in [10] can cover the lower band (750-960 MHz) as well as the higher band (1700-2700 MHz). However, the abovementioned MIMO antenna systems cannot satisfy the 5G MIMO antenna applications which requires at least 6 to 8 antenna elements to ensure the data throughput and spectrum efficiency [11].

To better adapt to 5G mobile communications, several 5G MIMO antenna systems have been proposed. An 8-element antenna systems operating at single band are reported [12, 13, 14, 15, 16, 17, 18]. These antenna systems are limited by the narrow bandwidth, considering the multi-band requirement for the 5G mobile handsets application. Hence, other 5G MIMO antennas with multi-band feature have been introduced [19, 20, 21, 22, 23, 24, 25, 26, 27, 28]. Although some MIMO antenna systems [19, 20, 21, 22, 23, 24, 25, 26] have been designed for 5G mobile handset

1Guangdong Provincial Mobile Terminal Microwave and Millimeter-Wave Antenna Engineering Research Center, College of Electronics and Information Engineering, Shenzhen University, Shenzhen, Guangdong 518060, China
2Shenzhen Academy of Information and Communications Technology, Shenzhen, Guangdong 518060, China
3State Key Laboratory of Terahertz and Millimeter Waves, Department of Electronic Engineering, City University of Hong Kong, Hong Kong
4School of Physics, University of Electronic Science and Technology of China
a) zhangbojun@caiet.ac.cn

DOI: 10.1587/elex.16.20190631
Received October 13, 2019
Accepted October 28, 2019
Publicized November 20, 2019
applications, the bandwidth are not wide enough to cover the whole Sub-6 GHz band such as Bands 42/43/46 simultaneously. Recently, multi-band antenna systems covering Bands 42/43/46 have been investigated for 5G smartphones [27, 28] with broad impedance bandwidth and decent MIMO performance. Even though they are considered as promising candidates for the upcoming 5G mobile communications, it would be necessary to provide wider coverage.

In this paper, a wideband 8-element MIMO antenna system operating at Bands 42/43/46/79 is proposed. An L-shaped strip is adopted to introduce new resonance to widen the bandwidth. Therefore, the wideband property is achieved to cover more available frequency bands. As a result, the wideband characteristic can mitigate the frequency deviation effect caused by hand-grip and head-approach. Also, the existence of the L-shaped strip extends the current paths thus result in miniaturization, which is of great significance for the mobile handset applications. To validate the performance of the proposed antenna, the S-parameters, the radiation efficiency, and the envelope correlation coefficient (ECC) are investigated.

2. Antenna design and analysis

2.1 Antenna structure

Fig. 1 depicts the overall geometry of the proposed MIMO antenna system as well as the detailed structure of the antenna element. In this design, the 8 antenna elements, namely Ant. 1 to Ant. 8, are placed along the two long edges of a rectangular FR-4 substrate with a relative permittivity of 4.4 and loss tangent of 0.02. The size of the ground plane is $150 \times 75 \times 0.8 \text{ mm}^3$, which is well compatible with a 5.7-inch smartphone with ground plane printed on its backside.

The MIMO antenna system has symmetrically mirrored structure, where Line A and Line B are two mirror lines of the 8-element antenna system. 8 L-shaped strips are located at the center of the open slot widening the bandwidth and achieving miniaturization simultaneously. Additionally, 8 T-shaped feeding strips are placed on the front side of the substrate and utilized to excite the 8 antenna elements independently. The detailed analyses of the slot antenna element as well as the MIMO antenna system are studied in subsection 2.2.

2.2 Open-slot antenna element

The detailed configuration of the antenna element can also be seen in Fig. 1. A rectangular slot with a size of $10.2 \times 4 \text{ mm}^2$ is initially etched on the ground plane acting as the main radiator. Then, an opening (0.5 mm) is cut to form an open-slot antenna. To further enhance the impedance bandwidth, an additional L-shaped strip is adopted at the center of the open slot. Latter, a T-shaped feeding strip is employed to excite the antenna. Additionally, the T-shaped feeding strip consists of two parts: a horizontal strip and a...
vertical strip, which can adjust the impedance matching flexibly. The antenna performance analysis is operated through the commercial electromagnetic simulation software CST® Microwave Studio. By properly optimizing the size of the slot and the T-shaped feeding strip, a wideband open-slot antenna system covering 3 GHz to 6 GHz can be realized.

The simulated reflection coefficients are displayed in Fig. 2(a). Since the antenna elements are identical and symmetrically arranged, only Ants. 1 to 4 are utilized to show the MIMO antenna system performance. As can be seen in the Fig. 2(a), the simulated -6 dB impedance bandwidth is wide enough (3-6 GHz) to cover Bands 42/43/46/79. Additionally, the transmission coefficients are listed in Fig. 2(b), indicating the isolations between any two adjacent antenna elements are better than 11 dB through the operating bandwidth. Also, the isolations between all non-adjacent antennas are better than 14 dB, which is acceptable for 5G MIMO mobile handset applications.

