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Study of the Interaction User Head-Ultrawideband MIMO Antenna Array for Mobile Terminals

S. S. Zhekov, A. Tatomirescu, O. Franek, and G. F. Pedersen

Abstract—This paper presents a numerical study of the interaction between the user head and MIMO antenna array for mobile phones. The antenna array is composed of two identical antennas and covers the frequency ranges 698-990 MHz and 1710-5530 MHz with a good radiation efficiency in free space. The two aspects of the interaction are considered: 1) the influence of the user head on the antenna operation, and 2) the exposure of the human head tissue to antenna electromagnetic radiation. The first aspect is related to the degradation of the antenna performance in a proximity to the user which is evaluated by the reduction of the antenna radiation efficiency. The second aspect refers to the antenna operation effect on the human and the exposure of the user head is studied by Specific Absorption Ratio (SAR).

I. INTRODUCTION

In recent years, the mobile communications have undergone a significant development. The designing of multiple-input multiple-output (MIMO) antennas for mobile terminals faces two challenging problems. The first problem is that the space for integrating multiple antennas inside a mobile terminal is quite limited. Therefore, the antennas should be compact but this in turn hampers the fulfilment of the requirements for the handset MIMO antennas (large bandwidth, good efficiency and low correlation). However, the achievement of such a performance allows the antennas to be used not only for communications but also for channel sensing in cognitive radio networks.

The second problem is the electromagnetic interaction between the mobile phone antennas and human body. The inherent operation of the mobile devices in a close proximity to the user, usually located in the antenna near-field zone, affects the antenna parameters and cause electromagnetic energy absorption in the human body [1]. The human tissue is a dielectric material with losses and its interaction with the antennas has to be viewed from two perspectives: 1) the influence of the user on the antenna performance and 2) the exposure of the human tissue to antenna electromagnetic radiation. The presence of the user in the antenna near-field region causes changes in the input impedance of the antenna and therefore in its bandwidth. These changes are a consequence of the dielectric loading introduced by the tissue. Also, the absorption in the human body decrease the radiation efficiency of the antenna. The user effect on a single element antenna has been investigated in [2]-[5]. Studies about the user influence on a mobile phone antenna arrays have been presented in [6]-[8].

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The electromagnetic energy absorption of the biological tissue has drawn a great amount of attention due to the potential health risk. The dosimetric quantity used to evaluate the exposure of the biological tissue to electromagnetic fields is specific absorption rate (SAR). The latter is defined as the rate of energy absorption in unit mass biological tissue when the body is exposed to an electromagnetic radiation. Currently, there are two widely adopted standards for the maximum allowed SAR: 1) 1.6 W/kg averaged over a 1 g volume of tissue (in United States), and 2) 2 W/kg averaged over a 10 g volume of tissue (in Europe). Studies on the SAR for a single antenna have been shown in [2], [9], [10]. Multi-element antenna investigations on the SAR have been presented in [6], [11], [12].

In this paper, a numerical study of the interaction between the user head and an ultrawideband (UWB) MIMO antenna array is presented for mobile terminals. The antenna system consists of two identical radiators and covers the frequency bands 698-990 MHz and 1710-5530 MHz in free space. The user head effect on the antennas performance is evaluated in terms of radiation efficiency and the body loss is calculated. The exposure of the user head to the antenna electromagnetic radiation is determined by SAR. All investigations were carried out with CST Microwave Studio [13].

II. ANTENNA DESIGN

The geometry of the antenna array is shown in Figure 1. The array comprises two identical antennas placed diagonally and each has a total volume of only $29.5 \times 17 \times 5 \text{ mm}^3$. The PCB is made of a 0.8 mm thick FR4 substrate with planar dimensions of 120 mm x 60 mm. The ground plane is printed on the back side of the PCB and the part of it under each antenna (with dimensions of 33 mm x 17 mm) is removed. To model the mobile phone housing, a 1 mm thick plastic cover with a total volume of $124 \times 64 \times 10 \text{ mm}^3$ is used. Each antenna element consists of two coupled parts: a driven strip monopole and a parasitic shorted strip [14].

