Impact of the Mobile Phone Dimensions on the Hearing Aids Compatibility

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***Abstract*-** In this work, we have investigated the influence of the mobile phone physical dimensions on the hearing aids compatibility (HAC). In our study, we have considered an inverted F antenna (IFA) and a planar inverted F antenna (PIFA) both fitting into a typical candy bar mobile phone. We have used a generic cubical head model to investigate the user impact on the near fields (NF). The field values are obtained by using the finite difference time domain (FDTD) method. We have observed significant difference in the peak field values between free space and with the head included although only free space values are specified in the relevant standard. Important outcome for the physical dimensions of the mobile phone is that the increase of the length of the handset significantly decreases the peak H value.

I. INTRODUCTION

Several studies have shown that the electromagnetic interference in the hearing aids (HA) due to the GSM digital mobile phones has an annoying effect on the user and a negative influence on the intelligibility of the speech [1-3]. In [4], the presence of discrete peaks in the output spectrum corresponding to the time division multiple access frame rate and its harmonics was shown. In the same study, the interference has been characterized as a buzzing sound. These results were confirmed by a more detailed investigation [5]. A comprehensive study of the NF for typical antennas in mobile handsets does not exist in the open literature. Moreover, the great variety of the HA available on the market complicates the HAC of the mobile phones. This article investigates the influence of the mobile handsets dimensions on the HAC. The IFAs and PIFAs have been investigated for the low band (850 MHz) and high band (1900 MHz) frequency ranges. The conducted analysis is based on the available HAC standard which has been defined for free space [6]. Further, a comparison between free space and with the impact of the head has been carried out to see how well the standard reflects the real case.

II. PREDICTION METHOD

An implementation of a generic mobile handset in the FDTD for computing the electromagnetic field distribution has been presented in [7]. In the same study, the “thin wire” method is used to model the antenna and avoid the “staircasing” effect in FDTD. A parallel FDTD code developed at the Antennas, Propagation and Radio-Networking (APNET) group at Aalborg University has been used for the investigation. The code has been used in a previous study [8]. A cell size of 1 mm which ensures at least twenty samples per wavelength was used. For the termination of the simulation space the perfectly matched layer absorbing boundaries [9] were used.

III. ANTENNA DESIGN AND HEAD MODEL

Figure 1 shows the IFA and PIFA for the low band.

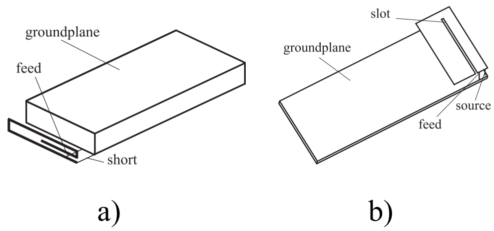

Fig. 1. (a) IFA for the low band and (b) PIFA for the low band.

The initial dimension of the mobile handset has been chosen to be 40 x 100 x 10 mm (width x length x thickness). The ground plane and the metallic antenna elements have been modelled as a perfect electric conductor. The heights of the antennas have been chosen in such a way that the proper bandwidth has been established for low and high band cases. The width has been varied to 50, 60, 70 mm; the length to 120, 140, 160, 180, 200 mm; and the thickness to 8, 9, 11, and 12 mm. The IFAs has been placed on the top, on the side or at the bottom of the box phone. The PIFAs has been located on the back top or back bottom of the phone.

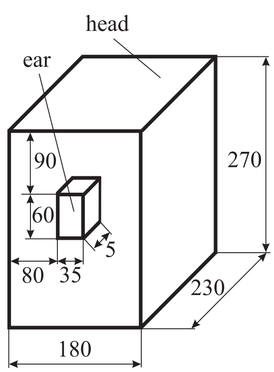

Fig. 2. Generic cubical head model (dimensions in mm).

For simplicity, the head and the ears have been modelled as homogeneous tissue bricks (Fig. 2). The dimensions of the ears have been chosen according to [10]. The thickness of the cubical ear is 5 mm. The electrical properties of the head material have been taken from [11]. We have assumed that the ear consists of fat tissue [12]. In our analysis, we have assumed horizontal orientation of the mobile phone with respect to the head and no gap between the phone and the ear. The mobile phone is positioned in such a way that the speaker, the center of the ear, and the center of the calculation plane (defined in the next part) lie on a line perpendicular to the phone. We have assumed that the speaker is positioned 15 mm from the top edge of the phone.