Theoretically, the resonant frequencies of an antenna aim at the circumstances where resistance of the input impedance reaches maximum value that of reactance value comes to zero [22]. Therefore, the input impedances are investigated to ensure the resonant frequencies of the proposed and referenced antenna. Note that the reference antenna refers to the slot antenna without the L-shaped strip as depicted in Fig. 3. As can be seen in Fig. 3, three resonances (3 GHz, 4.5 GHz and 5.8 GHz, respectively) are observed among 3-6 GHz band for the proposed antenna, and only two resonances (3.2 GHz and 4.9 GHz) are observed for the referenced antenna. Hence, the L-shaped strip introduces extra resonance within 3-6 GHz band, thus helps to widen the bandwidth of the proposed antenna. Furthermore, to better understand the working mechanism of the proposed antenna, the surface current distributions are given in Fig. 4. Blue dotted lines are adopted to indicate the surface current distribution for brevity. The first resonance at 3 GHz can be regarded as the whole open slot mode, whose current distribution concentrates along the whole open slot. While the second and the third resonances are more like to be generated by the longer and the shorter strips of the open slot. Moreover, according to the current distribution at 3 GHz, the L-shaped strip extends the total length of the slot, thus, indicating its miniaturization effect on the whole antenna size.

In fact, different parts of the slot interact with each other even if the surface current mainly focus on a certain
2.3 The simulated results of the MIMO antenna system

The simulated isolations between any two antenna elements are better than 11 dB without any additional decoupling technique as shown in Fig. 2. The simulated radiation efficiencies are also plotted in Fig. 5. Since the antenna elements are identical and arranged symmetrically, only the efficiencies of the Ant. 1 and the Ant. 2 are listed for brevity. The efficiencies in the whole band are almost higher than 55%, and the peak value reaches 65% in operational bands. Fig. 6 shows the envelope correlation coefficients (ECCs) verifying the MIMO performance of the proposed antenna system. ECC is used to characterize the envelope correlation of the radiation pattern between two antenna elements, and it is calculated using the far-field data according to the following equations:

\[ \rho_{ij} = \int \frac{\frac{X}{1 + X} G_{\theta_i}(\Omega)G_{\phi_j}(\Omega)P_\theta(\Omega) + \frac{1}{1 + X} G_{\theta_j}(\Omega)G_{\phi_i}(\Omega)P_\phi(\Omega)}{\sqrt{G_{\theta_i}G_{\theta_j}}}} d\Omega \]

(1)

\[ G_x = \int \frac{\frac{X}{1 + X} G_{\theta}(\Omega)P_\theta(\Omega) + \frac{1}{1 + X} G_{\phi}(\Omega)P_\phi(\Omega)}{\sqrt{G_{\theta}G_{\phi}}}} d\Omega \]

(2)

where \( P_\theta(\Omega) \) and \( P_\phi(\Omega) \) represent the \( \theta \) and \( \phi \) polarization components of the incident field, respectively. And \( X \) stands for the cross-polarization discrimination between the two polarizations. As shown in Fig. 6, ECCs between any two antenna elements are lower than 0.1, thus the conclusion can be drawn that the interferences between different antenna elements are weak and the radiation performance of the proposed MIMO antenna is satisfactory.

3. Results and discussion

A prototype is fabricated and displayed in Fig. 7. The measured reflection coefficients and transmission coefficients are illustrated in Figs. 8 and 9, respectively. By comparing the simulated and measured results, it can be concluded that both the simulated and measured -6 dB reflection coefficients cover 3-6 GHz. The measured
isolations between antenna elements are better than 11 dB, which are consistent with the simulated results. The measured efficiencies of higher than 40% in the whole operational band are shown in Fig. 9, which are 10% lower than the simulation. This is mainly caused by the losses introduced by the SMA connector and cable in the measurement. As shown in Fig. 10, the measured ECC are a litter higher than simulated ones, but both the simulated and measured ECC are lower than 0.1, indicating the better MIMO performance is obtained compared with antenna systems reported in [32, 33, 34].

The simulated and measured three-dimensional radiation patterns are displayed in Fig. 11, the maximum radiation direction of the measurement and simulation is similar. The differences between measurement and simulation are caused by manufacturing error and test environment error, they are generally agree with each other, and they both meet the operation requirements in the desired frequency bands.

