A Novel Mobile Phone Antenna for Effectively Reducing Specific Absorption Rate

Yejun He[1], Kun Liang[1], Jun Li[1], Qammer H. Abbasi[2]
[1]Guangdong Engineering Research Center of Base Station Antennas and Propagation,
Shenzhen Key Laboratory of Antennas and Propagation,
College of Information Engineering, Shenzhen University, 518060, China
heyejun@126.com, lkboy@163.com, lijun9415@126.com
[2]School of Electronics, University of Glasgow, Glasgow G12 8QQ, UK
Qammer.Abbasi@glasgow.ac.uk

***Abstract*—In this paper, a novel mobile phone antenna that can effectively reduce the harm of electromagnetic radiation to the human body is proposed. An inverted F-shaped antenna (IFA) is designed to reduce specific absorption rate (SAR) and all the measurements are done in over the air (OTA) test system. Measured results show that the proposed mobile phone antenna has excellent electrical characteristics such as reflection coefficient (700-870 MHz and 1710-2450 MHz), radiation pattern, total radiation power (TRP >17.5 dBm), hot spot map and low SAR values (< 1.4 W/kg). Due to these advantages, the proposed antenna is used to reduce SAR in the future mobile phone.**

Index Terms—*electromagnetic radiation, SAR, mobile phone antenna.*

I. Introduction

With the significant development of the mobile communication system, mobile phones have become indispensable tools for human daily life. Meanwhile, the number of the mobile phone has increased with an unprecedented rate around the globe including China. Since the three operators fully started 4G business in 2014, more and more users began to pay attention to and select 4G mobile phones with the reduction of 4G fees in 2015. When we make phone calls, the antenna is close to the human's face, and its microwave radiation directly affects the human's head. It will have a negative effect on the human body when the microwave signal power absorbed by the body exceeds the limiting value [1], [2]. Since its damage to human health is long and chronic, many domestic and foreign companies and institutions at present are studying how to keep mobile phones at a suitable level for human radiation [3].

It is obvious that increasing the distance between the antenna and the head can directly reduce the radiation of the electromagnetic wave to the human head. However, the terminal manufacturers are now in pursuit of appearance design, and the mobile phone has developed to ultrathin trend, resulting in the inability to increase the distance to reduce specific absorption rate (SAR). There are a lot of patents mentioning the need to increase the distance between the antenna and the user. Some of these patents can adjust the position of the antenna or use the special printed circuit board (PCB) ground plane to reduce the radiation of the SAR [4]. In addition, if some ferrite material is attached to the area where the antenna SAR values is high, it can also effectively reduce the SAR radiation [5], [6], meantime the antenna efficiency is not obviously affected. There are some materials that can control the electromagnetic field in the way that we want [7], [8], the SAR radiation can also be controlled.

In this paper, a novel mobile phone antenna for effectively reducing SAR is developed in terms of antenna design. The paper is organized as follows. Section II introduces the method of antenna design. Results and analysis are presented in Section III. Conclusion is drawn in Section IV.

II. The method of proposed antenna

Nowadays, most of the current phone's internal antennas are basically planar inverted F-shaped Antenna (PIFA) [9] or monopole antenna. PIFA is the most commonly used for internal antenna of mobile phone, which is developed from inverted F-shaped antenna and has many advantages, such as small volume, high gain and low profile and so on. Monopole antenna has great radiation efficiency, but SAR value is a problem [10]. For PIFA antenna, the antenna placed on the back of the phone has the least radiation exposure to the body, but it mainly depends on height to radiation, with relatively narrow bandwidth, which is not suitable for the trend of ultra-thin mobile phone at present. Therefore PIFA antenna and monopole antenna generally cannot meet the design requirements.

