User's Impact on PIFA Antennas in Mobile Phones

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Abstract

Thanks to a recent grip study, CAD models of the human hand have been generated, investigating user's impact on PIFA antennas in mobile phones. The simulation results show that the hand and especially the index finger exhibit a major contribution in determining the total loss when compared to the upper torso alone, while the influence of the position of the fingers on the handset is found to be more important when close to the antenna. The palm-handset gap and the index finger location are the main responsible for both absorption and mismatch loss.

Index Terms
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Controlled Indexing
CAD mobile handsets planar inverted-F antennas user interfaces

Non-controlled Indexing
CAD models PIFA absorption loss index finger location mismatch loss mobile phones user's impact

User's Impact on PIFA Antennas in Mobile Phones

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Abstract— **Thanks to a recent grip study, CAD models of the human hand have been generated, investigating user's impact on PIFA antennas in mobile phones. The simulation results show that the hand and especially the index finger exhibit a major contribution in determining the total loss when compared to the upper torso alone, while the influence of the position of the fingers on the handset is found to be more important when close to the antenna. The palm-handset gap and the index finger location are the main responsible for both absorption and mismatch loss.**

Keywords-Antenna proximity factors, efficiency, FDTD, hand phantom.

I. Introduction

When mobile phones are used in close proximity with the human body, this results in a detrimental effect in its communication performances [1]. While it was shown that a SAM (Specific Anthropomorphic Mannequin) phantom can well represent the user's upper torso in average sense [2], the hand modelization still encounters some practical difficulties [3, 4]. Though some standardization bodies have already proposed some preliminary hand phantoms, they utilize a hand grip that is not supported by grip studies [3]. Thanks to a recent contribution within the COST Action 2100 [5] it was possible to generate more detailed hand models. The objective of this work is to investigate through FDTD (Finite Difference Time Domain) simulations the user's impact on PIFA (Planar Inverted F Antenna) antennas for talk mode in mobile phones, focusing on both absorption and mismatch loss and isolating the contribution of both user's head and hand to the total loss. Moreover the influence of the palm-handset gap and the position of the index finger are investigated too. This paper is structured as follows: Section II describes the grip study and its main results. Section III illustrates the used procedure to generate proper hand phantoms. In Section IV all the FDTD simulations are presented. Section V finally summarizes our conclusions.

II. Grip Study Description

A recent contribution within the COST Action 2100 [5] reports a first grip study for talk and data modes in mobile phones, where a rigorous investigation methodology was used over a sample population of 100 subjects (figure 1); thanks to an unobtrusive data acquisition system and a proper investigation protocol most of the experimental biases were minimized, allowing the collection of stable and comprehensive statistics. The index finger's location was confirmed to be in the back region of the handset in most cases. The palm-handset distance was indirectly estimated based on grip style, fingers' contact points and relative anthropometric properties.

A proper categorization procedure led to the identification of two main ways of holding mobiles while talking, naming them "firm" and "soft" grip styles respectively. In the "firm" grip style the fingers are placed around the handset so that while the intermediate phalanges touch its side, the distal ones reach its front region, with a corresponding palm-handset gap that does not exceed the length of the longest proximal phalanx.
In the "soft" grip style the hand holds the handset only with the distal phalanges, creating an air gap between the palm and the handset that does not exceed the length of the thumb.

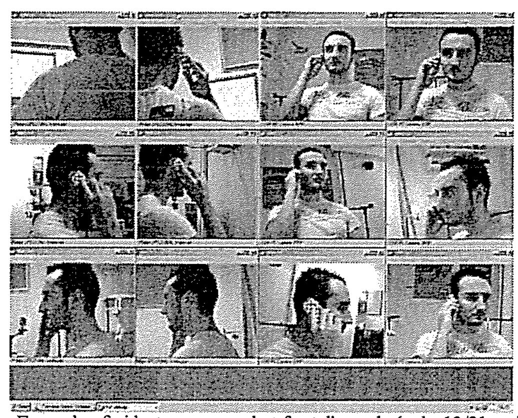

Fig. 1. Example of videotape screenshot for talk mode (only 12/21 webcams are displayed here)[5].

