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Simple assessment of Specific Absorption Rate (SAR) for MIMO terminals

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***Abstract*— Evaluating SAR for multi-antennas is difficult and impractical due to the arbitrary power allocation and phase of the electric fields from different antennas causing the total field to change randomly. In this context, a simple approach was recently proposed for assessing SAR when more than one antenna is transmitting simultaneously. The metric of time averaged simultaneous peak SAR (TASPS) was derived for the purpose of showing that only the stand-alone SAR for each antenna needs to be evaluated in order to verify if the SAR for multi-antenna transmissions also stays within the exposure limit. In this paper, we briefly review the derivation and illustrate the physical mechanism underlying this result for a two-antenna prototype using stand-alone and simultaneous SAR distributions.**

I. INTRODUCTION

With the launch of LTE-Advanced [1], multi-antennas in mobile terminals may now be used simultaneously to achieve multiple-input multiple-out (MIMO) performance enhancement in the uplink. As in single-antenna uplink transmissions, multi-antenna uplink transmissions in terminals should comply with the standards for limiting human exposure to electric fields.

The exposure of the body to an RF electromagnetic field is usually measured by Specific Absorption Rate (SAR), which is defined as the power absorbed per mass of tissue, with a unit of watt per kilogram (W/kg):

$$SAR = \frac{\sigma}{\rho}\left|\vec{E}\right|^2 , \tag{1}$$

where σ and ρ denote the conductivity and mass density of the tissue, respectively. $\vec{E}$ is the root mean square (RMS) electrical field vector in the biological tissue. When multiple antennas are transmitting simultaneously, the power level and phase of the electric field at a given point from each antenna vary rapidly, so that the total electric field changes rapidly as well. To capture the simultaneous SAR values, exhaustive field measurements should be performed quickly over time and at multiple spatial points, which is impractical.

In [2], field summation schemes and testing methodologies were proposed for the evaluation of simultaneous peak SAR. However, the schemes were shown to be conservative for multi-antenna devices. A simplified method to obtain simultaneous SAR was proposed in [3], but the method becomes complicated as the number of transmitting antennas increases.

Recently, it has been shown that evaluation of SAR for multi-antenna terminals can be greatly simplified by taking into account the characteristics of MIMO transmissions [4]. Importantly, the testing of stand-alone SAR of the individual antennas is adequate to ensure SAR compliance of the multi-antenna terminal. In this work, we first review the concept of time averaged simultaneous peak SAR (TASPS) defined for the evaluation of multi-antenna SAR and the derivation that TASPS never exceeds stand-alone SAR [4]. Then, to provide further insights, we present simultaneous and stand-alone SAR distributions for two dual-antenna terminal prototypes with different antenna designs to visualize this result.

II. TIME-AVERAGED SIMULTANEOUS PEAK SAR

In this section, we review the derivation in [4]. For a MIMO terminal with n antenna elements, stand-alone SAR measures the exposure when only one antenna is transmitting, with the other antennas terminated by their source impedances. The stand-alone SAR for the pth antenna is expressed as

$$SAR_p = \frac{\sigma}{\rho}\left|\vec{E}_p\right|^2 , \tag{2}$$

To comply with a given SAR standard, the peak of stand-alone SAR for each antenna should be smaller than the corresponding limit (e.g., L), i.e., max(SAR_p) $\leqslant L$.

When m antennas ($1 < m \le n$) transmit simultaneously, the total power is divided among m ports. Assuming that the total input power (P_{total}) remains the same regardless of the number of transmitting antennas, the power allocated to the pth port is given by [4]

$$P_p = \alpha_p P_{\text{total}} , \tag{3}$$

where α_p is a real constant with $0 \le \alpha_p \le 1, \sum_{p=1}^{m} \alpha_p = 1$. Since the square of the electric field magnitude is linearly proportional to the input power, i.e., $\left|\vec{E}_p\right|^2 \propto P_p$, the total electric field in phasor form at a given point is given by

$$\vec{E}_{\text{total}} = \sum_{p=1}^{m} \sqrt{\alpha_p}\, \vec{E}_p e^{j\phi_p} , \tag{4}$$

where ϕ_p is the phase of the electric field generated by the pth antenna , with $\phi_p \in (0°, 360°)$. Thus, as shown in [4],

$$\begin{aligned}\left|\vec{E}_{\text{total}}\right|^2 &= \left|\sum_{p=1}^{m}\vec{E}_p\cos\phi_p + j\sum_{p=1}^{m}\vec{E}_p\sin\phi_p\right|^2 \\ &= \left|\sum_{p=1}^{m}\vec{E}_p\cos\phi_p\right|^2 + \left|\sum_{p=1}^{m}\vec{E}_p\sin\phi_p\right|^2 \\ &= \sum_{p=1}^{m}\left|\vec{E}_p\right|^2 + 2\sum_{p\ne q}\vec{E}_p\bullet\vec{E}_q\sin\phi_p\sin\phi_q + 2\sum_{p\ne q}\vec{E}_p\bullet\vec{E}_q\cos\phi_p\cos\phi_q .\end{aligned} \tag{5}$$