IV. HAC STANDARD

According to the last version of the available standard, the common operation of a mobile phone and a hearing aid is classified as normal if the HAC category is at least 5. The latter is defined as a sum of the category of the mobile phone (dependent on the measured NF) and the category of the HA (dependent on the HA immunity). Owing to the fact that for the present HA, the achievement of HA category equal to 2 is very easy; the aim for the mobile phone manufacturers is to ensure a mobile phone category of 3 and above. The standard specifies measurement of the NF in a plane 50 by 50 mm at distance 15 mm from the mobile phone (Fig. 3).

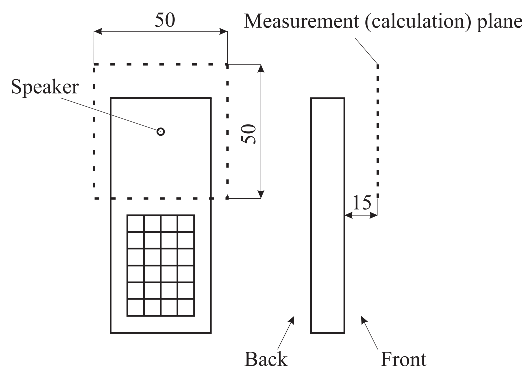

Fig. 3. Set up for the NF measurement according to the available HAC standard.

The phone speaker and the center of the measurement plane lie on a line perpendicular to the phone. After the data are obtained, for both E and H fields, the measurement plane is divided into nine equal sub-grids. For each E and H sub-grid, the maximum value is estimated. In our analysis, the maximum value of the entire measurement plane will have an index m. Then the exclusion procedure has to be applied following the rules:

- The center sub-grid cannot be excluded.
- Three E and three H sub-grids have to be eliminated as at least 4 out of the 6 left sub-grids have to be common for both E and H field.
- For each E and H field, the excluded sub-grids have to be contiguous.

The mobile phone category is defined by the maximum E and H values after the exclusion (these values are called characteristic and in this article are denoted with an index c).

Table 1: Phone emission limits and categories (for frequencies below 960 MHz the values are 10 dB higher)

Category	Telephone RF parameters (above 960 MHz)	
Near Field	E field [dB V/m]	H field [dB A/m]
M1	48.5 to 53.5	-1.9 to 3.1
M2	43.5 to 48.5	-6.9 to -1.9
M3	38.5 to 43.5	-11.9 to -6.9
M4	< 38.5	< -11.9

Table 2: System performance classification

System classification	HAC category
Useable	4
Normal use	5
Excellent performance	6

V. RESULTS AND DISCUSSION

The HAC standard has been defined for the GSM working frequency bands at 850 MHz (low band) and 1900 MHz (high band). These frequencies are used in the USA, Canada, and other countries in the Americas. Of particular interest is to compare the NF produced at these GSM frequency bands with the ones used in the GSM system in Europe. The comparison has been made with respect to the peak electric and magnetic values as we have taken into an account the planar values as defined in the standard and explained in the previous section. To obtain an antenna resonating at lower or higher frequency, we have changed only the length of the radiating element and all other dimensions have been kept constant. Moreover, to be able to fulfill the bandwidth requirements for all four investigated frequency bands, the distance from the wire to the ground-plane for the IFAs has been chosen to be 9 mm. In the case of PIFAs, the minimum investigated height has been 8 mm. The latter was enough to cover the necessary bandwidth. The analysis has been made between all possible antenna configurations obtained via combination of the different physical dimensions of the antennas - width, length, and thickness.

Table 3: Similarity between the NF at close frequencies in free space

Comparison between the NF for close frequencies			Difference in the peak NF between 850 and 900 MHz, [dB]			
Type	Position	Head?	Mean		Deviation	
			ΔE_m	ΔH_m	ΔE_σ	ΔH_σ
IFA	Top	No	0.3	0.8	0.6	0.6
IFA	Top	Yes	0.3	0.5	0.2	0.4
IFA	Side	No	0.5	1	0.1	0.1
IFA	Side	Yes	0.05	0.2	0.2	0.2
IFA	Bottom	No	0.2	0.7	0.2	0.2
IFA	Bottom	Yes	0.1	0.1	0.4	0.2
PIFA	Top	No	0.2	0.3	0.5	0.4
PIFA	Top	Yes	0.3	0.3	0.8	1.1
PIFA	Bottom	No	0.3	0.8	0.2	0.2
PIFA	Bottom	Yes	0.3	0.3	0.1	0.1

