Impact of the Hand on the Specific Absorption Rate in the Head

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Abstract **─** In this article, we have investigated the influence of the hand on the Specific Absorption Rate (SAR) in the head for single and dual-antenna mobile terminals. The SAR in the head has been evaluated via Finite Difference Time Domain (FDTD) numerical computations. In the numerical models, the user has been represented not only by using the Specific Anthropometric Mannequin (SAM) head phantom, but also by including a hand phantom. Two types of hand grips (soft and firm) have been used to investigate the impact of the hand on the SAR. Moreover, the influence of the index finger position on the SAR has been investigated by using hand models with different locations of the index finger. At low band, the SAR evaluation in the head without including the hand phantom overestimates the actual value, with the hand phantom presents independently on the type, location and number of antennas. The highest overestimation of 50% has been observed for the mobile terminal with bottom positioned Folded J Antenna (FJA). At the high band and when considering the dual-antenna mobile terminals, the hand increases the SAR in the head by up to 40% compared to the respective calculated values without a hand phantom. Further, the SAR evaluation when the firm hand grip is used can be considered as a worst case estimation, because higher SAR values in the head have been obtained compared to when using the soft phantom.

Index Terms **─** Hand phantom, near fields and specific absorption rate.

I. INTRODUCTION

The effect of the electromagnetic radiation from the mobile phone towards the user, has been evaluated through the SAR in the head [1]. However, in the estimation procedure, a hand phantom is not included due to the lack of detailed knowledge on the hand grips up until recently. In a recent study [2], two hand grip models have been identified when the mobile phone is used in talk mode. The SAR is related to the Near Fields (NF) in vicinity of the antenna. Some fundamental results have been outlined in [3]. In [4], the first antenna solution with a reduced SAR in the head has been proposed. The use of a parasitic element connected to the ground plane to manipulate the Near Fields (NF) and consequently the SAR, has been proposed in [5]. In [6], when the SAM phantom has been used, a dual-antenna configuration has been found to have higher SAR in the head than the respective one when single antenna is used.

In this article, we have investigated different antenna configurations having one or two antennas. The types of the antennas have been chosen in a way to represent the most common types used in the mobile phones nowadays. In our study, we have considered four antenna configurations with one antenna and four with two antennas; combining FJA, Planar Inverted F Antenna (PIFA) and Folded Inverted Conformal Antenna (FICA), fitting into a typical candy bar mobile phone. The two main issues, which have been addressed and investigated in the current work, were the contribution of the hand on the SAR value in the head for both single and dual-antenna mobile terminals and the influence of the index finger position on the SAR in the head for both general hand grips in use. A useful conclusion for the future SAR evaluation by using

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an appropriate hand grip has been given.

II. ANTENNA DESIGNS AND USER PHANTOM MODELS

The information for the mobile terminals under investigation is summarized in Table 1.

Table 1: Mobile terminals' antennas used in the investigation

Type	Location	Notation
FJA	Top	H1
FJA	Bottom	H2
PIFA	Top	H3
PIFA	Bottom	H4
PIFA-PIFA	Bottom	H5
PIFA-PIFA	Top	H6
PIFA-PIFA	Top and Bottom	H7
FICA-FICA	Top and Bottom	H8

H1 to H4 are mobile terminals with single antenna, while H5 to H8 are with two antennas. The single antennas have been designed to cover the 900 MHz (low) and 1800 MHz (high) GSM bands. The dual-antenna configurations have covered the LTE (746-796) MHz (low) and (1920 -2170) MHz (high) frequency bands. In order to obtain maximum bandwidth, the trivial position of the planar antennas is the one coinciding with the edges of the ground plane. The dimension of the mobile handset is 40 mm x 100 mm x 10 mm (width x length x thickness). The ground plane and the metallic antenna elements have been modelled as a Perfect Electric Conductor (PEC). All mobile terminals in our analysis have been designed including a battery, which is made of PEC and it may have an important significance on the SAR in the head. Other parts available in the real phones, such as a phone case, are made of dielectric material with low relative permittivity and therefore will not influence drastically the SAR results. Thus, they will not be included in the mobile phone models. A parallel in-house FDTD code [7] developed at Antennas, Propagation and Radio-Networking (APNET) group at Aalborg University, has been used for the investigation. For the termination of the simulation space, the perfectly matched layer absorbing boundaries [8] were used. The profiles of the antenna configurations are shown in Fig. 1.