It is known that users hand effect on handset antennas is a critical criterion to evaluate the antenna performance in practical environment. Therefore, the performance of both single-hand (SH) and double-hand (DH) scenarios are studied in this subsection. The two typical scenarios of the hand-grip smartphone are shown in Figs. 12(a) and 12(b), respectively. The users hand effect on antenna performance are given in Fig. 13. It can be observed that the radiation properties of the Ants. 1, 3, 4 and 5 are deteriorated under SH mode, and that of Ant. 5 and Ant. 8 are deteriorated under DM mode. The reflection coefficients are nearly below -6 dB within the desired band. The isolations are also better than 11 dB. The efficiencies are almost beyond 40% in the whole frequency band. In general, the investigation of the hand-grip scenarios show that the proposed antenna can satisfy the practical application requirements. Furthermore, performance comparison with published works and the proposed design is listed in Table II. The comparison shows the proposed approach has advantage in realizing a wideband MIMO antenna system, which is essential for 5G handset applications.

4. Conclusion

In this work, an 8-element MIMO antenna system is investigated for Sub-6 GHz MIMO handset applications. Broadband characteristic shows its great superiority to other works. Moreover, the miniaturized design makes it possible to integrate the 8-element MIMO antenna system into a limited space with acceptable isolation higher than 11 dB.
The efficiency of each antenna element is higher than 40% across the desired bands. In addition, the antenna system exhibits good MIMO performances with measured ECC lower than 0.1. Finally, the hand-grip effect has been investigated to verify the proposed MIMO antenna system a promising candidates for the 5G mobile handset applications.

Acknowledgments

This work was supported by the Shenzhen Basic Research Project. No. JCYJ20170413151115990.

References

[1] L. Zheng and D. N. C. Tse: “Diversity and multiplexing: A fundamental tradeoff in multiple-antenna channels,” IEEE Trans. Inf. Theory 49 (2003) 1073 (DOI: 10.1109/TIT.2003.810646).

[2] K. Xu, et al.: “A compact planar ultra-wideband handset antenna with L-shaped extended ground stubs,” IEICE Electron. Express 14 (2017) 20170680 (DOI: 10.1587/exle.14.20170680).

[3] X. Liu, et al.: “Wideband MIMO antenna with enhanced isolation for wireless communication application,” IEICE Electron. Express 15 (2018) 20180948 (DOI: 10.1587/exle.15.20180948).

[4] Y. Yin, et al.: “A compact planar UWB MIMO antenna using modified ground stub structure,” IEICE Electron. Express 14 (2017) 20170883 (DOI: 10.1587/exle.14.20170883).

[5] X. He, et al.: “MIMO antenna with working-frequency-accompanied isolation characteristic,” IEICE Electron. Express 14 (2017) 20170602 (DOI: 10.1587/exle.14.20170602).

[6] S. Yang, et al.: “Substrate integrated waveguide filter based on novel coupling-enhanced semicircular slots for 5G applications,” IEICE Electron. Express 16 (2019) 20190125 (DOI: 10.1587/exle.16.20190125).

[7] Y. L. Ban, et al.: “Decoupled closely spaced heptaband antenna array for WWAN/LTE smartphone applications,” IEEE Antennas Wireless Propag. Lett. 13 (2014) 31 (DOI: 10.1109/LAWP.2013.2295623).

[8] Y. Wang and Z. Du: “Wideband monopole antenna with less nonground portion for octa-band WWAN/LTE mobile phones,” IEEE Trans. Antennas Propag. 64 (2016) 383 (DOI: 10.1109/TAP.2015.2503730).

[9] J. Guo, et al.: “A four-antenna array with high isolation for mobile phones,” IEEE Antennas Wireless Propag. Lett. 12 (2013) 979 (DOI: 10.1109/LAWP.2013.2273551).

[10] S. Zhang, et al.: “Adaptive quad-element multi-wideband antenna array for user-effective LTE MIMO mobile terminals,” IEEE Trans. Antennas Propag. 61 (2013) 4275 (DOI: 10.1109/TAP.2013.2260714).

[11] H. Elshaer, et al.: “Downlink and uplink cell association with traditional macrocells and millimeter wave small cells,” IEEE Trans. Wireless Commun. 15 (2016) 6244 (DOI: 10.1109/TWC.2016.2582152).

[12] J. Lu, et al.: “Compact eight-antenna array in the smartphone for the 3.5-GHz LTE 8 × 8 MIMO operation,” 2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (2016) 323 (DOI: 10.1109/APCAP.2016.7843224).

[13] K. L. Wong, et al.: “Two asymmetrically mirrored gap-coupled loop antennas as a compact building block for eight-antenna MIMO array in the future smartphone,” IEEE Trans. Antennas Propag. 65 (2017) 1765 (DOI: 10.1109/TAP.2017.2670534).

[14] A. A. Al. Hadi, et al.: “Eight-element antenna array for diversity and MIMO mobile terminal in LTE 3500 MHz band,” Microw. Opt. Technol. Lett. 56 (2014) 1323 (DOI: 10.1002/mp.28316).