Table 4: Similarity between the NF at close frequencies in free space

Comparison between the NF for close frequencies			Difference in the peak NF between 1800 and 1900 MHz, [dB]			
Type	Position	Head?	Mean		Deviation	
			ΔE_m	ΔH_m	ΔE_σ	ΔH_σ
IFA	Top	No	0.4	0.2	0.6	0.4
IFA	Top	Yes	0.3	0.2	0.4	0.3
IFA	Side	No	0.2	0.1	0.3	0.2
IFA	Side	Yes	0.4	0.3	0.3	0.2
IFA	Bottom	No	0.6	0.7	0.1	0.3
IFA	Bottom	Yes	0.3	0.1	0.5	0.3
PIFA	Top	No	0.3	0.1	0.6	0.3
PIFA	Top	Yes	0.2	0.1	0.3	0.2
PIFA	Bottom	No	0.4	0.3	0.1	0.2
PIFA	Bottom	Yes	0.2	0.4	0.3	0.3

As it can be seen from the table, the difference in the peak values is negligible. This is an important conclusion because it gives us the possibility to investigate the NF at the frequency bands defined in the HAC standard and then translate the obtained results for the neighbour frequency bands.

In the analysis of the NF between free space and with the head model, in Table 2 and 3 are shown only the cases for the initial physical dimension of the antennas. Further, if changing any of the dimensions causes a significant difference in the NF for either free space or with the head present, it will be outlined and explained in the text.

For both frequency bands of interest and in the case of top positioned IFAs and PIFAs, the presence of the head model decreases the peak E value compared to the free space cases. For both bands and top positioned radiating elements, except the case of top positioned IFA, when comparing the free space with a user, the opposite trend has been observed for the magnetic peak value meaning that the presence of the user increases the peak H value. For that case of top positioned IFA, the interesting fact is the large margin between the peak value H_m and the characteristic value H_c in free space. The peak E and H values are decreased when the head is present compared to free space for bottom low band IFAs and bottom positioned PIFAs. The latter is not the case for bottom located IFA working at high band as both peak electric and magnetic field values increase in the case of a user compared to free space.

Table 5: Peak electric and magnetic NF at low band

Antenna type, position	Electric field [dB V/m]				Magnetic field [dB A/m]			
	E_m		E_c		H_m		H_c	
	Free space	With head	Free space	With head	Free space	With head	Free space	With head
IFA, top	60.3	43.3	58.3	43.3	17.4	7.7	1.8	7.6
IFA, bottom	58.4	55.5	57.5	55.3	11.4	8.5	3.5	8.3
PIFA, top	48.6	42	47.9	41.8	4.4	7.8	3.6	7.1
PIFA, bottom	55	42.2	54.8	42	8.6	6.8	0.6	6.8

Table 6: Peak electric and magnetic NF at high band

Antenna type, position	Electric field [dB V/m]				Magnetic field [dB A/m]			
	E_m		E_c		H_m		H_c	
	Free space	With head	Free space	With head	Free space	With head	Free space	With head
IFA, top	52.8	42.5	52.5	42.5	3	7.6	3	7
IFA, bottom	50.1	55.5	46.8	53.8	-1.4	3.6	-3.2	2.8
PIFA, top	53	39.8	52.5	38.8	1.6	5.2	0.8	3
PIFA, bottom	48.8	35.0	48.5	34.8	7.8	0.4	5.1	0.1

In the cases of low and high band bottom positioned IFAs and PIFAs and high band top located IFA for both free space and with an user, increasing the width of the phone from 40 to 70 mm causes reduction of between 3 and 4 dB V/m (A/m) in the peak electric (magnetic) value. For all of the other investigated cases, the width of the handset does not have a significant impact on the peak field values.

The length of the mobile phone appears to be the most important physical dimension. As a general conclusion, increasing the length of the mobile phone from 100 to 200 mm reduces the peak H values.

We have not observed a strict tendency for the influence of the length of the mobile phone on the peak E value. In free space for all different antenna configurations and types, due to the increased length of the mobile phone the reduction of the peak magnetic values is within 4 to 5 dB dB A/m. The decrease in the peak values is stronger with the head present compared to the free space. A simple example has been shown in the next figure.