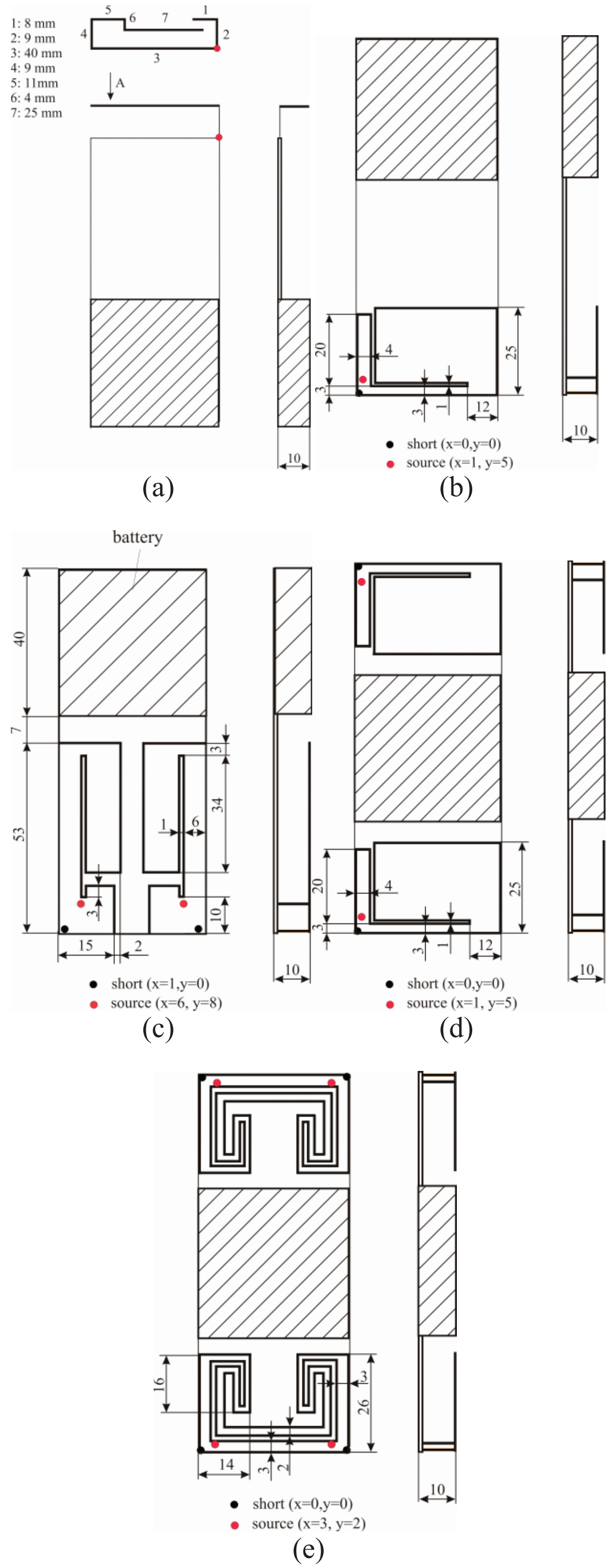
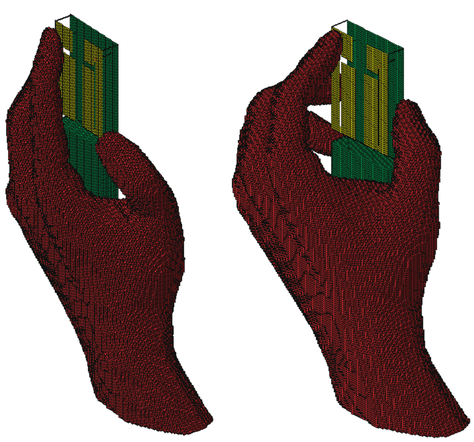


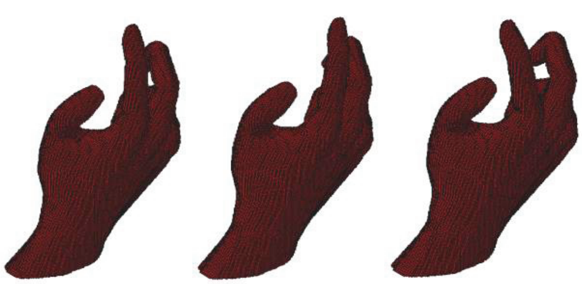
Fig. 1. Profiles of the designed antennas: mobile terminals (a) H1, (b) H3, (c) H5, (d) H7 and (e) H8.