[15] D. Wu, et al.: “A compact loop antenna with seven resonant modes for smartphones,” Proc. IEEE-APS Topical Conf. Antennas Propag. Wireless Commun. (2015) 355 (DOI: 10.1109/APWC.2015.7300159).

[16] D. Wu, et al.: “A compact and low-profile loop antenna with multiband operation for ultra-thin smartphones,” IEEE Trans. Antennas Propag. 63 (2015) 2745 (DOI: 10.1109/TAP.2015.2412962).

[17] K. L. Wong, et al.: “16-antenna array in the smartphone for the 3.5-GHz MIMO operation,” Proc. Asia-Pacific Microw. Conf. (2015) 1.

[18] Y.-L. Ban, et al.: “4G/5G multiple antennas for future multi-mode smartphone applications,” IEEE Access 4 (2016) 2981 (DOI: 10.1109/ACCESS.2016.2582786).

[19] K. Yan, et al.: “Eight-antenna array in the 5G smartphone for the dual-band MIMO array,” 2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting (2018) 41 (DOI: 10.1109/APUSNCURSINRSM.2018.8608394).

[20] W. Wang, et al.: “Compact 8-port MIMO antenna array for dual-band 5G mobile terminals,” 2018 International Conference on Microwave and Millimeter Wave Technology (2018) 1 (DOI: 10.1109/ICM WM.2018.8563454).

[21] J. Guo, et al.: “Side-edge frame printed eight-port dual-band antenna array for 5G smartphone applications,” IEEE Trans. Antennas Propag. 66 (2018) 7412 (DOI: 10.1109/TAP.2018.2872130).

[22] K. L. Wong and J. Y. Lu: “3.6-GHz 10-antenna array for MIMO operation in the smartphone,” Microw. Opt. Technol. Lett. 57 (2015) 1699 (DOI: 10.1002/mop.29181).

[23] Z. Qin, et al.: “Printed eight-element MIMO system for compact and thin 5G mobile handset,” Electron. Lett. 52 (2016) 416 (DOI: 10.1049/el.2015.3960).

[24] K. L. Wong, et al.: “8-antenna and 16-antenna arrays using the quad-antenna linear array as a building block for the 3.5-GHz LTE MIMO operation in the smartphone,” Microw. Opt. Technol. Lett. 58 (2016) 174 (DOI: 10.1002/mop.29527).

[25] M.-Y. Li, et al.: “Eight-port orthogonally dual-polarized antenna array for 5G smartphone applications,” IEEE Trans. Antennas Propag. 64 (2016) 3820 (DOI: 10.1109/TAP.2016.2583501).

[26] Y. L. Ban, et al.: “4G/5G multiple antennas for future multi-mode smartphone applications,” IEEE Access 4 (2016) 2981 (DOI: 10.1109/ACCESS.2016.2582786).

[27] Y. Li, et al.: “12-port 5G massive MIMO antenna array in sub-6GHz mobile handset for LTE bands 42/43/46 applications,” IEEE Access 6 (2018) 344 (DOI: 10.1109/ACCESS.2017.2763161).

[28] Y. Li, et al.: “Multiband 10-antenna array for sub-6 GHz MIMO applications in 5-4G smartphones,” IEEE Access 6 (2018) 28041 (DOI: 10.1109/ACCESS.2018.2838337).

[29] W. L. Schroeder, et al.: “Utilisation and tuning of the chassis modes of a handheld terminal for the design of multiband radiation characteristics,” Proc. IEEE Conf. Wideband Multi-Band Antennas Arrays (2005) 117 (DOI: 10.1049/ic: 20050298).

[30] C.-H. Chang and K.-L. Wong: “Bandwidth enhancement of internal WWAN antenna using an inductively coupled plate in the small size mobile phone,” Microw. Opt. Technol. Lett. 52 (2010) 1247 (DOI: 10.1002/mop.25196).

[31] R. D. Straw: ARRL Antenna Book (American Radio Relay League, Newington, 2007) 21st ed. 68.

[32] M. S. Shariawi: “Printed multi-band MIMO antenna systems and their performance metrics [wireless corner],” IEEE Antennas Propag. Mag. 55 (2013) 218 (DOI: 10.1109/MAP.2013.6735522).

[33] Y.-L. Ban, et al.: “Decoupled closely spaced heptaband antenna array for WWAN/LTE smartphone applications,” IEEE Antennas Wireless Propag. Lett. 13 (2014) 31 (DOI: 10.1109/LAWP.2013.2295623).

[34] K. L. Wong, et al.: “Four LTE low-band smartphone antennas and their MIMO performance with user’s hand presence,” Microw. Opt. Technol. Lett. 58 (2016) 2046 (DOI: 10.1002/mop.29969).