III. RESULTS AND DISCUSSION

A. Free space performance of the antenna array

The simulated S-parameters of the antennas in free space are shown in Figure 2. For handsets, S_{ii} around or below -6 dB is considered acceptable and as one can see, based on this specification, the antennas cover the frequency bands 698-990 MHz and 1710-5530 MHz. Also, for mobile terminals S_{ij} has to be around and below -10 dB. The employed antenna array meets this requirement over the covered frequency bands. The radiation efficiency of the antennas in free space is shown in

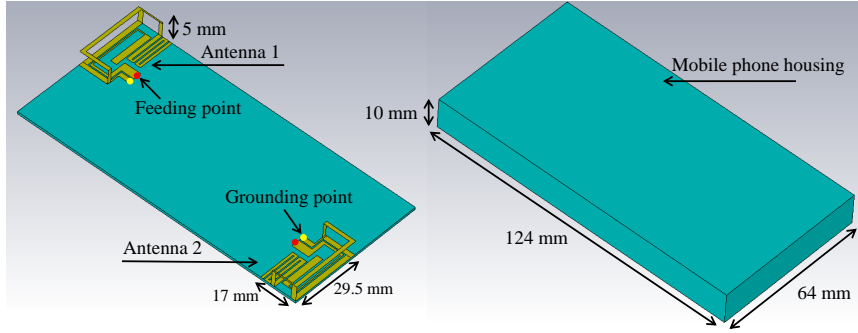


Fig. 1: Geometry of the antenna array.

Figure 3. It can be seen, that a good efficiency is achieved over the covered frequency ranges. These features make the antenna array appropriate for channel sensing in cognitive radio networks and for communications in cellular networks [14].

B. User head effect on the antenna array performance

The degradation of the antenna performance due to the user head proximity is evaluated by the reduction of the radiation efficiency and the exposure of the user head by SAR. In both investigations, the antenna system is placed in “cheek” position to the specific anthropomorphic mannequin (SAM) head phantom in accordance with the CTIA standard revision 3.5.2 [15]. The antenna elements locations and the user head model are shown in Figure 4.

The radiation efficiency of each antenna element is shown in Figure 5. In the presence of the user head close to the antennas their radiation efficiencies additionally decrease due to the absorption of a portion of the power in the lossy human tissue. As one can see antenna 2 has a higher radiation efficiency than antenna 1 over both frequency bands. This is due to the fact that the distance between antenna 2 and user head is larger than the distance between antenna 1 and user head. Over the lower frequency band the difference between the radiation efficiency of antenna 1 and that of antenna 2 varies from 1.9 to 2.7 dB. Over the higher frequency band the difference ranges from 0.5 to 3.2 dB.

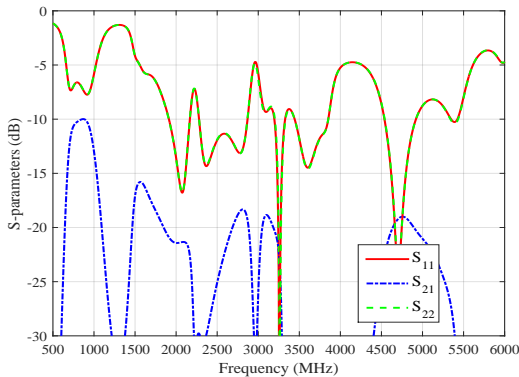


Fig. 2: Simulated S-parameters of the antennas in free space.

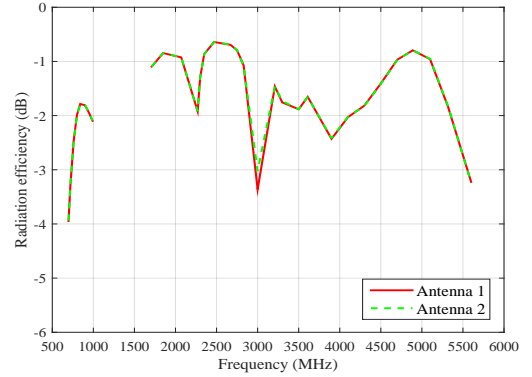


Fig. 3: Simulated radiation efficiency of the antennas in free space.

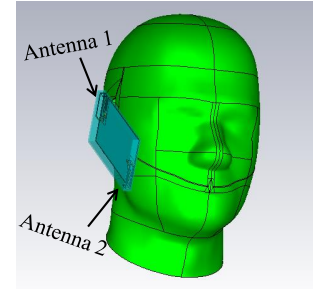


Fig. 4: Head phantom and antenna elements locations (the housing is made semitransparent).