Now, given the efficiency of the antenna and the problem of SAR, we use another form of antenna called inverted F-shaped antenna. It can be regarded as the derivation of monopole antennas. It is adjusted according to the specific conditions when the height and area of internal antenna are difficult to meet the PIFA antenna requirements, and the clearance of the antenna is not well. Compared with the PIFA antennas, the inverted F-shaped antenna (IFA) antennas are generally on the bevel and side of the support, that is far away from the ground plane of machine. Compared with the monopole antennas, the IFA antennas adopt dual feed form, that is a feed to signal, another feed point to the ground point of the PCB. Antennas are designed in a similar way as PIFA antenna but SAR can be well controlled. The proposed reduction SAR method is based on IFA.

The signal is coupled to the radiation band by feed point, and the electrical length of the radiation is determined by the frequency of the radiation. The length of the initial radiation can be determined by [1]:

$$L = \frac{c}{f_r * W * \sqrt{\varepsilon_r}} \tag{1}$$

where f_r is the resonant frequency, c is the speed of light, L and W are the length and width of radiation band, and ε_r is the permittivity.

With the increasing use of smart phones, the radiation of electromagnetic waves has attracted more and more attention. Specific Absorption Rate (SAR) is used to indicate the intensity of electromagnetic waves radiation absorbed by the human body. The size of the body's tissue fluid absorption electromagnetic waves can be expressed as [11]:

$$SAR = \frac{\sigma}{2 * \rho} * |E|^2 \tag{2}$$

where E is the intensity of electric field within the tissue, σ is the dielectric conductivity, ρ is the tissue density.

The higher the SAR, the more radiation the body absorbs, which results in the greater damage to the human body. In Europe, the European commission has set a limit of 2.0 W/kg for SAR in the 10g tissue according to the recommendation of the international commission on non-ionizing radiation protection (ICNIRP) guidelines [12]. In America, the federal communications commission (FCC) has set the maximum SAR to 1.6 W/kg in the 1g tissue. Therefore, only when SAR value produced by the smartphone must meet the two limits, smartphone can be used in the market.

The different forms of antennas have different effects on the SAR. For example, compared with the monopole antenna, there is a large area between PIFA antenna and PCB, and it constitutes a loop with the PCB, so the current can be distributed evenly and the SAR value is generally lower. In this paper, the proposed reduction method is to add a new amplitude wave, by adjusting the antenna in some frequencies with higher SAR values, offsets part with the original amplitude wave to distribute peak values of the current, so as to achieve the goal of reduction SAR values.

For a fair comparison we select the same smart phone twice. Firstly, we adjust the state of the sample antenna on its basis, then measure the return loss, radiation power, and the SAR of the adjusted antenna, and record the relevant data. Then a new antenna is designed by adjusting the routing of the antenna and tuning impedance matching of the antenna. The new antenna will produce a new amplitude wave at the frequency of LTE band 30 (2.3 GHz). The change path of the proposed antenna and the route structure of the original antenna are shown in Fig. 1 and Fig. 2. As can be seen from Fig. 3, the proposed antenna can give two wide bandwidths, in which the low band and high band are 700-870 MHz and 1710-2450 MHz. Compared with the reference antenna (original antenna), it is clearly observed that the method can expand a new band (LTE band 30) by changing route of original antenna to increase a new amplitude wave.

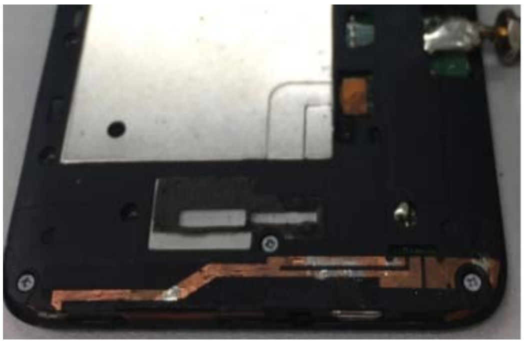


Fig. 1. Reference PIFA mobile phone antenna.