Two hand grips have been identified when the mobile phone is used in talk mode in [2]. Both are shown in Fig. 2. In the case of soft grip style, there is a significant gap between the hand palm and the mobile phone, as opposed to the firm grip where the hand holds the phone tightly. The hand phantoms have been originally created using the 3D software POSER and then converted to “wrl” type of files. Lastly, they have been processed via MATLAB, in order to create the hand phantoms as external objects in our in-house FDTD code. The dimensions of the hands were scaled according to the study in [9] and their electromagnetic properties were chosen according to the investigation in [10]. As a head phantom, we have used the SAM phantom head which has been standardized for SAR evaluation [1]. According to the latter, the mobile phone is placed in “right tilt position” with respect to the SAM head phantom. The hand models with different location of the index finger are shown in Fig. 3.

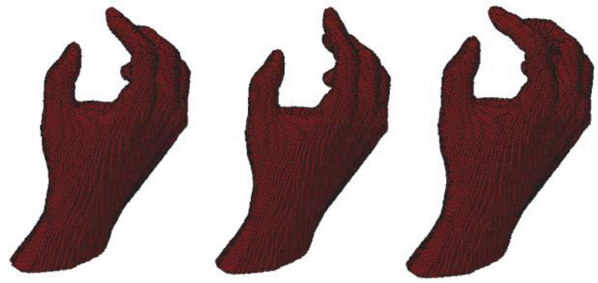


(a) (b)

Fig. 2. (a) Firm and (b) soft hand phantoms.



(a) (b) (c)



(d) (e) (f)

Fig. 3. Firm hand phantom with the index finger positioned on: (a) “initial,” (b) “right” and (c) “left;” and soft hand having the index finger located on: (d) “initial,” (e) “right” and (f) “left”.

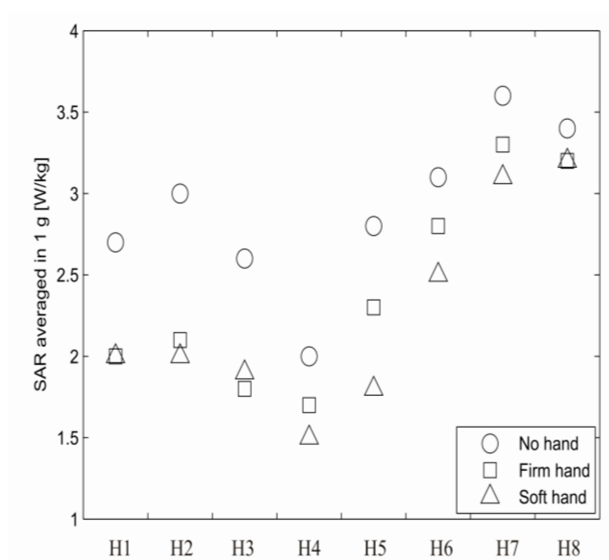
III. RESULTS AND DISCUSSION

The SAR is defined via the equation:

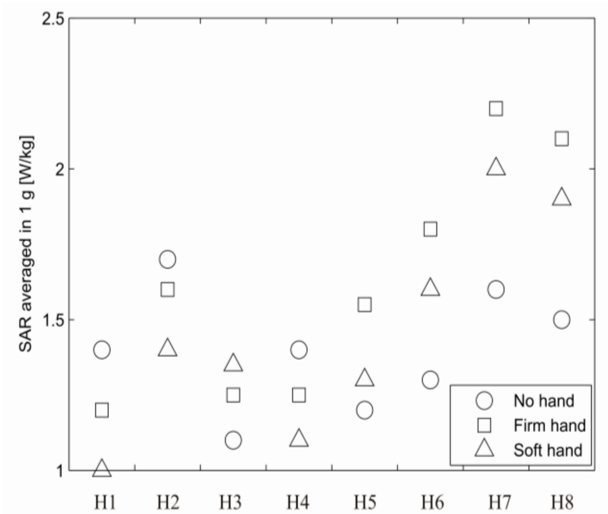
$$\mathrm{SAR} = \frac{\sigma |E|^2}{\rho}, \tag{1}$$

where σ is the conductivity of the tissue where the computation is made, E is the total electric field within the tissue and ρ is the sample density.