To evaluate the degradation of the radiation efficiencies of each antenna in the presence of the user head is used the parameter body loss (BL) defined as [2]:

$$BL_i(\text{dB}) = \eta_{\text{free space},i}(\text{dB}) - \eta_{\text{user},i}(\text{dB}) \quad (1)$$

where $\eta_{\text{free space},i}$ is the radiation efficiency in free space and $\eta_{\text{user},i}$ is the radiation efficiency in the user case of antenna i ($i=1,2$), respectively. The parameter BL measures the decreasing of the antenna radiation efficiency in the presence of a user [2]. Figure 6 shows the BL of each antenna. The BL of antenna 1 varies within 1.4 dB over the lower band, while that of antenna 2 within 1.5 dB. Over the higher band the BL of antenna 1 changes within 5.5 dB and the BL of antenna 2 within 2.7 dB. The results in Figure 6 show that antenna 1 is

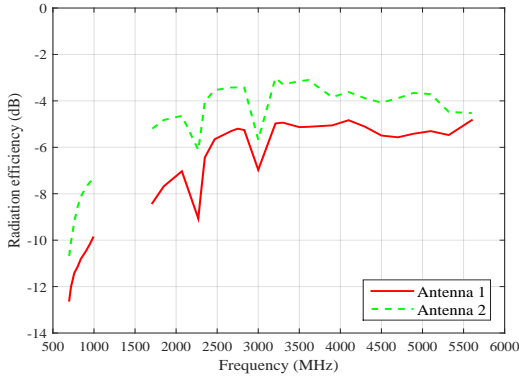


Fig. 5: Simulated radiation efficiency of the antennas in the user case.

more affected by the user head and due to the power absorption by the user head its radiation efficiency can decrease with up to 9.1 dB compared to free space. For antenna 2 the maximum reduction of the radiation efficiency is 6.8 dB.

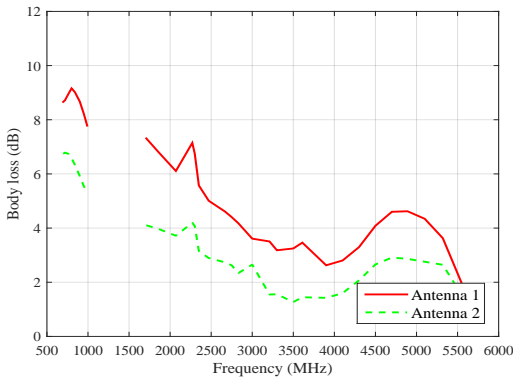


Fig. 6: Body loss of the antennas.

C. Antenna array effect on the user head

The absorption of electromagnetic energy by the human tissue has to be viewed not only from antenna performance point of view, but also the exposure of the biological tissue needs to be evaluated due to the potential health risk. The adopted quantity for such an evaluation is SAR. The employed antenna structure is of off-ground type and the latter generally shows higher SAR values compared to the on-ground type radiators. In the study, an input power of 23 dBm (0.2 W) is set for each antenna, which is the maximum allowable emission power for LTE mobile phones regardless of the operating frequency. In contrast to the accepted power, by setting the input power the effect of the S-parameters is taken into account on the transmitted power in addition to the radiation efficiency. The calculated SAR values of the two antennas by following the European standard (averaging over a 10 g volume of tissue) are presented in Table I. As can be seen from the results antenna 1 irradiates the user head more than antenna 2. The main factor which controls the SAR value is the distance between the antenna and user head. Antenna 1 is very close to

the ear while antenna 2 is further away from the phantom (see Figure 4). Therefore, the larger distance between antenna 2 and the head is the reason for its lower SAR values compared to these of antenna 1. Based on the presented results, at a few frequencies in the higher band the SAR of antenna 1 slightly exceed the maximum allowed SAR in Europe (SAR < 2 W/kg). The main reason for the high values is the small distance between this antenna and the user head. Also, in the study is used the maximum emission power and therefore the most critical scenario is realized, i.e. the highest SAR values are obtained. However, the SAR of antenna 2 is quite below the European standard.

Frequency (MHz)	Antenna 1 (W/kg)	Antenna 2 (W/kg)
700	0.8	0.4
960	0.7	0.6
1750	2	1.1
2900	2.3	0.8
3800	2.5	0.7
4700	2	1.2
5500	1.4	0.5

TABLE I: SAR values of antenna 1 and antenna 2.

IV. CONCLUSION

The interaction between the user head and a dual-element antenna array for mobile phones, operating in the frequency bands 698-990 MHz and 1710-5530 MHz, has been investigated numerically from two points of view. The first is the effect of the user head on the antenna performance in terms of radiation efficiency. By using the radiation efficiency in free space and that in the user case, the body loss of each antenna has been calculated. The second aspect which has been studied is the exposure of the human head to antenna electromagnetic radiation. The SAR values of each antenna has been obtained by following the European safety standard.

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