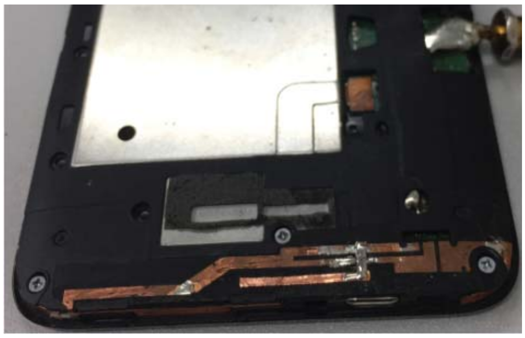


Fig. 2. The novel reduced SAR antenna.

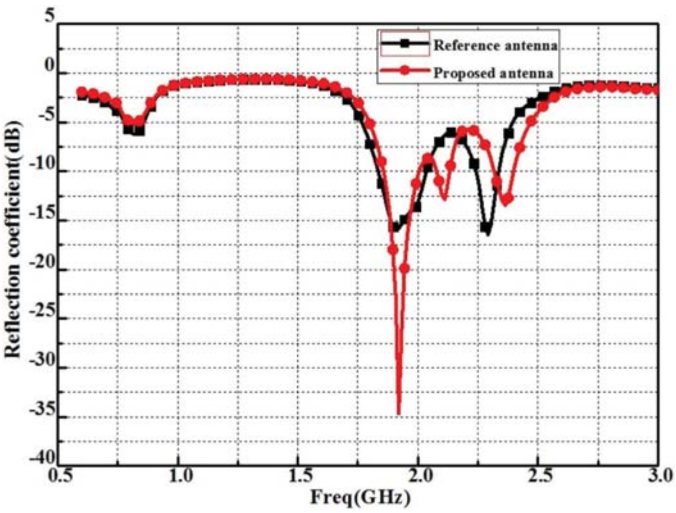


Fig. 3. The comparison results of S_{11} from reference antenna and the new antenna.

III. RESULTS AND ANALYSIS

After the new antenna is adjusted, reflection coefficient, radiation power, and the SAR are measured, and the relevant data are recorded. Because the test time of the SAR is relatively long, select the suitable channel to test the SAR.

TABLE II
TOTAL RADIATED POWER OF TWO ANTENNAS

LTE BAND	Channel	Frequency (MHz)	Reference Antenna TRP (dBm)	Proposed Antenna TRP (dBm)
LTE BAND 2	18650	1855	18.3	18.2
	18900	1880	17.2	17.7
	19150	1905	17.7	17.5
LTE BAND 4	20000	1715	18.7	18.6
	20175	1732	18.9	19.4
	20350	1750	19.2	19
LTE BAND 5	20450	829	18.8	18.62
	20525	836	18.4	18.2
	20600	844	18.9	18.4
LTE BAND 12	23060	704	17.5	17.5
	23095	707	17.7	18
	23130	711	17.8	17.6
LTE BAND 30	27660	2305	18.6	18.1
	27710	2310	18.4	18.5
	27760	2315	18.2	18.1

And other channel tests are ignored, as long as the SAR of the channel can be lower than the limit value, other channels can also meet the requirements. Measured results of radiation power and the SAR of the two antennas are shown below in Table I and Table II.

According to the measured data from OTA and SAR test systems, the total radiated power (TRP) of antennas has not changed much (17.2-19.4 dBm), but the SAR(0.4-1.38 W/kg) of novel antenna is lower than that (0.44-1.65 W/kg) of the initial state, which basically achieves the goal to reduce the SAR. Although the SAR data of the novel antenna is higher than the original antenna on some channels, the difference value is not more than 0.2, and the data is below the threshold of 1.6 W/kg.

Additionally, two antennas also can be seen the difference by hot spot position of SAR. On a hot map, the brighter the color is, the higher the ratio of absorption is. As shown in Fig. 4, the white point is the highest SAR value, then the yellow region is slightly higher, and the red area is the lowest. The hot spot of original antenna at LTE band 30 is a complete area (left), but the hot spot of improved antenna at LTE band 30 is divided into two yellow regions (right), which will disperse the biggest current peak of the antenna in a certain extent, in order to achieve the intention of reduction SAR.

