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Antenna Proximity Effects for Talk and Data Modes in Mobile Phones

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Abstract

Based on a recent study of the ways a phone is held (a grip study), CAD models of the human hand have been generated, and antenna proximity effects for both talk and data modes in mobile phones have been investigated using an FDTD code. The simulation results showed that the hand, and especially the index finger, exhibited a major contribution in determining the total loss when compared to the upper torso alone. The influence of the position of the fingers on the handset was found to be more important when close to the antenna. The palm-handset gap and the index-finger location were the main factors for both absorption and mismatch loss. Different data-mode hand phantoms and configurations were investigated, showing that both "overlapped" and "interlaced" grip styles similarly influenced the antenna's communication performance.

Keywords: Antenna proximity factors; antenna measurements; body loss; efficiency; FDTD methods; hand phantom; mobile antennas; land mobile radio cellular systems; land mobile radio equipment

1. Introduction

Recently, significant effort has been devoted to quantifying the interaction between wireless terminals and biological tissues. Beside possible health hazards, it is now apparent that the antenna's proximity to the human body has a detrimental effect on the communication performance of the handset.

The proximity of the user's body to the handset has several consequences, such as radiation-pattern deterioration [1], input-impedance variation, detuning of the resonance frequency, and increase in absorption loss [2]. While the contribution of the head is well understood, the impact of the hand is more complex to identify and isolate [3]. In the past, the absence of the hand in standard measurement guidelines has been partly justified for SAR (Specific Absorption Rate) investigations, considering that the overestimation of its value in the head is a conservative view [4, 5]. In fact, the presence of the human hand has been found to reduce the SAR value in the head, as part of the power is dissipated in the hand [6, 7]. Historically, the user's hand was at first represented by simple homogeneous block models [1]. Multilayered brick models [2, 6], consisting of both muscle and bone tissues, were then investigated. Simplified hand phantoms followed, including the presence of the thumb [8] or the index finger [9, 10]. In [11], heterogeneous hand phantoms with several tissues were obtained by magnetic-resonance (MR) scanning, while in [12] they were compared with their homogenous counterparts. With the evolution of both CAD and computational electromagnetics software, the generation of more-detailed hand phantoms [13, 14] become easier and more intuitive, so that both the human hand's anatomy and its ergonomics started to be included in many investigations [15].

The progressive literature migration from simplified to more-realistic hand phantoms originated from the common understanding that even small features of the hand could be significant when calculating the impact of the hand on the antenna's radiation performance. In fact, when the index finger touches the antenna region, both absorption loss and detuning dramatically increase [12], especially when internal antennas are used [16, 17]. The antenna's performance depends especially on the palm-phone distance [14, 18] and on the position of the index finger [12, 14], while wrist length, hand size, and tolerances in the material properties of hand phantoms have little impact [14]. Initial investigations on the impact of the user's hand on the performance of MIMO systems have shown that the position of the hand with respect to the handset may affect capacity [19, 20] and cause gain imbalance [21]. Surprisingly, nowadays, standards do not yet consider a specific "hand phantom," mainly because of the large number of grip positions and practical issues [22]. Although some standardization bodies [23] are already in an advanced stage in choosing proper hand phantoms, they are not based on grip studies [24].

A recent grip study [12] allowed investigating numerical hand phantoms that were representative of average use. The objec-

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tive of this work was to investigate, trough FDTD (Finite-Difference Time-Domain) methods, the antenna-proximity effects for talk and data modes in mobile phones. Four different antenna types were compared, focusing on both absorption and mismatch loss. The contribution of both the upper torso and the hand to the total loss was isolated by integrating the dissipated power in different tissue regions. Because an incorrect placement of a hand phantom with respect to the handset may affect the reproducibility of the measurements [3], the influence of the positioning of fingers on the handset side was also investigated. The influence of the palm-handset gap and the position of the index finger were studied. Moreover, several grip styles and configurations were investigated in data mode.

2. Grip Study Description

For the first time, a recent contribution [12] reported a grip study for both talk and data modes in mobile phones where a rigorous investigation methodology was used over a sample population of 100 subjects. Thanks to a proper investigation protocol and to an unobtrusive data-acquisition system, most of the experimental biases were minimized, allowing the collection of stable and comprehensive statistics. Concerning the choice of the form factor for the phones, it was decided to select the bar and shell form factors, as they are very popular, and they are different, radiation-wise. In the next section, some of the main results found in the aforementioned paper [12] are summarized.

2.1 Talk-Mode Results

The grip style was found to depend more on the phone's size rather than on its form factor, while the index finger was located in the back region of the handset in most cases. Two main ways of holding mobiles while talking were identified: these were named the "firm" and "soft" grip styles, respectively [12]. In the "firm" grip style, the fingers were placed around the handset (Figure 1), so that while the intermediate phalanges touched its side, the distal phalanges reached its front region, with a palm-handset gap that did not exceed the length of the longest proximal phalanx [12]. In the "soft" grip style, the hand held the handset only with the distal phalanges (Figure 2), creating an air gap between the palm and the handset that did not exceed the length of the thumb [12].

2.2 Data-Mode Results

It has been reported that most people use both hands while browsing or sending SMS (short message service), with the possibility of the hands being overlapped or interlaced [12]. While the right and left index fingers were used as anchors to grip the handset, the position of the other fingers was registered to be more unpredictable, as the other fingers tended to move while browsing [12].

3. CAD Numerical Models of the Phantom Hands

As a natural continuation of the grip study [12], all the most-significant grip positions were converted to CAD models, to be utilized in FDTD simulations. The hand-grip positions were modeled using the three-dimensional modeling tool *POSER*®, and were then exported as `.wrl` files, to be further processed with *MATLAB*®. Given a standard hand model, it was possible to reproduce the grip position of interest through the rotation of all needed joints. At the end of this process, the hand models were input into our in-house FDTD code for the actual electromagnetic simulation. The hand models were properly scaled according to a hand-anthropometric study [25], while their dielectric composition was adjusted to comply with the homogeneous material properties described in [26].

4. FDTD Simulations: Parameters and Geometries

In order to obtain more-general tendencies, several antennas with different features were used (Figure 5, Table 1). All antennas used were dual-band antennas, operating over the GSM frequency ranges of 880-960 MHz and 1710-1880 MHz. The handset's metallic ground plane was modeled as a PEC (perfect electric conductor) box of dimensions 8 × 40 × 100 mm. A cell size of 1 mm was chosen for the FDTD simulations.