III. CAD Numerical Models of the Phantom Hands

As a natural prosecution of the grip study [5], all the most significant grip positions were converted in CAD models to be utilized in FDTD simulations. The hand grip positions have been modeled using the 3D modeling tool POSER® and then exported as ".wrl" files to be further processed with MATLAB®. Given a standard hand model, through the rotation of all needed joints it was possible to reproduce the

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grip position of interest. At the end of this process the hand models have been input to our in-house FDTD code for the actual electromagnetic simulation. The hand models have been properly scaled according to a hand anthropometric study [6], while their dielectric composition has been adjusted to comply with the homogeneous material properties described in [7].

IV. FDTD SIMULATIONS PARAMETERS AND GEOMETRIES

The used antenna was a dual-band PIFA (figure 2) operating over the GSM frequency ranges 880-960 MHz and 1710-1880 MHz. The handset's metallic ground plane was modeled as a PEC (Perfect Electric Conductor) box, of dimensions 8x40x100 mm. Several configurations were investigated to find tendencies concerning the user's impact on the variation of both mismatch and absorption loss at 900 and 1800 MHz.

In order to be consistent with current bar-type mobile phones antennas design, in some cases the antenna location was moved from the handset's back-top region to its back-bottom one.

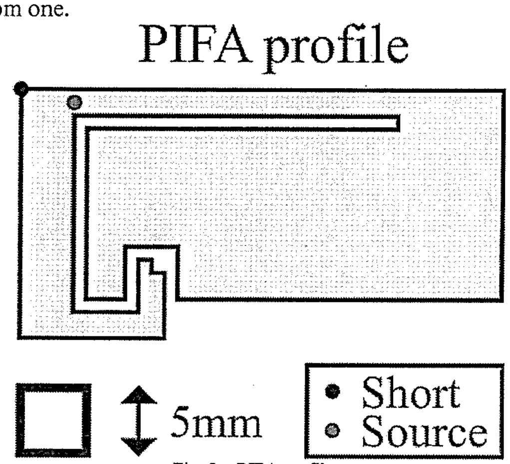

Fig. 2. PIFA profile.

The following issues were investigated:

A. Contribution of the SAM and the hand to the total loss.
B. Influence of the palm-handset gap variation.
C. Absorbed power distribution in different tissue regions
D. Influence of the index finger's location on the handset back-top region.

A. Contribution of the SAM and the hand to the total loss

In this section several configurations are investigated, using hand models 1-4 (figures 4-7) representing the "firm" and "soft" grip styles described in table I:

1. Handset in free space.
2. Handset with SAM.
3. Handset with hands 1-4.
4. Handset with hands 1-4 and SAM.

The handset's placement with respect to the SAM phantom (figure 3) was selected according to the standard right tilt position [8]. As we can see from figure 8, because of a shorter palm-handset gap, the "firm" grip hands contribute the most in determining the total loss. When only the SAM phantom is present the antenna placed on the handset's back-top region experience higher losses with respect to that placed at the bottom. This may be explained by the fact that the right tilt position implies a larger SAM-handset gap in the handset's back-bottom region. The SAM phantom alone is responsible for an absorption loss at 900 MHz up to 4dB.

By looking at the final configuration in which both SAM and hand models are included, a similar behavior is found, while the total absorption loss seems very similar to the sum of the hand and the SAM single contributions.

TABLE I
PHANTOM HANDS' DESCRIPTION

Hand	Grip style	Index finger's location
1	"Firm"	handset's side region
2	"Soft"	handset's side region
3	"Firm"	handset's back region
4	"Soft"	handset's back region

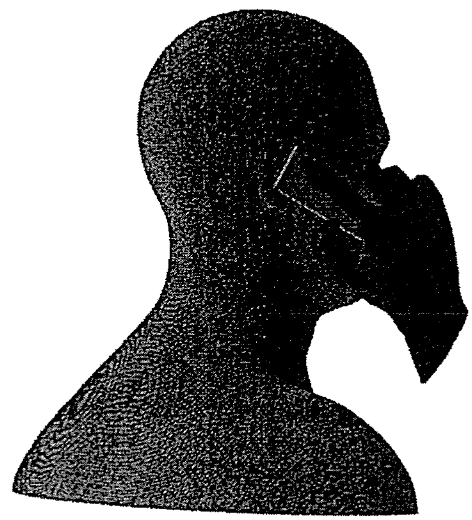

Fig. 3. Example of "firm" grip hand 3 next to the SAM phantom.