We compare the 3D radiation patterns of two antennas at 700 MHz, 1810 MHz and 2300 MHz, as shown in Fig. 5 and Fig. 6, measured results show that the 3D radiation patterns of two antennas are basically the same.

From the aspect of passive characteristics, we compare the gain pattern at 0.7, 1.81, 2.3 GHz. As shown in Fig. 7 and Fig. 8, the gain patterns are not changed much at 0.7, 1.81GHz, respectively in horizontal plane (H-plane) and vertical plane(E1 and E2). In addition, the H-plane is basically identical at 2.3 GHz, while there is a big gap between two antennas in E1 and E2. The proposed antenna changes the antenna gain in the E1 and E2 at 2.3 GHz.

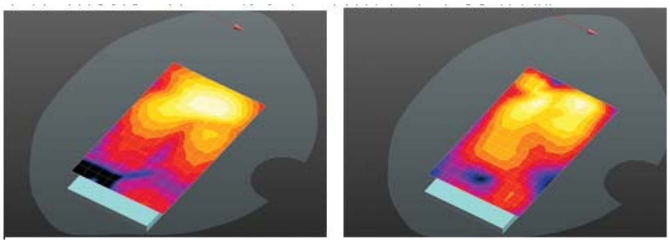
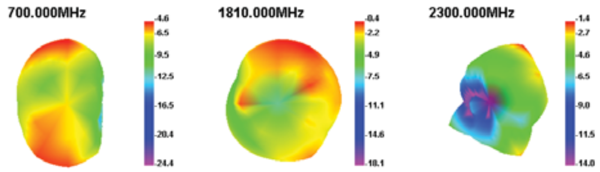
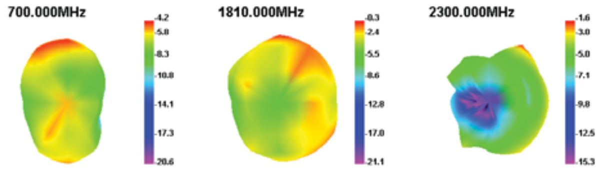


Fig. 4. Hot spot of SAR from two antennas.



(a) (b) (c)

Fig. 5. Measured 3D radiation pattern of the original antenna.



(a) (b) (c)

Fig. 6. Measured 3D radiation pattern of the novel reduced SAR antenna.

IV. CONCLUSION

A novel mobile phone antenna with lower SAR values is presented in this paper. By changing the routing of antenna on a mobile phone, it can increase the new amplitude wave to disperse the current peak, so that a new band (LTE band 30) can be obtained. Measured results show that the proposed antenna is simple and effective with wide bandwidths (700-870 MHz and 1710-2450 MHz), stable TRP (17.5-19.4 dBm) and lower SAR values (0.4-1.38 W/kg). In addition, the proposed antenna has lots of advantages, including low cost, compact structure, good stability, as well as easiness for fabrication. The proposed antenna can be a new solution in reducing mobile phone SAR values for modern mobile communication systems.

ACKNOWLEDGEMENT

This work was supported in part by the National Natural Science Foundation of China under Grant 61372077, in part by the Shenzhen Science and Technology Programs under Grant ZDSYS 201507031550105, JCYJ20170302150411789, JCYJ20170302142515949 and GCZX2017040715180580, as well as in part by the Guangdong Provincial Science and Technology Program under Grant 2016B090918080.