5. Talk-Mode Simulations

Several configurations were investigated, to find tendencies concerning the effects of the user's hand proximity for talk mode on the communication performance of a bar-type mobile phone. The main focus was on the efficiency variations of several dual-band antennas, looking at both mismatch and absorption loss at 900 and 1800 MHz. In order to be consistent with antenna designs of current bar-type mobile phones, in some cases, the antenna's location was moved from the handset's back-top region to its back-bottom region.

For our investigations, the SAM (Specific Anthropomorphic Mannequin) upper-torso phantom [27] was used, as this is commonly used for performance testing of handheld devices. The handset's placement with respect to the SAM phantom was selected according to the standard right tilt position (Figure 6) [27]. In order to better isolate the influence of the user's hand, the SAM phantom was not included in some investigations. The following issues were investigated:

1. The contribution of the SAM phantom and the hand to the total loss.
2. The absorbed power distribution in different tissue regions.
3. The influence of the positioning of the fingers on the handset's side region.
4. The influence of the variation in the palm-handset gap.

Table 1. Descriptions of the antennas.

Antenna	Type
1	PIFA (Planar Inverted-F Antenna)
2	FICA (Folded Inverted Conformal Antenna)
3	PIFA with substrate $\varepsilon_r = 3$
4	ILA (Inverted-L Antenna)

Figure 1. An example of the "firm" grip Hand 1 plus Antenna 3.

Figure 3. An example of the "firm" grip Hand 3 plus Antenna 2.

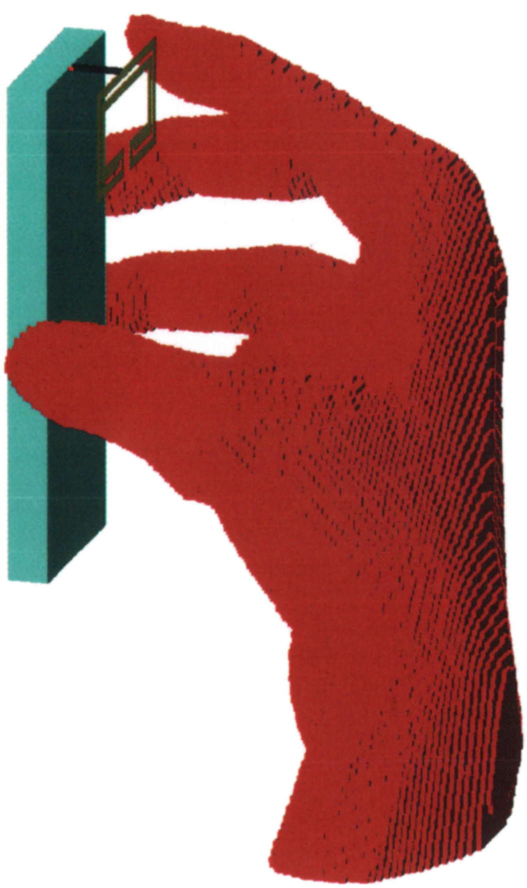


Figure 2. An example of the "soft" grip Hand 2 plus Antenna 2.

Table 2. Descriptions of the phantom hands.

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

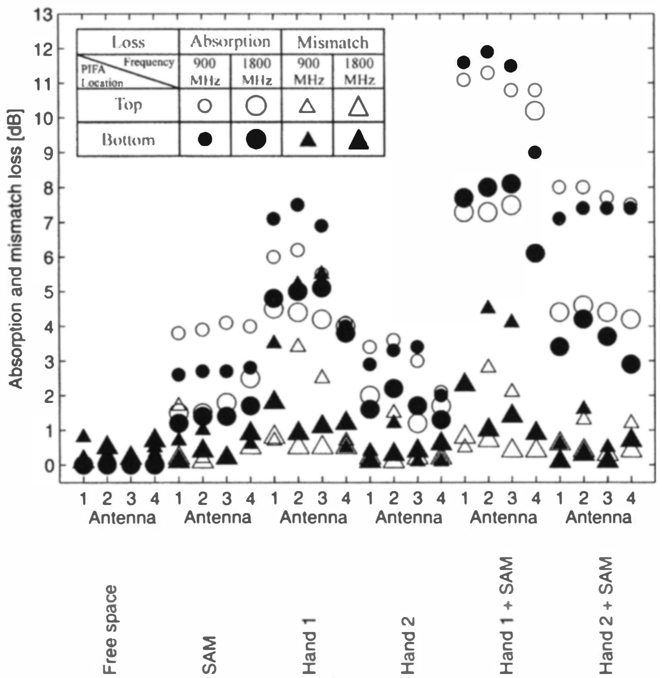


Figure 7. The absorption and mismatch losses for different antennas and configurations.

5. The influence of the index finger's location on the handset's back-top region.

5.1 Contribution of the SAM Phantom and the Hand to the Total Loss

In this section, several configurations were investigated, using hand models 1 and 2 (Figures 1 and 2), representing the "firm" and "soft" grip styles described in Table 2:

1. The handset in free space.

2. The handset with the SAM.

3. The handset with Hands 1 and 2.

4. The handset with Hands 1, 2, and the SAM.

As can be seen from Figure 7, the "firm" grip hand contributed the most in determining the total loss. When only the SAM phantom was present, the antennas placed on the handset's back-top region experienced higher losses with respect to those 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. All of the antennas showed similar tendencies, and the SAM phantom alone was responsible for an absorption loss at 900 MHz up to 4 dB. When the hand was included, the "firm" grip configuration experienced higher losses than the "soft" grip configuration, caused by the smaller palm-handset gap. By looking at the final configuration in which both SAM and hand models were included, a similar behavior was found, while the total absorption loss seemed very similar to the sum of the single contributions from the hand and the SAM.

In order to better comprehend the loss phenomenon, in the next section is a description of how the distribution of the absorbed power among different tissue regions was investigated.

5.2 Absorbed Power Distribution in Different Tissue Regions

In this section, a description is given of how the distribution of the absorbed power, P_{Abs}, in different tissue regions was investigated. Because of absorption loss, not all of the antenna's input power, P_{In}, is radiated, so that

$$P_{In} = P_{Rad} + P_{Abs}. \tag{1}$$

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, $P_{Abs}^{\rho}(i,j,k)$, have to be integrated over the corresponding volume, V^{ρ}, in the following way:

$$P_{Abs}^{\rho} = \sum_{(i,j,k)\in V^{\rho}} P_{Abs}^{\rho}(i,j,k). \tag{2}$$

The individual absorbed-power contributions of the following tissue regions were investigated: the SAM, the hand, the palm, the pinky finger, the ring finger, the middle finger, the index finger, and the thumb. Four different antennas were used, changing their locations on the handset's back region, and calculating the P_{Abs} distribution at 900 MHz.

