Varheenmaa, Harri; Lehtovuori, Anu; Viikari, Ville

SAR measurements for back cover mobile antennas

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Abstract—We compare different low-profile antenna prototypes designed on the back cover of mobile devices around 2 GHz. Especially, we focus on controlling the specific absorption rate (SAR) without sacrificing the antenna efficiency. In addition, we study techniques to reduce the size of the antenna. We compare a traditional patch antenna, a sophisticated SAR-optimized design, and a patch minimized with a matching circuit. All these three options are manufactured. The measurement results show that SAR values can be decreased remarkably without compromising the antenna performance if exposure effects are taken into account in the design.

Index Terms—antenna, measurements, mobile antenna, specific absorption rate.

I. INTRODUCTION

The number of antennas nearby the human body will increase, which emphasizes the importance of considering electromagnetic exposure in the antenna design. Recently, design methods resulting into a low specific absorption rate (SAR) have gathered a lot of interest [1]–[4] both in wearable and portable devices.

In future handheld devices, antennas could, for example, be placed on the back cover of the device [5], [6]. Thus, the antenna radiates towards the user when the phone is in the hand or inside the pocket. In this case, the SAR safety limits might become an issue. This can lead to a need for decreasing the transmit power, which reduces the coverage and limits the usability of the device.

The current design tools are well suited for maximizing antenna efficiency, but considering exposure effects is not as straightforward. Some SAR reduction methods have been presented in previous literature. The antenna can be insulated with wave-absorbing material or shielded [7]–[11], but this decrease the efficiency, bandwidth, and gain of the antenna [10]. In addition to that, those structures are rather voluminous and therefore they are not suitable for mobile devices. General methods to consider also electromagnetic exposure during the design process are missing. Therefore, we have studied different figure-of-merits in order to include exposure consideration to an optimization process of the antenna [12]. This approach is also tested for a practical implementation with measurements [13].

Decreasing the size of a single antenna would be beneficial because the space in mobile devices is limited since phones have to cover a large range of different frequency bands from a low band up to mm-waves. Also, other phone components e.g. large screens and cameras limit the space even more. In addition to that, it would be favorable to implement a high-order multiple-input multiple-output (MIMO) system. In [13], we presented a sophisticated back cover antenna design that has both a smaller footprint and lower SAR than a rectangle patch antenna.

A simple structure of a radiating element would be beneficial, but it should not be obtained at the expense of a larger size. In addition, strong resonances of patch antennas cause high SAR peak value [13]. Therefore, in this paper, we study the use of non-resonant antennas, which are typical in modern mobile devices in the low band. The small radiating structure is tuned to resonance with a matching circuit. The effect and potential of the matching circuit to decrease the SAR value is analyzed. The prototype is manufactured and measurement results are analyzed and compared with the prototypes from [13].

II. LOW-SAR ANTENNAS

A. Design goal

One of the main goals in antenna design is to maximize efficiency, but at the same time, we should keep SAR as small as possible so that the SAR would be below safety limits at high power levels. European SAR limit for a 10 g tissue is 2 W/kg [14] and the USA SAR limit for a 1 g tissue is 1.6 W/kg [15]. Therefore, we have defined a figure-of-merit that describes the ratio of the total efficiency, \( \eta_{\text{tot}} \), and the maximum SAR [12].

\[
\text{FoM} = \xi \frac{\eta_{\text{tot}}}{\eta_{\text{max}(\text{SAR})}}, \quad \eta_{\text{tot}} = \frac{P_{\text{rad}}}{P_{\text{in}}},
\]

where \( P_{\text{rad}} \) and \( P_{\text{in}} \) are the radiated and input power of an antenna, and \( \xi = P_{\text{rad}} / n \) is a normalization factor. Mass \( m \) is 1 g or 10 g depending on the used SAR standard [14], [15]. To determine SAR, the dielectric body is divided into small cubes \( D_i \) with mass \( m \) and volume \( V_i \). SAR for a cube \( i \) is defined as the power absorbed by the unit mass of tissue [16], [17]:

\[
\text{SAR}_i = \frac{1}{2V_i} \int_{D_i} \frac{\sigma(r) \| E(r) \|^2}{\rho(r)} dV_i,
\]

where \( \sigma \) and \( \rho \) are the conductivity and density of the tissue, respectively. \( E \) is the electric field.

The SAR is typically the largest on the body surface [8]. In order to avoid high SAR peak values, it is important to achieve a wider SAR distribution on the surface of the body. We reduced SAR in [13], with adequately shaped loops and slots on the antenna which controls the surface current distribution and spreads the electromagnetic fields over a wider area than...
in a conventional patch. Consequently, the SAR value was significantly lower compared to that of the reference patch antenna with equally strong radiated fields.

B. Antenna designs

In this study, we use the same overall dimensions for the phone model, 140 mm × 70 mm, and for the used body phantom, 210 mm × 105 mm × 40 mm, as in [13]. The material parameters of the rectangle body block correspond to Speag Head Tissue Simulating Liquid (HBBL600-10000 V6) [18]. We assume that the device is in the breast pocket and therefore the distance between the body and the device is only 3 mm.