TABLE I
THE SAR DATA OF TWO ANTENNAS

LTE BAND	Channel	Frequency (MHz)	Reference Antenna				Proposed Antenna			
			Body SAR 10mm (Back)1kg	Body SAR 10mm (Bottom) 1kg	Right Head 1kg (<1.6)	Left Head 1kg (<1.6)	Body SAR 10mm (Back) 1kg	Body SAR 10mm (Bottom) 1kg	Right Head 1kg (<1.6)	Left Head 1kg (<1.6)
LTE BAND 2	18650	1855	NA	NA	NA	NA	NA	NA	NA	NA
	18900	1880	1.08	1.23	0.53	0.62	1.17	1.08	0.4	0.55
	19150	1905	NA	NA	NA	NA	NA	NA	NA	NA
LTE BAND 4	20000	1715	NA	NA	NA	NA	NA	NA	NA	NA
	20175	1732	NA	NA	NA	NA	NA	NA	NA	NA
	20350	1750	1.10	1.16	0.65	0.54	1.07	1.25	0.5	0.49
LTE BAND 5	20450	829	NA	NA	NA	NA	NA	NA	NA	NA
	20525	836	0.58	0.68	0.57	0.7	0.62	0.59	0.65	0.58
	20600	844	NA	NA	NA	NA	NA	NA	NA	NA
LTE BAND 12	23060	704	NA	NA	NA	NA	NA	NA	NA	NA
	23095	707	0.63	0.71	0.64	0.62	0.60	0.68	0.55	0.56
	23130	711	NA	NA	NA	NA	NA	NA	NA	NA
LTE BAND 30	27660	2305	NA	NA	NA	NA	NA	NA	NA	NA
	27710	2310	1.62	1.65	0.45	0.44	1.34	1.38	0.55	0.57
	27760	2315	NA	NA	NA	NA	NA	NA	NA	NA

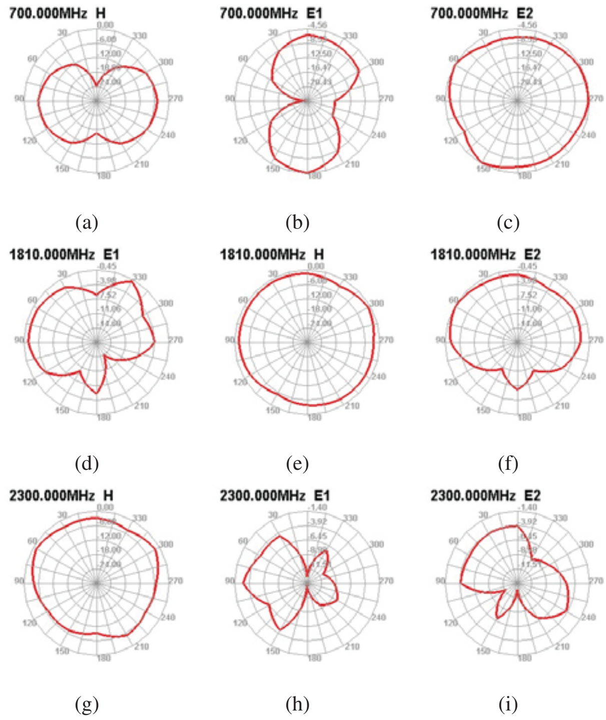


Fig. 7. Measured gain pattern of reference antenna.