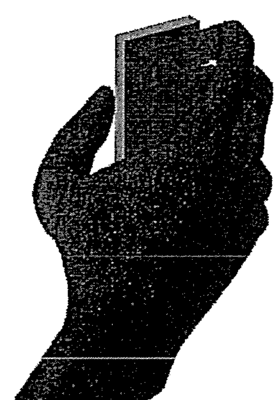

Fig. 4. Example of "firm" grip hand 1.

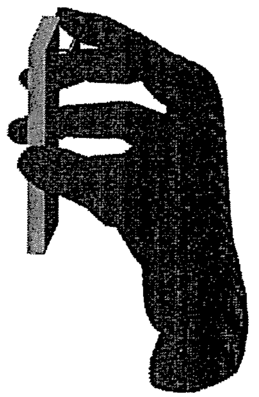

Fig. 5. Example of "soft" grip hand 2.

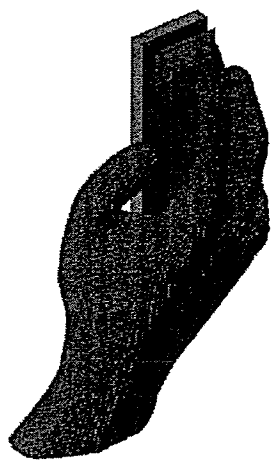

Fig. 6. Example of "firm" grip hand 3.

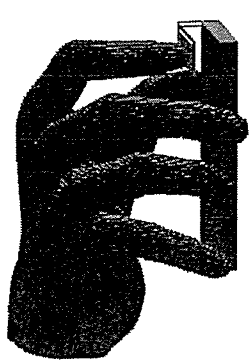

Fig. 7. Example of "soft" grip hand 4.

B. *Influence of the palm-handset gap variation*

As the antenna communication performances have been found to be strongly influenced by the air gap that separates the antenna from the palm of the hand, several palm-handset gaps were investigated ranging from 1mm (almost no gap) to 52mm (average thumb length [6]).

Figure 9 show the obtained simulation results: all losses decrease as the palm-handset gap increases as expected.

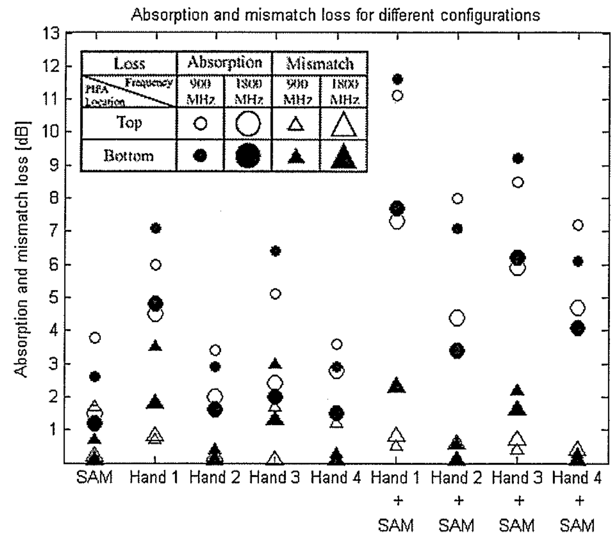

Fig. 8. Absorption and mismatch loss for different configurations.

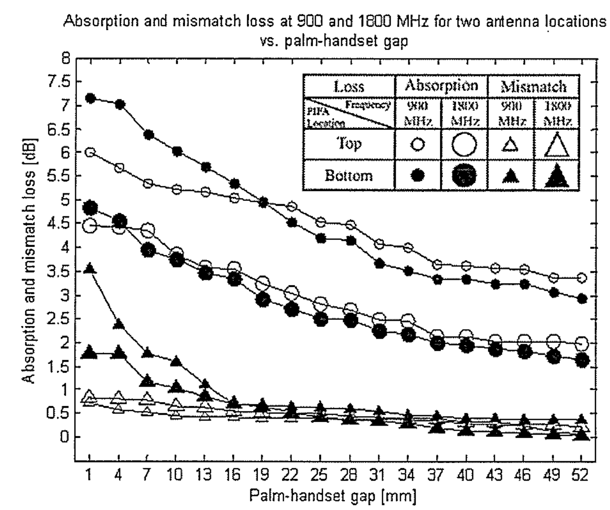

Fig. 9. Absorption and mismatch loss at 900 and 1800 MHz for two antenna locations vs. palm-handset gap.