The SAR values averaged in 1 g for all mobile terminals under investigation are shown in Fig. 4.



(a)



(b)

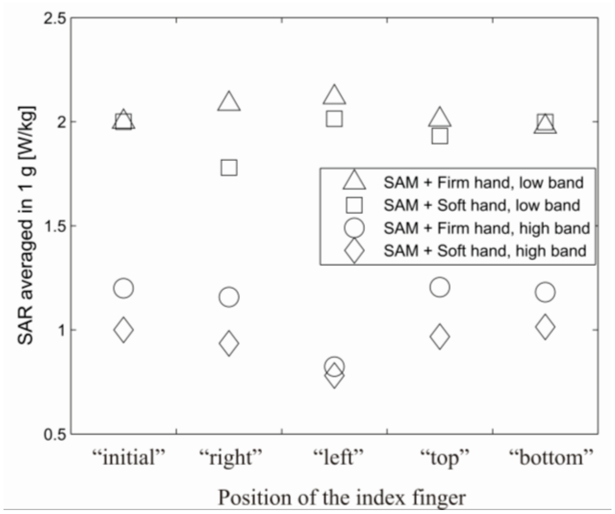
Fig. 4. SAR averaged in 1 g for: (a) low band and (b) high band, for initial location of the index finger.

At low band, the presence of the hand leads to decrease of the SAR in the head independently on the type, location and number of antennas. In this aspect, according to [1], the current evaluation of the SAR without a hand phantom seems to overestimate the realistic value (when the hand phantom is present). This overestimation can be assumed to be the worst case and therefore the evaluation of the SAR in the head without using a hand phantom can be considered as an acceptable solution. The highest overestimation has been observed in the case of H2 and it is approximately 50%. Comparing the obtained results for H1 and H2, we can easily see that the hand model equalizes the SAR values in the head for both types of mobile phones, as opposed to when it is not present. The PIFA single-antenna mobile terminals have lower SAR values compared to the ones having FJA. The mobile terminal H4 having the radiating element on the bottom of the ground plane has the lowest SAR values.

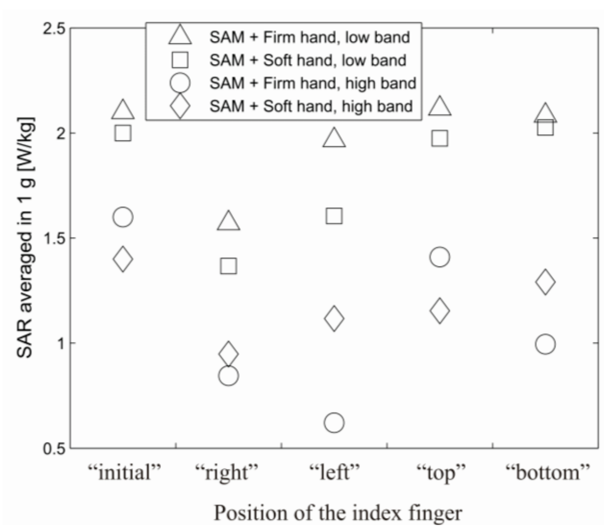
Following equation (1), the SAR is dependent on the electric field within the head phantom. There is a strict relationship between the electric field and the frequency for a given antenna under consideration. The lower the frequency is, the higher the electric field is. The low band of the LTE technology is lower than the low band of the GSM. The high band of the GSM is lower than the high band of the LTE. Due to these reasons we would expect that at the low band intrinsically, the SAR in the head when the mobile terminal has more than one antenna would be slightly higher than the one with one antenna. H5 and H6 consist of two PIFA on one side of the ground plane. However, in the case of H5, which has two PIFA on the bottom of the ground plane, the SAR in the head is comparatively low. The latter can be explained by lowering of the total peak electric field, because the fields provided by both antennas are out of phase. As expected, when the radiating elements are located on the top side (H6), the SAR in the head is higher than in the case when the elements are on the bottom (H5). However, when the radiating elements are bottom and top located as it is the case of H7 and H8, the SAR in the head has high values. The same trend observed for H1 and H2 is valid for the influence of the hand model on the SAR in the head, when H7 and H8 are used. The hand seems to make the computed SAR values in the head very close to each other for H7 and H8.