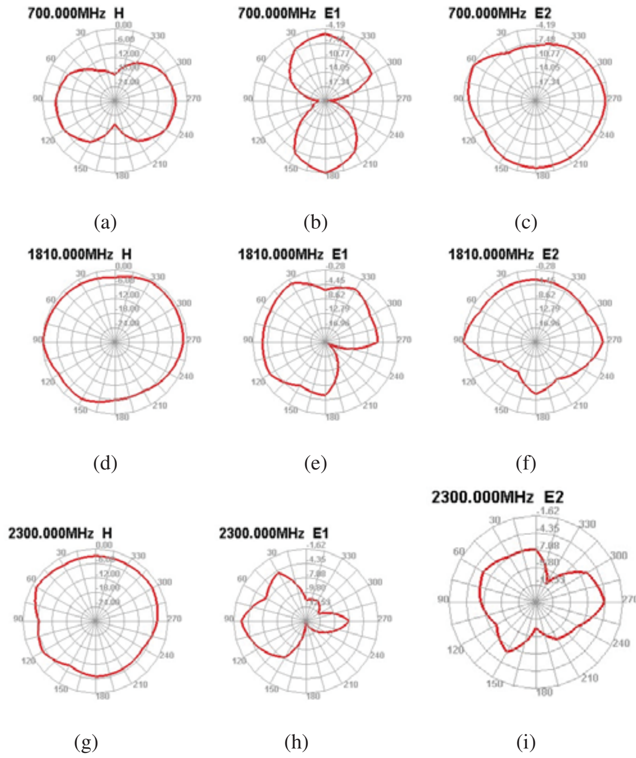


Fig. 8. Measured gain pattern of novel reduced SAR antenna.

REFERENCES

[1] Ryo Ikeuchi, Akimasa Hirata, "Dipole Antenna Above EBG Substrate for Local SAR Reduction," *IEEE Antennas & Wireless Propagation Letters*, vol. 10, pp. 904-906, Dec. 2011.

[2] L. L. Morgan, E. Barris, J. Newton*et al.*, "Cell Phones and Brain Tumors, 15 Reasons for Concern," *Available: http://www.radiationresearch.org/pdfs/15reasons.asp*, pp. 1-44, Aug. 25, 2009.

[3] European Commission, "Report from the Commission on the application of Council Recommendation of 12 July 1999 (1999/519/EC) on the limitation of the exposure of the general public to electromagnetic fields (0 hz to 300 ghz). Second Implementation Report 2002-2007," *Available: http://eurlex.europa.eu/en/dossier/dossier36.html*, pp. 1âĂŞ13, Sep. 2008.

[4] K. Takagi, Y. Furukawa, *et al.*, "Portable telephone with reduced specific absorption rate and improved efficiency," *IEEE International Symposium on Wearable Computers*, U.S. Patent 7274953 B2, Sept. 25, 2007.

[5] J. Wang, O. Fujiwara and T. Takagi, "Effects of ferrite sheet attachment to

portable telephone in reducing electromagnetic absorption in human head," *IEEE International Symposium on Electromagnetic Compatibility*, vol. 2, pp. 822-825, Aug. 1999.

[6] M. Jung, and B. Lee, "SAR reduction for mobile phones based on analysis of EM absorbing material characteristics," *Proc. Antennas and Propagation Society International Symposium*, vol. 2, pp. 1017-1020, Jun. 2003.

[7] J. B. Pendry, D. Schuring, and D. R. Smith, "Controlling Electromagnetic Fields," *Science*, vol. 312, pp. 1780-1782, Jun. 2006.

[8] D. Schurig, J. J. Mock, B. J. Justice, S. A. Cummer, J. B. Pendry, A. F. Starr, D. R. Smith, "Metamaterial Electromagnetic Cloack atMicrowave Frequencies," *Science*, vol. 314, pp. 977-980, Nov. 2006.

[9] Y. X. Guo, I. Ang, and M. Y. W. Chia, "Compact internal multiband antennas for mobile handsets," *IEEE Antennas Wireless Propag. Lett*, vol. 2, pp. 143-146, Apr. 2003.

[10] P. L. Teng, H. T. Chen, and K. L. Wong, "Multi-frequency planar monopole antenna for GSM/DCS/PCS/WLAN operation," *Microw. Opt. Technol. Lett*, vol. 36, no. 5, pp. 350-352, 2003.

[11] K. S. Sultan, H. H. Abdullah, E. A. Abdallah and E. A. Hashish, "Low SAR, compact and multiband antenna for mobile and wireless communication," *2012 Middle East Conference on Antennas and Propagation (MECAP)*, vol. 1, no. 5, pp. 29-31, Dec. 2012.

[12] International Non-Ionizing Radiation Committee of the International Radiation Protection Association, "Guidelines on limits on exposure to radio frequency electromagnetic fields in the frequency range from 100 kHz to 300 GHz," *Health Physics*, vol. 54, pp. 115-123, 2012.