Figure 4 shows the impact of the length of the mobile phone on the maximum E and H values before and after the exclusion rule was applied for top positioned low band IFA (a) and PIFA (b) with the head presented. The left axis is the E scale, the right axis is the H scale, and the top axis is the mobile phone category specified by the characteristic values E_c (H_c). Each group of four values is specified for a concrete length of the mobile phone as in a consecutive way are shown the electric and magnetic values before and after the exclusion procedure has been applied. For both types of antennas, increasing the length from 100 to 200 mm leads to significant reduction by more than 10 dB A/m of the peak H value, which also will increase the mobile phone category to the value of 3 which will ensure normal common work of the mobile phone with a typical hearing aid. Of all the investigated physical dimensions, the thickness of the mobile phone has the least influence on the NF

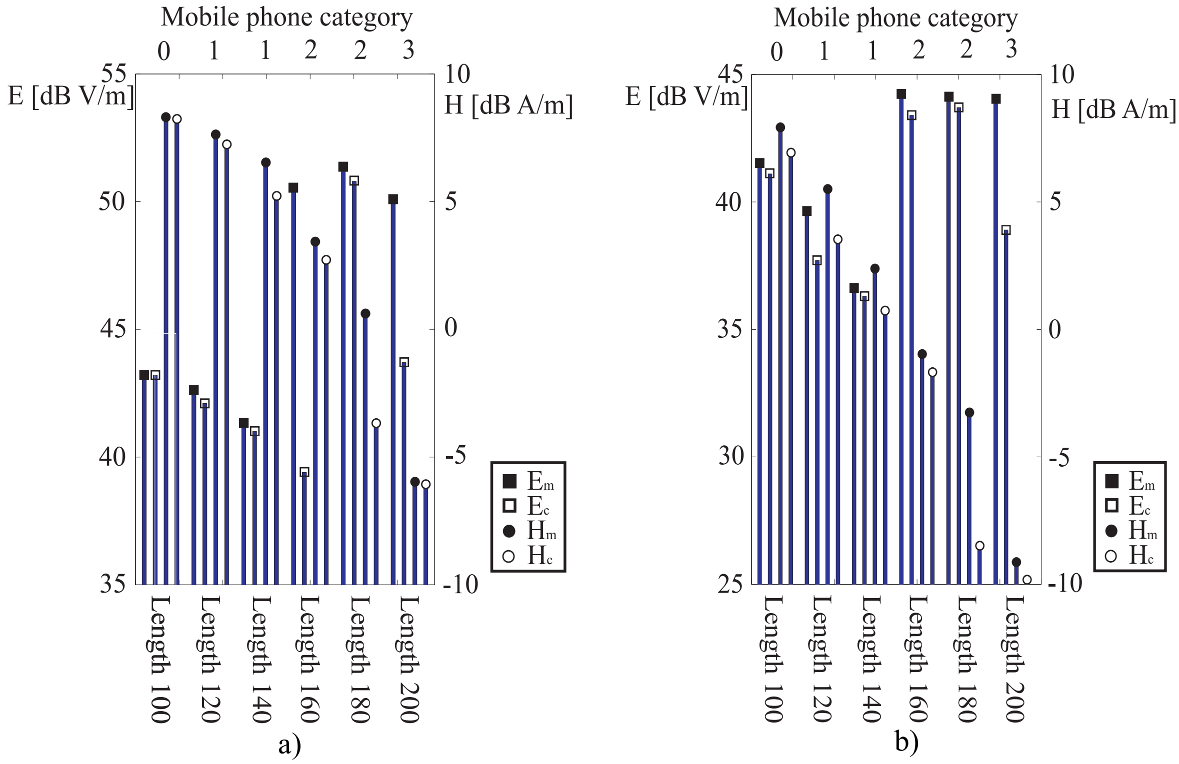

Fig. 4. Bar graphs of maximum E and H values for 850 MHz top positioned antenna with the head present: (a) IFA and (b) PIFA.

values as we have not observed difference in the NF larger than 0.5 dB V/m (dB A/m) when changing the thickness from 8 to 12 mm.

VI. CONCLUSION

In this paper, we have shown that there is a difference in the NF values between free space and with a head. The length of the mobile phone appears to be an important parameter as with its increase, the peak H value decreases. The width and the thickness of the mobile phone do not have significant impact on the NF. The influence of the hand on the NF may, also, need to be explored.

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