The following phantom hands (Figures 1-4, Table 2) and configurations were investigated:

1. Handset with Hands 1-4.

2. Handset with Hands 1-4 and the SAM.

Looking at Table 3, it can be seen that although the PIFA/FICA (planar inverted-F antenna/folded inverted conformal antenna) types of antennas follow a similar trend, the ILA (inverted-L antenna) exhibited a larger deviation. This may be explained by the fact that it had a significantly different near-field distribution relative to the other antennas. The middle finger and the index finger are the fingers that absorbed most of the power. When the SAM was included, the absorbed power distribution depended on the hand model. In fact, when Hand 1 was used, because of a shorter palm-handset gap, more power was dissipated in the hand.

In Table 4, it can be seen that when the antenna's location was at the handset's bottom, more power was absorbed that time by the ring and middle fingers, as they are the fingers closest to the antenna. Moreover, the power absorbed in the palm of the hand was also larger than before, since this was the tissue region closest

Table 3. The absorbed power distributions at 900 MHz for Hands 1 and 2, for the "top" antenna location.

Configuration		Hand								Hand + Sam							
Hand		1				2				1				2			
Antenna		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
P^{ρ}_{Abs} (%)	SAM	–	–	–	–	–	–	–	–	43.0	42.5	46.3	43.7	73.2	71.3	75.3	82.9
	Hand	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	57.0	57.5	53.7	56.3	26.8	28.7	24.7	17.1
	Palm	60.4	59.4	60.7	81.2	54.8	75.8	75.2	80.5	35.7	34.6	34.7	43.1	14.5	15.4	13.2	11.7
	Pinky	4.0	4.2	4.0	1.2	7.0	3.7	4.1	5.0	1.9	2.1	1.7	0.3	2.0	2.0	1.9	1.6
	Ring	4.7	4.5	4.8	3.5	6.9	3.4	4.3	2.7	2.7	2.7	2.6	2.8	1.7	1.6	1.7	0.7
	Middle	18.0	19.9	17.2	5.5	16.1	11.7	11.4	8.2	7.9	9.7	6.6	5.2	5.1	5.8	4.6	2.2
	Index	11.0	10.7	10.4	4.0	14.5	5.2	4.8	3.1	7.6	7.6	6.5	3.6	3.4	3.8	3.2	0.6
	Thumb	1.9	1.3	2.9	4.6	0.7	0.2	0.2	0.5	1.2	0.8	1.6	1.3	0.1	0.1	0.1	0.3
Absorp. Loss [dB]		6.0	6.2	5.5	4.1	3.4	3.6	3.0	2.1	11.1	11.3	10.8	10.8	8.0	8.9	7.7	7.5

Table 4. The absorbed power distribution at 900 MHz for Hands 1 and 2, "bottom" antenna location.

Configuration		Hand								Hand + SAM							
Hand		1				2				1				2			
Antenna		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
P^{ρ}_{Abs} (%)	SAM	–	–	–	–	–	–	–	–	34.2	34.7	34.9	26.9	73.5	72.0	74.4	76.0
	Hand	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	65.8	65.3	65.1	73.1	26.5	28.0	25.6	24.0
	Palm	68.5	67.1	69.8	87.3	79.0	77.8	79.3	81.9	46.4	44.9	46.9	66.4	16.5	16.6	16.5	16.2
	Pinky	4.5	4.7	4.1	0.6	4.7	6.7	3.9	3.3	3.3	3.5	3.1	0.5	2.4	3.5	2.0	1.5
	Ring	7.5	7.5	7.2	2.0	2.8	3.5	2.5	1.2	5.4	5.6	5.0	1.4	2.3	2.7	2.0	0.6
	Middle	10.6	10.8	10.3	4.4	10.1	8.9	10.7	8.9	5.4	5.6	5.0	1.5	3.7	3.7	3.6	3.8
	Index	4.6	4.9	4.3	1.4	2.4	2.4	2.4	2.8	1.8	2.0	1.6	1.0	0.9	1.0	0.8	1.0
	Thumb	4.3	5.0	4.3	4.3	1.0	0.7	1.2	1.9	3.5	3.7	3.5	2.3	0.7	0.5	0.7	0.9
Absorp. Loss [dB]		7.1	7.5	6.9	4.0	2.9	3.3	3.4	2.0	11.6	11.9	11.5	9.0	7.1	7.5	7.6	6.5

Table 5. The absorbed power distribution at 900 MHz for Hands 3 and 4, "top" antenna location.

Configuration		Hand								Hand + SAM							
Hand		3				4				3				4			
Antenna		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
P^{ρ}_{Abs} (%)	SAM	–	–	–	–	–	–	–	–	25.6	25.9	30.2	28.2	35.4	37.3	35.0	46.7
	Hand	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	74.4	74.1	69.8	71.8	64.6	62.7	65.0	53.3
	Palm	35.0	36.9	36.0	74.9	47.4	49.4	46.1	46.1	21.5	23.0	20.2	56.3	26.4	27.0	25.4	22.3
	Pinky	0.2	0.2	0.1	0.2	4.3	4.5	4.2	3.9	0.1	0.1	0.1	0.1	2.2	2.3	2.1	1.6
	Ring	3.0	3.0	3.1	0.3	5.4	5.2	5.6	4.5	1.9	2.0	1.8	0.2	3.0	2.9	3.0	2.4
	Middle	1.2	1.2	1.3	1.1	6.2	6.0	6.3	3.3	0.7	0.8	0.7	1.1	2.9	2.9	2.8	0.9
	Index	58.0	56.0	56.8	17.2	35.6	33.7	36.7	41.2	48.7	46.7	45.6	9.1	29.6	27.0	31.2	25.3
	Thumb	2.6	2.7	2.7	6.3	1.1	1.2	1.1	1.0	1.5	1.5	1.4	5.0	0.5	0.6	0.5	0.8
Absorp. Loss [dB]		5.1	4.7	4.5	2.5	3.6	3.7	3.4	2.3	8.5	8.3	8.1	7.3	7.2	7.1	7.4	7.3

Table 6. The absorbed power distribution at 900 MHz for Hands 3 and 4, "bottom" antenna location.