Due to the rapid and uniformly distributed phase variation, the last two terms in (5) are equal to zero when averaged over time. The time-averaged total electric field is then given by

$$\left|\vec{E}_{\text{total}}\right|^2_{avg} = \sum_{p=1}^{m} \alpha_p \left|\vec{E}_p\right|^2 . \quad (6)$$

Substituting from (2), the averaged simultaneous SAR is

$$SAR_{avg} = \frac{\sigma}{\rho}\left|\vec{E}_{\text{total}}\right|^2_{avg} = \sum_{p=1}^{m} \alpha_p \frac{\sigma}{\rho}\left|\vec{E}_p\right|^2 = \sum_{p=1}^{m} \alpha_p SAR_p \ , \quad (7)$$

where SAR_p is the stand-alone SAR for each antenna, whose peak value $\max(SAR_p) \le L$. Hence, TASPS satisfies

$$TASPS \le \sum_{p=1}^{m} \alpha_p \max\left(SAR_p\right) \le \sum_{p=1}^{m} \alpha_p L = L \ , \quad (8)$$

where the first equality is only obtained when all peak stand-alone SARs appear at the same location. The second inequality concerns the SAR limit $\max(SAR_p) \leqslant$ L. Based on (8), it can be concluded that TASPS always meets the SAR limit as long as each stand-alone SAR meets that limit.

III. TASPS FOR DUAL-ANTENNA MOBILE HANDSETS

In this section, two dual-antenna mobile terminals are used as examples to visualize the analysis in Section II. The first terminal consists of identical co-located dual-antennas [5], which represent a challenging case for simultaneous peak SAR, since the hotspots of the stand-alone SARs are very close to each other. The second terminal has two antennas exciting two orthogonal modes of the chassis [1], so that the current is more distributed along the chassis. The terminals were placed on a flat phantom with dimensions of 225 × 150 × 150 mm^3 and the same properties as those of a human body. To evaluate SAR, the accepted power at the antennas was set to 24 dBm (0.25W) at 0.859 GHz, the center frequency of LTE Band 5. For simultaneous SAR, the same accepted power was evenly divided over the two ports. The simulation was carried out in CST Microwave Studio. SAR values were calculated over the volume containing a mass of 1 g, following FCC requirement. The terminal prototypes, SAR distributions over the flat phantom and Peak SAR (P-SAR) values for stand-alone and simultaneous SAR are shown in Tables I and II for the two terminals, respectively.

Table I. SAR for co-located antenna terminal.

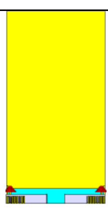
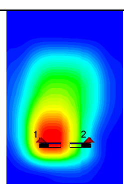
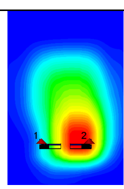
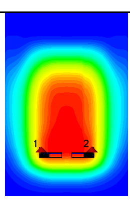
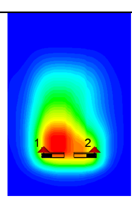
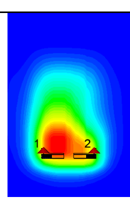
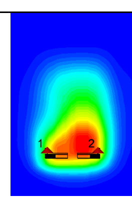
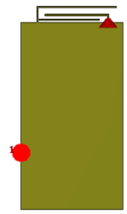
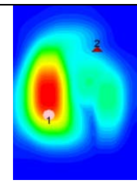
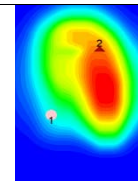
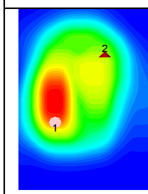
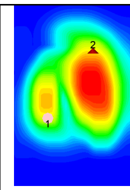
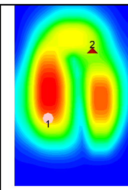
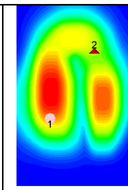
Antenna	Stand-alone SAR		TASPS
	 P-SAR:2.6W/kg	 P-SAR:2.6W/kg	2 W/kg
Simultaneous SAR			
 P-SAR:1.2W/kg	 P-SAR:1.7W/kg	 P-SAR:2.7W/kg	 P-SAR:1.7W/kg

Table II. SAR for chassis mode based antenna terminal.

Antenna	Stand-alone SAR		TASPS
	 P-SAR:3.4W/kg	 P-SAR:1.6W/kg	2 W/kg
Simultaneous SAR			
 P-SAR:2.1W/kg	 P-SAR:1.9W/kg	 P-SAR:2 W/kg	 P-SAR:2.1W/kg

It is observed that for co-located antennas, due to the centralized hotspots and their proximity, the simultaneous SAR at certain phase differences can be higher than stand-alone SAR, however, TASPS is smaller than stand-alone SAR. For the chassis mode based antennas, since the current is flowing along the chassis, the hotspot is more spread, and the peak of the simultaneous SAR does not vary considerably with phase difference. As a result, both the simultaneous SAR and TASPS are smaller than stand-alone SAR.

IV. CONCLUSION

This paper reviews a simple approach to evaluate SAR for MIMO terminals using only stand-alone SAR, by assuming random and fast-varying channel-dependent MIMO precoding. Simulation of two terminal prototypes shows that the proximity of centralized hotspots can lead to high simultaneous SAR, yet TASPS is always smaller than stand-alone SAR.

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