However, at the high band, the hand phantom seems to be an importance for SAR evaluation. For all dual-antenna mobile terminals, the averaged increase in the SAR in the head when the hand is included, is more than 25% compared to the respective case without the hand included. Moreover, the SAR in the head when the firm grip style is used is almost always higher (always for all dual-antenna configurations) than the respective case with a soft grip phantom. The differences in the SAR in the head when the hand is present or not, are much higher for the case of dual-antenna mobile terminals than for the single-antenna mobile terminals.

In the next four figures, the SAR values in the head have been calculated for hand phantoms having different locations of the index finger. Soft and firm hand grips having different locations of the index finger (see Fig. 3) needs to be investigated, because the variation of the SAR values can be used to define a generalized hand model for correct and realistic evaluation of the SAR in the head.



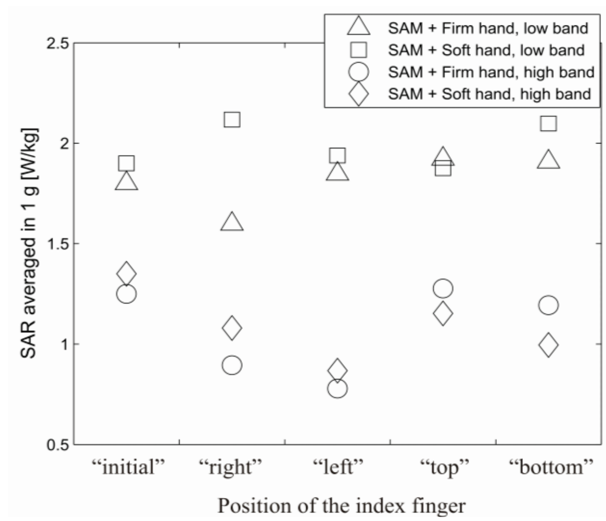
(a)



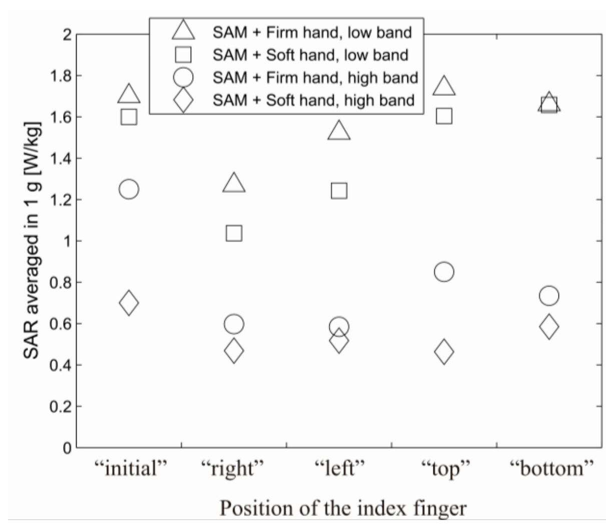
(b)

Fig. 5. SAR averaged in 1 g in the case of: (a) H1 and (b) H2, for different positions of the index finger.

The hand may influence the SAR in the head significantly depending on the hand grip in use. In the case of H1 at both frequency bands, when moving the index finger in y direction (see Fig. 1), the SAR in the head does not change significantly. The same trend has been observed when using H2 at low band. However, in the case of H2 at high band, when the index finger is on the “top” or “bottom” position, the SAR in the head gets reduced by up to 60%, compared to the one when the index finger is in “initial” position. When the index finger is placed on the “right” or “left” position, the SAR in the head may get decreased drastically, as it is the case of H2 at high band.



(a)

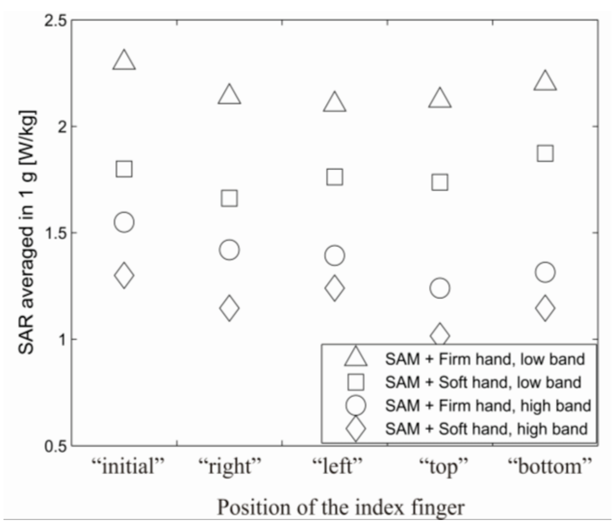


(b)