Configuration		Hand								Hand + SAM							
Hand		3				4				3				4			
Antenna		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
P^{ρ}_{Abs} (%)	SAM	–	–	–	–	–	–	–	–	21.2	21.7	21.9	20.2	25.3	25.5	24.2	19.7
	Hand	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	78.8	78.3	78.1	79.8	74.7	74.5	75.8	80.3
	Palm	38.1	37.5	38.6	77.2	63.0	62.9	63.4	67.1	35.3	33.4	35.8	64.3	48.5	47.2	48.9	58.7
	Pinky	3.2	3.5	2.9	0.9	3.3	4.1	3.1	2.8	1.1	1.2	0.9	0.4	1.0	1.2	0.9	0.6
	Ring	4.2	4.5	4.1	3.0	4.0	4.5	3.7	2.9	3.5	3.6	3.1	2.2	2.9	3.2	2.7	1.5
	Middle	5.3	5.5	5.0	3.1	5.1	4.8	5.2	4.7	4.7	4.8	4.3	1.7	3.1	2.8	3.3	2.3
	Index	45.1	44.7	45.0	13.8	23.4	22.7	23.3	19.8	31.1	31.7	31.9	9.7	18.9	19.3	19.6	16.0
	Thumb	4.1	4.3	4.4	2.0	1.2	1.0	1.3	2.7	3.1	3.6	2.1	1.5	0.3	0.8	0.4	1.2
Absorp. Loss [dB]		6.4	6.1	6.3	4.1	2.9	3.4	3.3	2.1	9.2	9.0	8.8	7.3	6.1	6.4	6.2	5.0

to the antenna. Considering the configuration where only Hands 3 and 4 were present (Tables 5 and 6), more than 50% and 30% of the power, respectively, was absorbed in the index finger, alone. When the SAM was added, the index finger's impact was still very significant, so that more than 70% of the power was absorbed in the hand, alone.

All of the previous results showed that in some cases, the index finger was the main tissue responsible for absorption loss, while the impact of the overall hand was more important than that of the upper torso. In order to better identify the influence of the hand, in the following sections, the SAM phantom was not present, as the previous findings showed that it would only result in an additive loss.

5.3 Influence of Positioning of Fingers on the Handset's Side Region

In this section, the influence of the position of the fingers with respect to the handset's side was investigated. While varying the fingers' positions, the palm-handset gap was kept fixed, considering both the soft and firm grip styles (Hands 1 and 2). Several configurations were simulated where the position of the fingers was permuted along the handset's side in 15 different locations. The antenna's location was also changed from the back-top to the back-bottom region of the handset. Tables 7 and 8 show statistics concerning the simulation results, displaying both the mean and range values of absorption and mismatch loss at 900 and 1800 MHz. The highest losses were found in the "firm"-grip-style case. The maximum loss was reached when the antennas were at the bottom, where the palm-handset gap showed its strongest influence. In the "soft" grip style, the antennas placed on the top "saw" a more minor gap than did the "bottom" antennas, so that – surprisingly – this time, the latter experienced less losses. It should be noted that in most cases the absorption and mismatch loss range was less than 1.0 dB and 0.5 dB, respectively. The higher range in the "firm"-grip-style case was due to those configurations where the index finger was in the handset's side-top region, as this contributed to a further increase in the effect of the palm-handset gap. This means that the position of the fingers was less important if the index finger was not in the handset's side-top region, implying that the main issues were the palm-handset gap and the index finger's location.

5.4 Influence of the Palm-Handset Gap Variation

The antenna's communication performance has been previously found to be strongly influenced by the air gap that separates the antenna from the palm of the hand.

This is even more evident when the antenna was located in the back-bottom region of the handset. As stated in the grip study [5], most of the users hold bar-type phones with a firm grip that

Table 7. The statistics on the positioning of the fingers. Both the mean and range values of the absorption loss were calculated over 15 permutations of the positions of the fingers on the handset's side.

			Antenna							
			1		2		3		4	
Loss			Absorption		Absorption		Absorption		Absorption	
Hand Type	Antenna Location	f [MHz]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]
1	Top	900	5.5	0.7	5.8	0.7	4.0	1.0	5.0	0.8
1	Top	1800	4.5	0.5	4.4	1.7	3.8	0.6	4.3	0.6
1	Bottom	900	7.0	2.6	7.3	0.5	6.3	1.1	7.1	0.4
1	Bottom	1800	5.0	2.7	5.0	0.7	6.4	1.3	5.2	1.5
2	Top	900	3.3	1.3	3.8	2.5	1.9	0.5	2.8	1.7
2	Top	1800	1.9	1.0	2.4	1.8	1.5	0.5	1.8	1.4
2	Bottom	900	2.9	0.8	3.1	0.8	3.1	1.4	2.7	0.8
2	Bottom	1800	1.7	0.2	2.2	0.9	1.6	0.4	1.7	0.2

Table 8. The statistics on the positioning of the fingers. Both the mean and range values of the mismatch loss were calculated over 15 permutations of the positions of the fingers on the handset's side.

			Antenna							
			1		2		3		4	
Loss			Mismatch		Mismatch		Mismatch		Mismatch	
Hand Type	Antenna Location	f [MHz]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]	Mean [dB]	Range [dB]
1	Top	900	0.3	0.4	2.4	1.2	0.5	0.2	1.5	0.8
1	Top	1800	0.5	0.3	0.2	0.2	0.3	0.3	0.2	0.2
1	Bottom	900	4.3	1.8	5.7	1.5	1.5	1.0	6.0	2.0
1	Bottom	1800	1.6	0.6	1.6	1.8	0.3	0.2	1.2	1.0
2	Top	900	0.4	0.4	2.2	3.2	0.3	0.4	0.6	0.6
2	Top	1800	0.2	0.2	0.5	0.9	0.5	0.2	0.1	0.4
2	Bottom	900	0.5	0.5	1.2	0.9	0.1	0.2	0.3	0.3
2	Bottom	1800	0.1	0.1	0.4	0.4	0.5	0.3	0.1	0.1

Figure 4. An example of the "soft" grip Hand 4 + Antenna 2.

Figure 6. An example of the hand phantom next to the SAM upper-torso phantom.