Figure 1 shows the side view of the used ultra-low prototype model and the body block. The phone model contains two printed circuit boards (PCB), a bottom and a top PCB, and a foam layer between them. On the 0.422-mm thick bottom PCB, made of Rogers RO4350B, is the antenna feeding network and the ground plane (GND). The ground plane models both the battery and the frame of the phone. The antenna is placed on a 0.64-mm thick top PCB, made of Rogers RO3006. These electrical properties are very close to that of glass. The copper thickness in both PCBs is 35 µm.

The 1 mm gap between the battery (bottom PCB) and the antenna (top PCB) is modeled with a 1-mm thick Rohacell 71 HF foam. Table I shows all the parameter values of the antenna prototypes. PCBs and a foam layer are glued together and nylon screws are used to ensure a proper alignment. A soldered copper wire connects the top and the bottom PCBs.

In practice, multiple antennas for multiple-input multiple-output (MIMO) operation in mobile devices are preferred and thus, the size of a single antenna is crucial. In [13], one of the key advantages, in addition to its higher FoM, of the proposed design (called nested loops design in the rest of this paper), compared with reference patch design (later on called big patch design) is its about 30% smaller size. Therefore, we shrink the big patch antenna to the same size as the nested loops antenna and tune it to resonate at the desired frequency with an external matching circuit. The three-component matching circuit is designed by using Optenni Lab and all used components are 0402-sized Murata GJM15 capacitors.

Figure 2 shows all three low-SAR antennas and their dimensions that are compared in this paper: (a) nested loops, (b) big patch, and (c) matched patch. The matching circuit of the patch antenna with matching circuit is illustrated in Fig. 2(d). All dimensions of the nested loop design and its power splitter design are shown in [13]. In the next section III, we study and compare the SAR values and other key parameters of those three antennas. The analysis is based on the measured results.

III. MEASUREMENTS AND COMPARISON

The S-parameters are measured with a two-port Vector Network Analyzer (VNA) and SAR values with Speag Dasy6 equipment. In S-parameters measurements, a 3-mm thick Rohacell foam is placed between the antenna and SAR-liquid container to model the air gap. The size of the liquid container is the same (210 mm × 105 mm × 40 mm) as in the simulations.

Figure 3 illustrates the SAR measurement setup. The measured antenna is placed and supported from under the SAR-liquid container so that there is a 3 mm gap between the antenna and the container.

Figure 4 shows simulated and measured S-parameters for different antennas. An adequate matching level at the design frequency is achieved with all antennas. The widest -6 dB bandwidth is achieved with the big patch design (about 230 MHz), then with the match patch design (about 90 MHz),
Fig. 3. SAR measurement setups. a) Top and b) side views of the SAR measurement setup.

Fig. 4. Simulated (solid line) and measured (dashed line) S-parameters.

and the narrowest band with the nested loops design (about 50 MHz). Creating an accurate simulation model for this kind of setup is not easy which can be observed from the frequency shift in the measurement results.

The results in Fig. 5 show simulated total efficiencies, which are very low due to the close proximity of the body. However, the performance of all antennas is at the same level. Again, the patch antennas cover a wider band than the antenna with the nested loops.

An analysis of SAR values reveals that the SAR value of the nested loops design is roughly half of that of the big patch design (see Fig. 6). SAR values can be decreased from 8 W/kg to below 4 W/kg. This makes it possible to use larger transmitting powers in the system inside the safety limits. The used input power in the SAR measurements is 27 dBm (0.5 W). The SAR values of the match patch design (6 W/kg) settle between those two designs. A small frequency shift is due to the variation of simulation and measurement setups.

During the design process, we have used FoM to evaluate the performance of different antennas both from efficiency and SAR point of view. Fig. 7 shows that FoM results support the previous ranking of the low-SAR antennas. The traditional patch antenna without a matching circuit has roughly 50% lower performance in this comparison, where also SAR values are taken into account. The FoM for the matched patch is at a very competitive level compared to the more sophisticated design with nested loops. The results suggest that impedance matching and total efficiency can be improved with a matching circuit still remaining the wide distribution and without negative effects on SAR.

Fig. 5. Simulated total efficiency.

Fig. 6. Simulated (solid line) and measured (dashed line) 1 g SAR. Input power in all cases is 27 dBm (0.5 W).

Fig. 7. Simulated FoM. Input power in all cases is 27 dBm (0.5 W).
which improves the usability of the antenna. Ing the safety limits. Thus, better coverage can be reached, indicates that higher input power can be used without exceed-safety limit (1.6 W/kg) [15]. The smaller relative SAR directly is verified by comparing the SAR patterns of each three cases. The good correspondence of simulations and measurements IV. I CONCLUSION 5G SAR-reduction MIMO antenna with high isolation for full metal-rimmed tablet device,” IEEE Trans. Antennas Propag., vol. 70, no. 5, pp. 3846–3851, 2022.