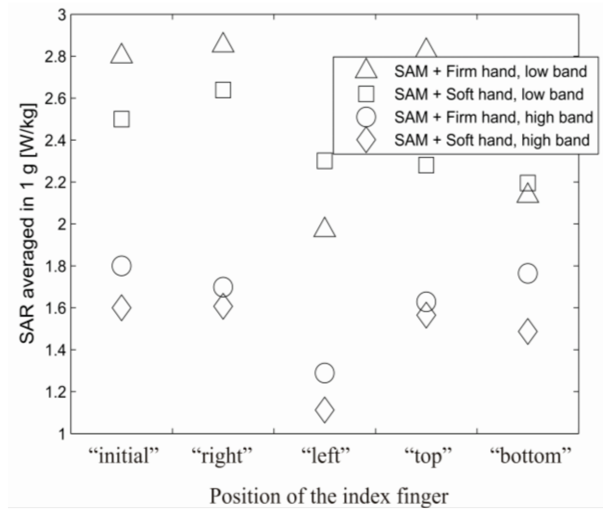
Fig. 6. SAR averaged in 1 g in the case of: (a) H3 and (b) H4, for different positions of the index finger.

As it is seen from the SAR results, when using the firm hand phantom in the SAR estimation, the computed SAR values in the head are higher compared to the respective cases with a soft hand phantom. However, the opposite trend has been observed for H3, being a single-antenna mobile terminal having a top positioned PIFA. Further, at the high band, the SAR values in the head when the index finger is positioned on "left" or on "right," positions are lower than the one obtained for the hand phantoms with initial position of the index finger. For example, when the index finger is positioned on "left," the SAR in the head is almost two times lower than the one for the case of the initial location of the index finger.

An important general conclusion for the influence of the index finger position on the SAR in the head, can be drawn in the case of single-antenna mobile terminals. The SAR in the head is dependent on whether the index finger is positioned in the region of high electric fields, considering the electric near field antenna pattern in free space. All investigated single-antenna mobile terminals have simplified electric near field pattern in free space. Therefore, when the index finger is positioned in the region of high electric fields, which is the case of the "initial" position of the index finger, the computed SAR in the head is high. When the index finger gets moved further from the region with the high electric fields, the SAR values get decreased. The same trend is not supposed to be observed in the case of the dual-antenna terminals, because of the more complicated total electric near field pattern in free space due to the presence of two antennas and the necessity of addition of their electric near fields.



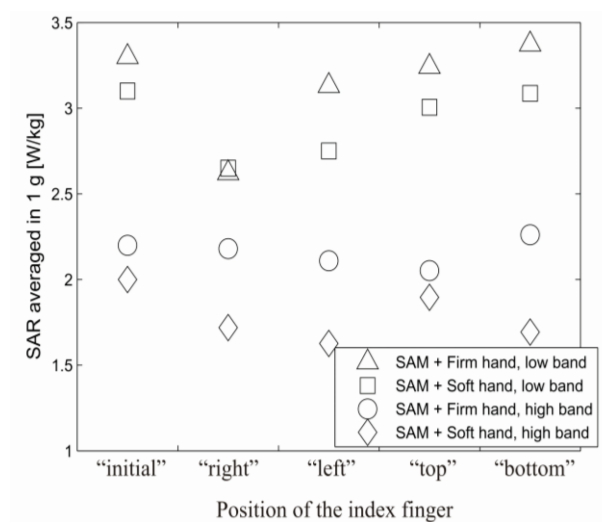
(a)



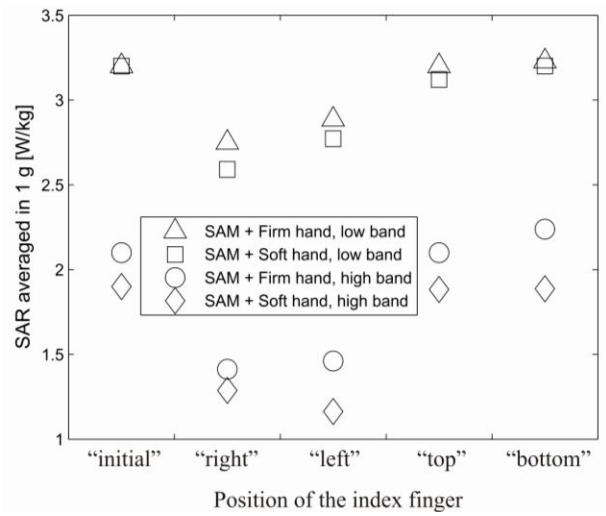
(b)

Fig. 7. SAR averaged in 1 g in the case of: (a) H5 and (b) H6, for different positions of the index finger.