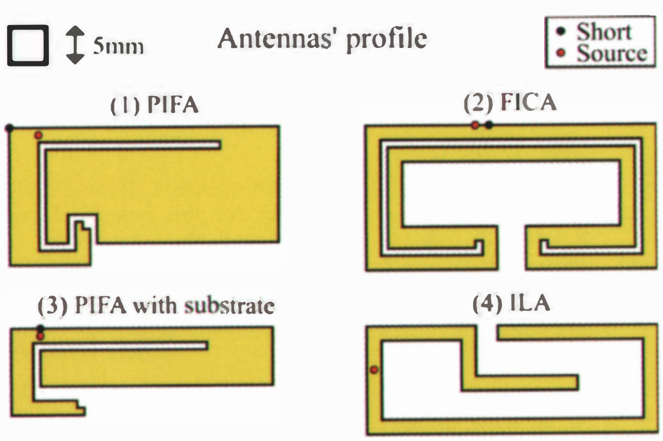


Figure 5. The profiles of the antennas.

implies a palm-handset gap not larger than the longest proximal phalanx. This gap increased when the fingers started to contact the handset mostly in its side region, becoming progressively a soft-grip style. For all these reasons, several palm-handset gaps were investigated, ranging from 1 mm (almost no gap) to 52 mm (average thumb length). Figures 8-11 show the simulation results obtained for different antennas: all losses decreased as the palm-handset gap increased, as expected. Looking at absorption loss at 900 MHz in Figure 8, it can be seen that when the palm-handset gap was equal to 19 mm, the curves representing the "top" and "bottom" PIFA locations crossed. This may be explained by the fact that at this point, both antennas "saw" an equivalent palm-handset gap. The mismatch loss was higher when the PIFA location was the "bottom" location, and it decreased below 1 dB when the palm-handset gap was larger than 16 mm. Both absorption and mismatch loss were lower at 1800 MHz, where the loss and detuning were less influenced by the hand. Absorption loss was always higher than mismatch loss, which did not exceed 1 dB in most cases. As can be seen in Figures 8-10, a similar trend was also observed for the PIFA/FICA types of antennas, while the ILA type

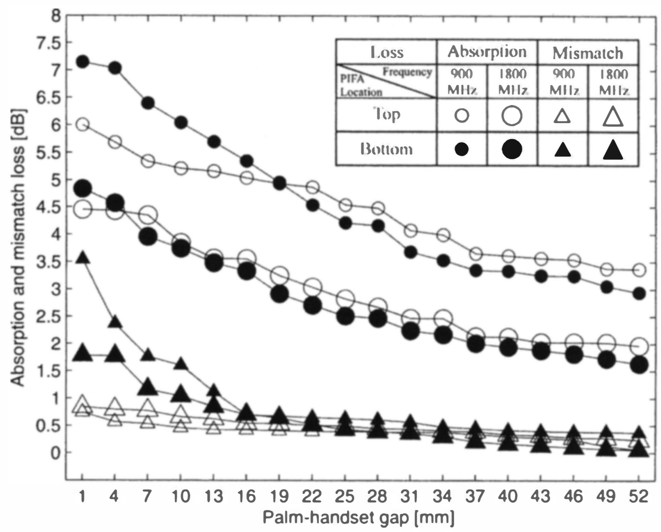


Figure 8. The absorption and mismatch losses at 900 and 1800 MHz for two antenna locations as a function the palm-handset gap, for Antenna 1 (PIFA).

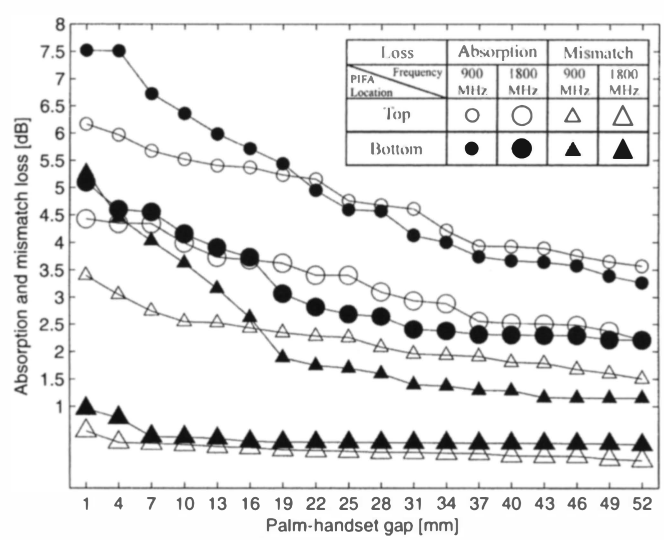


Figure 9. The absorption and mismatch losses at 900 and 1800 MHz for two antenna locations as a function of the palm-handset gap, for Antenna 2 (FICA).

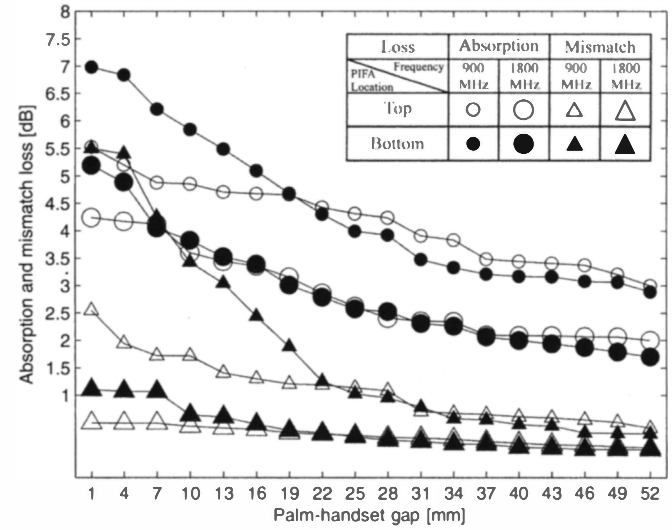


Figure 10. The absorption and mismatch loss at 900 and 1800 MHz for two antenna locations as a function of the palm-handset gap, for Antenna 3 (PIFA with substrate).