Looking at absorption loss at 900 MHz we see that when the palm-handset gap is equal to 19mm, the curves representing the "top" and "bottom" PIFA location cross. This may be explained by the fact that at this point both antennas see an equivalent palm-handset gap.

Mismatch loss is higher when the PIFA location is the "bottom" one, and it decreases below 1dB when the palm-handset gap is larger than 16mm. Both absorption and mismatch loss are lower at 1800 MHz, where loss and detuning are less influenced by the hand. Absorption loss is always higher than mismatch loss, which does not exceed 1dB in most cases.

C. Absorbed power distribution in different tissue regions

In this section it was investigated the distribution of the absorbed power P_{Abs} in different tissue regions. Because of absorption loss, not all the antenna input power P_{In} is radiated, so that:

$$P_{In} = P_{Rad} + P_{Abs} \qquad (1)$$

Each FDTD cell gives its contribution in determining the total amount of absorbed power, so that in order to isolate the contribution of a single tissue region ρ with respect to the P_{Abs} , the individual contributions of each FDTD cell $P^{\rho}_{Abs}(i,j,k)$ have to be integrated over the corresponding volume V^{ρ} in the following way:

$$P^{\rho}_{Abs} = \sum_{(i,j,k)\in V^{\rho}} P^{\rho}_{Abs}(i,j,k) \qquad (2)$$

The individual absorbed power contributions of the following tissue regions were investigated: SAM, hand, palm, pinky, ring, middle, index, and thumb. The PIFA antenna location was changed as before on the handset's back region, calculating the P_{Abs} distribution at 900 MHz.

The following phantom hands (table I) and configurations were investigated:

1. Handset with hands 1-4.
2. Handset with hands 1-4 and SAM.

Looking at table II, we see that the middle and the index are the fingers which absorb most of the power.

When the SAM is included, the absorbed power distribution depends on the hand model. In fact when hands 1 ,3 are used, because of a shorter palm-handset gap more power is dissipated in the hand. In table III we see that when the antenna location is at the handset' bottom, this time more power is absorbed by the ring and middle fingers, as they are the ones closest to the antenna. Moreover also the power absorbed in the palm of the hand is larger than before.

TABLE II
ABSORBED POWER DISTRIBUTION FOR DIFFERENT TISSUE REGIONS AND CONFIGURATIONS

Configuration		Hand				Hand + SAM			
Antenna position		Top				Top			
Frequency		900 [MHz]				900 [MHz]			
Hand model		1	2	3	4	1	2	3	4
P^{ρ}_{Abs} [%]	SAM					43.0	73.2	25.6	35.4
	Hand	100.0	100.0	100.0	100.0	57.0	26.8	74.4	64.6
	Palm	60.4	54.8	35.0	47.4	35.7	14.5	21.5	26.4
	Pinky	4.0	7.0	0.2	4.3	1.9	2.0	0.1	2.2
	Ring	4.7	6.9	3.0	5.4	2.7	1.7	1.9	3.0
	Middle	18.0	16.1	1.2	6.2	7.9	5.1	0.7	2.9
	Index	11.0	14.5	58.0	35.6	7.6	3.4	48.7	29.6
	Thumb	1.9	0.7	2.6	1.1	1.2	0.1	1.5	0.5
Absorption loss [dB]		6.0	3.4	5.1	3.6	11.1	8.0	8.5	7.2

TABLE III
ABSORBED POWER DISTRIBUTION FOR DIFFERENT TISSUE REGIONS AND CONFIGURATIONS

Configuration		Hand				Hand + SAM			
Antenna position		Bottom				Bottom			
Frequency		900 [MHz]				900 [MHz]			
Hand model		1	2	3	4	1	2	3	4
P^{ρ}_{Abs} [%]	SAM					34.2	73.5	21.2	25.3
	Hand	100.0	100.0	100.0	100.0	65.8	26.5	78.8	74.7
	Palm	68.5	79.0	38.1	63.0	46.4	16.5	35.3	38.5
	Pinky	4.5	4.7	3.2	3.3	3.3	2.4	1.1	1.0
	Ring	7.5	2.8	4.2	4.0	5.4	2.3	3.5	2.9
	Middle	10.6	10.1	5.3	5.1	5.4	3.7	4.7	3.1
	Index	4.6	2.4	45.1	23.4	1.8	0.9	31.1	28.9
	Thumb	4.3	1.0	4.1	1.2	3.5	0.7	3.1	0.3
Absorption loss [dB]		7.1	2.9	6.4	2.9	11.6	7.1	9.2	6.1

Considering the configuration where only hands 3 and 4 are present (tables II, III), in the index finger alone more than 50% and 30% of the power is absorbed respectively. When the SAM is added, the index finger's impact is still very significant, so that more than 70% of the power is absorbed in the hand alone. All the previous results show that in some cases the index finger is the main responsible for absorption loss, while the overall hand impact is more important than the SAM.