In the case of H5, both PIFA are located on the bottom of the mobile phone. As we would expect, because the index finger is located far from the radiating elements, the variation of the SAR values in the head due to the index finger position is negligible. However, for top positions of the PIFA (H6), the lowest SAR values in the head have been observed for case when the hand grips with index finger in "left" position is used. In general, the SAR values in the head when H6 is used are higher than the respective ones when with H5.



(a)



(b)

Fig. 8. SAR averaged in 1 g in the case of: (a) H7 and (b) H8, for different positions of the index finger.

The last two antenna configurations are dual, having top and bottom locations of the radiating elements (H7 and H8). In general, the SAR in the head in the case of H7 and H8 is higher than when H5 and H6 are used. Moreover, when the hand phantoms with the index finger on "right" or "left" position is used, the SAR in the head experiences lower values than the ones with the hand model with the initial location of the index finger. In that aspect, the dependence of the SAR in the head on the index finger position is similar to the trend obtained for the case of single-antenna mobile terminal; i.e., the SAR in the head experiences reduction when the index finger is positioned on "right" or "left".

In general, the SAR in the head when the firm hand has been used is almost in all cases higher than the respective one with the soft hand in use. Therefore, the antenna exposure to the user considering firm hand in the modelling can be assumed to be the worst case scenario and therefore it should be preferred for SAR evaluation.

IV. CONCLUSION

Two basic hand grips have been used to investigate the influence of the hand on the SAR in the head when using single and dual-antenna mobile terminals. Moreover, hand phantoms with different positions of the index finger for each hand grip have been modelled and included in the investigation. At low band, the way of SAR evaluation in the head without the presence of the hand overestimates the realistic value (when the hand phantom is included); i.e., the hand decreases the SAR in the head independently on the type, location and number of antennas. The highest overestimation has been observed for H2 as it reaches 50%. In the case of dual-antenna mobile terminals and at high band, we have shown that the hand increases the SAR in the head compared to the respective calculated values without a hand phantom. Namely, the increase of the SAR in the head is up to 40% (25% on average) compared to the case without a hand phantom.

Generally, the firm hand grip has been proved to be the hand grip which secures the highest SAR values and therefore it can be considered as a worst case evaluation. Therefore, a test hand phantom similar to the firm grip presented in the current work has to be used to evaluate the SAR in the head for the upcoming LTE technology using more than one antenna in the mobile terminal. Further, the index finger of the hand grip in use should be positioned in a position closed to the "initial" investigated in the current work.

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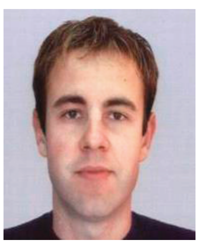

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Gert Frølund Pedersen was born in 1965 is married to Henriette and they have 7 children. He received his B.Sc. E. E. degree with honour in Electrical Engineering from the College of Technology in Dublin, Ireland, and his M.Sc. E. E. and Ph.D. degrees from Aalborg University in 1993 and 2003. He has been employed by Aalborg University since 1993, where he is now full Professor heading the Antenna, Propagation and Networking group and is also the head of the doctoral school on wireless communications, which has close to 100 Ph.D. students enrolled. His research has focused on radio communication for mobile terminals, especially small antennas, diversity systems and Propagation and Biological effects. He has published more than 75 peer reviewed papers and holds 20 patents. He has also worked as consultant for developments of more than 100 antennas for mobile terminals, including the first internal antenna for mobile phones in 1994 with lowest SAR, first internal triple-band antenna in 1998 with low SAR and high TRP and TIS, and lately various multi antenna systems rated as the most efficient on the market. He has been one of the pioneers in establishing over-the-air measurement systems. The measurement technique is now well established for mobile terminals with single antennas and he was chairing the COST2100 SWG2.2 group with liaison to 3GPP for over the-air test of MIMO terminals.