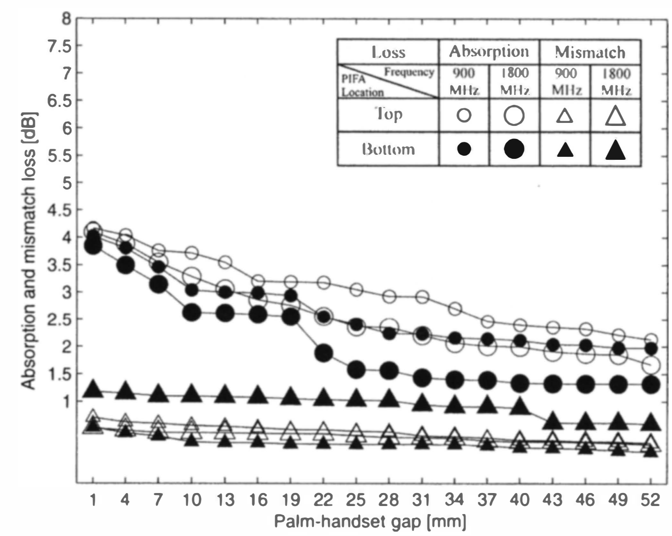


Figure 11. The absorption and mismatch loss at 900 and 1800 MHz for two antenna locations as a function of the palm-handset gap, for Antenna 4 (ILA).

experienced lower losses (Figure 11). This may be explained by the fact that this type of antenna had a larger amount of "open space" available.

5.5 Influence of the Index Finger's Location on the Handset's Back-Top Region

As stated before, the location of the index finger was very important when it got close to the region of the antenna, as it strongly affected the antenna's communication performance. 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 region of the antenna in 50 different locations, sampling the area every 4 mm (Figure 12), always keeping a constant 1 mm gap between the tip of the index finger and the handset's back. By looking at Figure 12, it can be seen how small

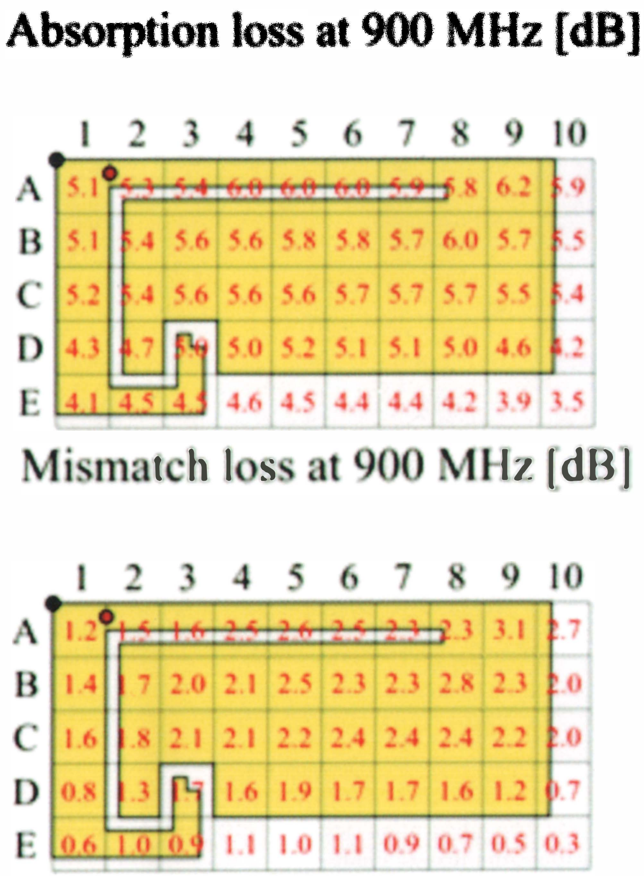


Figure 12a. The absorption and mismatch losses at 900 MHz as a function of the index finger's location on the handset's back-top region for the "firm" grip style, Antenna 1 (PIFA).

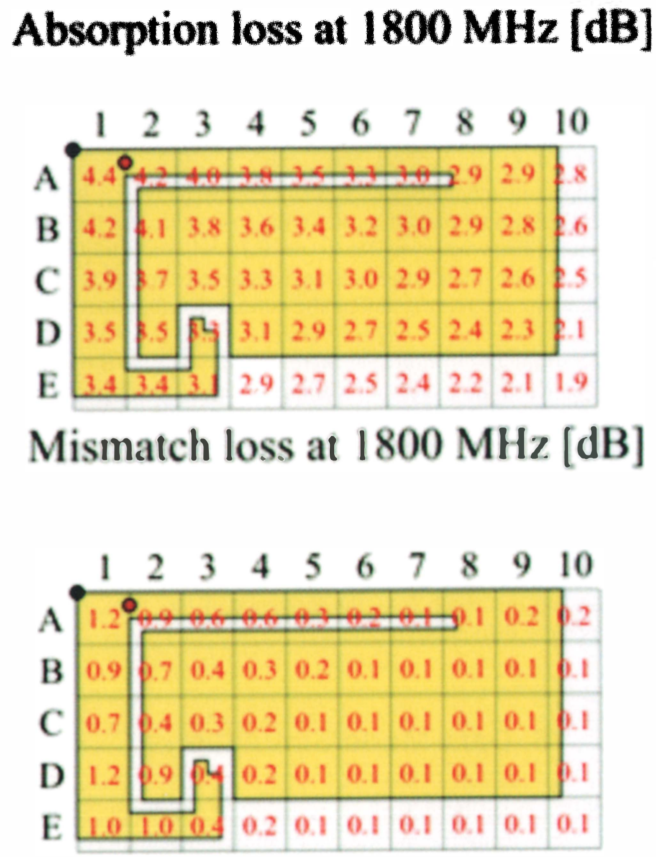


Figure 12b. The absorption and mismatch losses at 1800 MHz as a function of the index finger's location on the handset's back-top region for the "firm" grip style, Antenna 1 (PIFA).

Figure 13. An example of the "overlapped" and "interlaced" grip styles for data-mode hand phantoms.

changes in the index finger's location can affect both absorption and mismatch loss for the "firm"-grip-style case. The behavior of the loss curves was influenced by the proximity of the index finger to the slots of the PIFA. In fact, both absorption and mismatch loss at 1800 MHz decreased as the index fingers moved right, as a result of a larger distance from the vertical PIFA slot.

An opposite tendency was found at 900 MHz, where the horizontal PIFA slot now played a role in the loss value. As the index location moved down, lower losses were found, and this may be explained because of a larger distance between the index finger and the short/source region, and by the current distribution.

Concerning absorption loss, there was up to a 2.7 dB range of variation between the different locations of the index finger, while mismatch loss exhibited minor dynamics. Similar results were found for the "soft"-grip style, where a variation in loss range of up to 1.8 dB was found. Concerning the other antenna types, they were affected in nearly the same way as the changes in index-finger location. All the previous results implied that although a firm grip style may produce the upper bound in variation of both absorption and mismatch loss, the influence of the index finger's location is more difficult to predict.