D. Influence of the index finger's location on the handset back-top region

As stated before, the location of the index finger is very important when it gets close to the antenna region, as it strongly affects the antenna communication performances. The influence of the index finger's location on the back-top region of the handset was investigated for both "firm" and "soft" grip styles.

The position was varied in the antenna region in 50 different locations sampling the area every 4mm (figure 10), keeping always a constant 1mm gap between the tip of the index finger and the handset. By looking at figure 10, it can be seen how small changes in the index finger's location may affect both absorption and mismatch loss for the "firm" grip style case (hand 3). The behavior of the loss curves is influenced by the proximity of the index finger with the slots of the PIFA.

In fact concerning both absorption and mismatch loss at 1800 MHz, they decrease as the index fingers moves right, as a result of a larger distance from the vertical PIFA slot. An opposite tendency is found at 900 MHz, where the horizontal PIFA slot is now playing a role in the loss value. As the index location moves down, lower losses are found, and this may be explained because of a larger distance between the index finger and the short/source region. Concerning absorption loss, there is up to 2.7 dB range of variation between different index finger's locations, while mismatch loss exhibits minor dynamics. Similar results were found for the "soft" grip style, (hand 4) where an absorption loss range of variation up to 1.8 dB was found.

All the previous results imply that though a firm grip style may upper-bound both absorption and mismatch loss variation, the influence of the index finger's location is more difficult to predetermine.

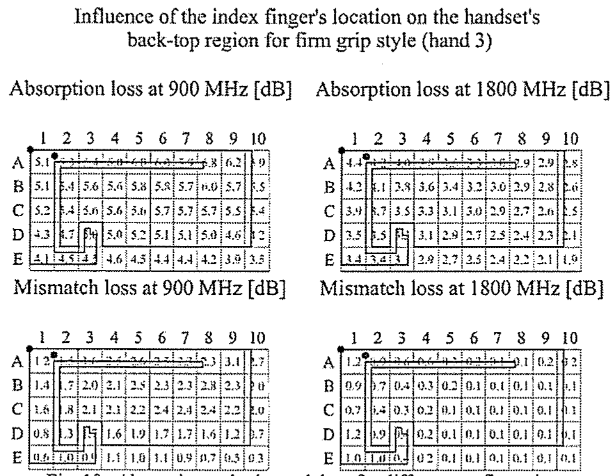

Fig. 10. Absorption and mismatch loss for different configurations.

V. CONCLUSION

In this paper, several CAD models have been realized according to a recent grip study [5], focusing on user's impact on both absorption and mismatch efficiency for talk mode in mobile phones. A GSM dual band PIFA antenna in two different handset's locations has been investigated.

The contributions of the SAM phantom and the hand to the total loss have been investigated, showing that when the "firm" grip model is used, the hand alone accounts for most of losses, while the SAM alone is responsible for an absorption loss at 900 MHz up to 4dB. The individual absorbed power contributions of several tissue regions were obtained, including the SAM, hand, palm and fingers.

Considering the configuration representing a firm grip style, when the index finger is located in the handset's back-top region it is responsible for more than 50% of the absorbed power. The middle and the index are the fingers which absorb most of the power. When the SAM is added, the index finger's impact is still very significant, so that more than 70% of the power is absorbed in the hand alone.

Several palm-handset gaps were investigated ranging from 1mm to 52mm, showing that absorption loss is always higher than mismatch loss, which does not exceed 1dB in most cases.

The influence of the index finger's location on the back-top region of the handset was investigated for both "firm" and "soft" grip styles in 50 different locations. The loss behavior is influenced by the proximity of the index finger with the slots of the PIFA. Concerning absorption loss, there is up to 3 dB range of variation between different index finger's locations on the handset's back-top region, while mismatch loss exhibits minor dynamics. All the previous results imply that though a firm grip style may upper-bound both absorption and mismatch loss variation, the influence of the index finger's location is more difficult to predetermine.

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