6. Data-Mode Simulations

In this section investigations of the effects of the presence of the hands while using the mobile phone in data mode are reported. The phantom-hand models were generated following the guidelines of the aforementioned grip study [5], focusing on the "both hands" grip style. Several configurations were investigated, including both "overlapped" and "interlaced" grip styles (Figure 13). It studied the effect of the individual contributions of the right and the left hands to the total absorption loss were also studied, comparing different antennas and configurations.

6.1 Contribution of the Right and Left Hands to the Total Absorption Loss

As displayed in Figure 14, all the antennas showed nearly similar tendencies. It can be seen that the right hand gave the major contribution in determining the total absorption loss. This behavior may be explained by the fact that the left-hand location with respect to the handset exhibited a larger distance from the antenna, thus reducing its impact on the absorption loss. Moreover, the configurations including both hands exhibited an absorption loss very correlated to the sum of the single right- and left-hand contributions. The "overlapped" and "interlaced" grip styles showed a similar impact concerning absorption loss. This suggested that the impact of the total mass of the hands is more important than the exact location of the fingers, as long as they are not in close proximity to the antenna.

When the antennas were placed at the bottom of the handset, they experienced a larger amount of absorption loss. This may be explained by a smaller palm-handset gap, thus resulting in proximity to a larger tissue region. All the previous results suggested that when considering the data mode, only the fingers in close proximity to the antenna and the surrounding total amount of lossy tissue give a significant contribution. This means that it is possible to relax some design constraints. The configuration of a proper hand phantom may be equivalent to a plethora of grip styles that – despite being topologically different – influence the handset's communication performance in a very similar way.

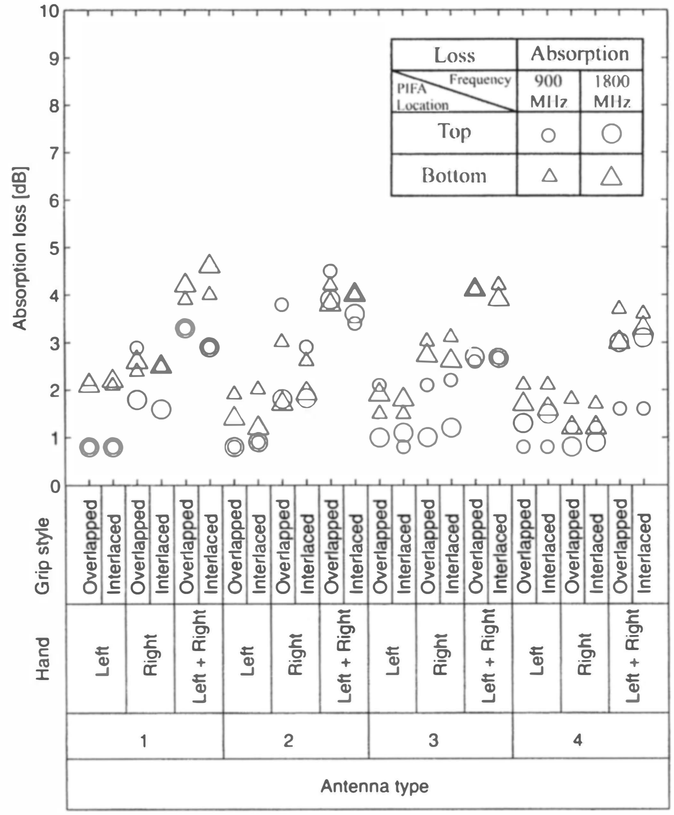


Figure 14. The absorption loss for different antennas and configurations in the data mode.

7. Conclusions

In this paper, several CAD models of phantom hands were generated according to a recent grip study, focusing on antenna-proximity effects for talk and data modes in mobile phones. Four different dual-band antennas were investigated, looking at both absorption and mismatch loss. The contributions of the SAM (Specific Anthropomorphic Mannequin)phantom and the hand to the total loss were studied. This showed that when the "firm" grip model was used, the hand alone accounted for most of losses, while the SAM alone was responsible for an absorption loss up to 4 dB at 900 MHz. The individual absorbed-power contributions of several tissue regions were investigated, including the SAM, hand, palm, and fingers. Considering the configuration representing a firm grip style, when the index finger was located in the handset's back-top region, it was responsible for more than 50% of the absorbed power. The middle and the index fingers were the fingers that absorbed most of the power. When the SAM was added, the index finger's impact was still very significant, so that more than 70% of the power was absorbed in the hand alone.

The influence of the positioning of the fingers with respect to the handset's sides was also investigated. Several configurations were simulated, permuting the position of the finger along the handset's side in 15 different locations. This showed that in most cases, the absorption and mismatch loss range was less than 1.0 dB and 0.5 dB, respectively. The higher range in the "firm" grip style case was due to those configurations where the index finger was in the handset's side-top region. The position of the index finger was less important if it was not in the side-top region of the handset, suggesting that the main issues are the palm-handset gap and the index finger's location. Several palm-handset gaps were investigated, ranging from 1 mm (almost no gap) to 52 mm (thumb length). Absorption loss was always higher than mismatch loss, which did not exceed 1 dB 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 was influenced by the proximity of the index finger to the slots of the PIFAs/FICAs (planar inverted-F antennas/folded inverted conformal antennas), affecting the ILA's (inverted-L antenna's) arms, as well. Concerning absorption loss, there was up to a 3 dB range of variation among different locations of the index finger on the handset's back-top region, while mismatch loss exhibited minor dynamics. All the previous results implied that although a firm grip style may be the upper bound for both absorption and mismatch loss variation, the influence of the index finger's location is more difficult to predict. Concerning the data mode, it has been shown that only the fingers in close proximity to the antenna and the surrounding total amount of lossy tissue give a significant contribution to determining the total amount of absorption loss.

8. References

1. J. Toftgard, S. N. Hornsleth, and J. B. Andersen, "Effects on Portable Antennas of the Presence of a Person," *IEEE Transactions on Antennas and Propagation*, **AP-41**, 6, June 1993, pp. 739-746.

2. M. A. Jensen and Y. Rahmat-Samii, "EM Interaction of Handset Antennas and a Human in Personal Communications," *Proceedings of the IEEE*, **83**, 1, January 1995, pp. 7-17.

3. J. Krogerus, J. Toivanen, C. Icheln, and P. Vainikainen, "Effect of the Human Body on Total Radiated Power and the 3-D Radiation Pattern of Mobile Handsets," *IEEE Transactions on Instrumentation and Measurement*, **IMS-56**, 6, December 2007, pp. 2375-2385.

4. Human Exposure to Radio Frequency Fields from Hand-Held and Body-Mounted Wireless Communication Devices – Human Models, Instrumentation, and Procedures – Part 1: Procedure to Determine the Specific Absorption Rate (SAR) for Hand-Held Devices Used in Close Proximity to the Ear (Frequency Range of 300 MHz to 3 GHz), IEC 62209-1, 2005.

5. N. Kuster, R. Kastle, and T. Schmid, "Dosimetric Evaluation of Handheld Mobile Communications Equipment with Known Precision," *IEICE Transactions on Communications*, **80-B**, 5, May 1997, pp. 645-652.

6. M. Okoniewski and M. A. Stuchly, "A Study of the Handset Antenna and Human Body Interaction," *IEEE Transactions on Microwave Theory and Techniques*, **MTT-44**, 10, October 1996, pp. 1855-1864.

7. O. P. Gandhi, "Some Numerical Methods for Dosimetry: Extremely Low Frequencies to Microwave Frequencies," *Radio Science*, **30**, 1995, pp. 161-177.

8. S. I. Watanabe, H. Taki, T. Nojima, and O. Fujiwara, "Characteristics of the SAR Distributions in a Head Exposed to Electromagnetic Fields Radiated by a Hand-Held Portable Radio," *IEEE Transactions on Microwave Theory and Techniques*, **MTT-44**, 10, October 1996, pp. 1874-1883.

9. J. Graffin, N. Rots, and G. F. Pedersen, "Radiation Phantoms for Handheld Phones," Proceedings of the IEEE Vehicular Technology Conference, Boston, MA, September 2000, pp. 853-860.

10. K. R. Boyle, Y. Yuan, and L. P. Ligthart, "Analysis of Mobile Phone Antenna Impedance Variations With User Proximity," *IEEE Transactions on Antennas and Propagation*, **AP-55**, 2, February 2007, pp. 364-372.

11. M. Francavilla, A. Schiavoni, P. Bertotto, and G. Richiardi, "Effect of the Hand on Cellular Phone Radiation," *IEE Proceedings on Microwaves, Antennas and Propagation*, **148**, 4, August 2001, pp. 247-253.

12. M. Pelosi, O. Franek, M. B. Knudsen, M. Christensen, and G. F. Pedersen, "A Grip Study for Talk and Data Modes in Mobile Phones," *IEEE Transactions on Antennas and Propagation*, **AP-57**, 4, April 2009, pp. 856-865.

13. N. Chavannes, P. Futter, R. Tay, K. Pokovic, and N. Kuster, "Reliable Prediction of Mobile Phone Performance for Different Daily Usage Patterns Using the FDTD Method," 2006 IEEE International Workshop on Antenna Technology Small Antennas and Novel Metamaterials, March 2006, pp. 345-348.

14. L. Chung-Huan, E. Ofli, N. Chavannes, and N. Kuster, "The Effects of Hand Phantom on Mobile Phone Antenna OTA Performance," EuCAP 2007: The Second European Conference on Antennas and Propagation, November 11-16, 2007, pp. 1-5.

15. T. Huang and K. R. Boyle, "User Interaction Studies on Handset Antennas," EuCAP 2007: The Second European Conference on Antennas and Propagation, November 11-16, 2007, pp. 1-6.

16. K. Ogawa and T. Matsuyoshi, "An Analysis of the Performance of a Handset Diversity Antenna Influenced by Head, Hand, and Shoulder Effects at 900 MHz I. Effective Gain Characteristics," *IEEE Transactions on Vehicular Technology*, **50**, 3, May 2001, pp. 830-844.

17. K. Ogawa, T. Matsuyoshi, and K. Monma, "An Analysis of the Performance of a Handset Diversity Antenna Influenced by Head, Hand, and Shoulder Effects at 900 MHz II. Correlation Characteristics," *IEEE Transactions on Vehicular Technology*, **50**, 3, May 2001, pp. 845-853.

18. O. Kivekas, J. Ollikainen, T. Lehtiniemi, and P. Vainikainen, "Bandwidth, SAR, and Efficiency of Internal Mobile Phone Antennas," *IEEE Transactions on Electromagnetic Compatibility*, **46**, 1, February 2004, pp. 71-86.

19. A. Michalopoulou, T. Zervos, K. Peppas, A. A. Alexandridis, F. Lazarakis, K. Dangakis, and D. I. Kaklamani, "The Impact of the Position of MIMO Terminal User's Hand on Channel Capacity," IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, 2007. September 3-7, 2007, pp. 1-5.

20. T. Zervos, K. Peppas, F. Lazarakis, A. A. Alexandridis, K. Dangakis, and C. Soras, "Channel Capacity Evaluation for a Multiple-Input Multiple-Output Terminal in the Presence of User's Hand," *IET Proceedings on Microwaves, Antennas & Propagation*, **1**, 6, December 2007, pp. 1137-1144.

21. M. Pascolini, S. Oh, C. Di Nallo, and M. Midrio, "Envelope Correlation Coefficient and Mean Effective Gain for Multiple

Antennas in Different Use Cases," EuCAP 2007: The Second European Conference on Antennas and Propagation, November 11-16, 2007, pp. 1-7.

22. 3GPP TR 25.914 V7.0.0 (2006-06) "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Measurements of radio performances for UMTS terminals in speech mode (Release 7)," available at http://www.3gpp.org.

23. P. Moller, "CTIA Hand Phantom Development Status," COST 2100 TD(08)523 Trondheim, Norway, June 4-6, 2008.

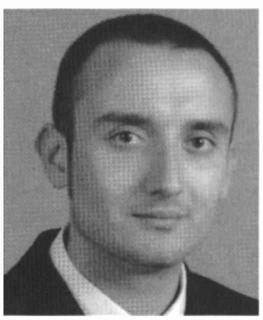
24. http://www.3gpp.org/ftp/tsg_ran/WG4_Radio/TSGR4_45/Report/

25. T. M. Greiner, "Hand Anthropometry of US Army Personnel," Natick/TR-92/011, 1991.

26. C. Gabriel, "Tissue Equivalent Material for Hand Phantoms," *Phys. Med. Biol.*, **52**, 2007, pp. 4205-4210.

27. IEEE, "Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques," IEEE Standard 1528, 2003.

Introducing the Feature Article Authors



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