A Study of the Hand-Hold Impact on the EM Interaction of a Cellular Handset and a Human

Salah I. Al-Mously, and Marai M. Abousetta

***Abstract*—**This paper investigates the impact of the hand-hold positions on both antenna performance and the specific absorption rate (SAR) induced in the user's head. A cellular handset with external antenna operating at GSM-900 frequency is modeled and simulated using a finite difference time-domain (FDTD)-based platform SEMCAD-X. A specific anthropomorphic mannequin (SAM) is adopted to simulate the user's head, whereas a semi-realistic CAD-model of three-tissues is designed to simulate the user's hand. The results show that in case of the handset in hand close to head at different positions; the antenna total efficiency gets reduced to (14.5% - 5.9%) at cheek-position and to (27.5% to 11.8%) at tilt-position. The peak averaged SAR_{1g} values in head close to handset without hand, are 4.67 W/Kg and 2.66 W/Kg at cheek and tilt-position, respectively. Due to the presence of hand, the SAR_{1g} in head gets reduced to (3.67-3.31 W/Kg) at cheek-position and to (1.84-1.64 W/Kg) at tilt-position, depending on the hand-hold position.

***Keywords*—**FDTD, phantom, specific absorption rate (SAR), cellular handset exposure.

I. Introduction

THE potential health hazard caused due to electromagnetic (EM) radiation from cellular handset antennas, is a major public concern. Besides, it is also the concern for the manufacturing companies, in keeping their products working within the safety standard guidelines. Measuring the induced specific absorption rate (SAR) in a human head exposed to the handset antenna radiation, most standards (IEEE-1528, EN 50360/1, IEC 62209, ARIB STD-T56, FCC, ACA) [1-7] are not considering the use of hand model due to many possible hand-hold positions and a worst case SAR value is obtained without the use of a hand model. However, a hand-hold has a considerable impact on the antenna performance which can be altered according to both antenna and handset positions [8].

The impact of hand-hold positions on the EM interaction of a handset and a human head in cellular communications has had been investigated by many authors [9]-[11] where in only the antenna performance was computed. In [9], a hand model, with a normal way of holding was simulated with only one tissue approximating the average hand-tissues relative permittivity. A homogeneous 3-D model was used in [10] to simulate a user's hand, whereas a realistic model with two tissues (bone and muscle) was used in [11].

In this paper both antenna performance and the SAR with the absorbed power in tissues are computed using a FDTD-based platform SEMCAD-X [12]. A handset in hand close to head at both cheek and tilt-position, according to IEEE-1528 [1], are considered during the simulation. A SAM-phantom is used to simulate the user's head whereas a semi-realistic model of three-tissues is designed to simulate the user's hand.

II. Method

The simulation is carried out in this paper using a FDTD-base platform SEMCAD-X, due to its handling, functionality and features for highly detailed CAD models as well as efficient FDTD solver for simulating advanced applications. SEMCAD-X is a 3-D full wave simulation environment based on the FDTD method in which Maxwell's curl equations are discretized using a 2^{nd} order finite-difference approximation both in space and in time in an equidistantly spaced mesh [12].

III. Modeling

A. Handset Model

A handset with most parts configuration is simulated using SEMCAD-X platform. The maximum dimensions of the proposed handset model are set to 43×16.5×104 mm. Fig. 1 shows the handset numerical components in different views.

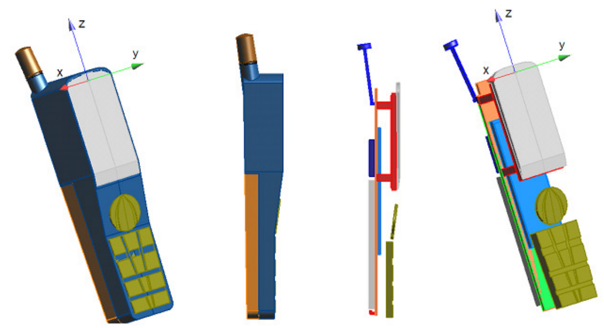

Fig. 1 Numerical components structure of the handset; (a) A 3-D view, (b) A side-view, (c) A side-view without housing and covers and (d) A 3-D view without housing and covers.

S. I. Al-Mously is a Ph.D. student with the Academy of Graduate Studies, School of Applied Sciences and Engineering, Department of Electrical and Electronics Engineering, Tripoli, Libya. He is also with the Department of Microwave and Radar Engineering, the Higher Institute of Electronics, Beni-Walid, Libya (Mobile phone: +218 926 898490; Fax: +218 322 242334; e-mail: salah.mously@hieb.edu.ly).

M. M. Abousetta is with the Department of Electrical and Electronics Engineering, School of Applied Sciences and Engineering, Academy of Graduate Studies, Tripoli, Libya. (e-mail: maraibusetta@yahoo.co.uk).

The considered handset electromechanical parts are: *antenna, antenna cover and bushing, PCB, shields, LCD and its holder, lenses and housing parts, keypad and buttons, battery and battery contact and connectors*. The dielectric parameters of handset materials are listed in Table I.

TABLE I
MATERIAL PARAMETERS OF THE HANDSET MAIN PARTS

Part	ε_r	σ [S/m]
Antenna cover and bushing	2.5	3e-3
PCB dielectric	4.5	7e-2
LCD glass	4.5	1e-2
LCD dielectric	3.0	1e-2
Housing and covers	3.5	2e-2
Keypad/buttons	3.5	2e-2
Battery case	3.5	2e-2

A short-whip antenna top loaded with a small cylinder [13] is suggested as in Fig. 2. The antenna is tuned at 900 MHz and is matched with a 15.25 nH lumped element. It is inclined back (8^o) to reduce the impact of the EM antenna radiation on the user's head.

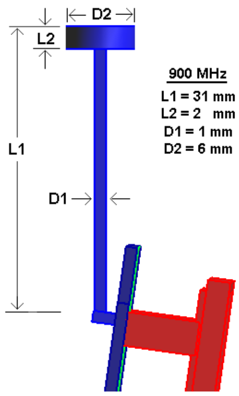

Fig. 2 The proposed loaded short-whip antenna attached to the PCB with dimensions at 900 MHz.

B. *Hand Model*

A semi-realistic hand model consists of three tissues; skin, muscle and bone, is designed with two usually different holding positions that will be referred later as hand1 and hand2. Hand1 grasping the lower part of the handset whereas hand2 grasping the upper part of the handset. These proposed hand-holds represent the two possible extreme hand-holdings.

C. *Head Model*

The user's head is simulated using a homogeneous SAM phantom available with SEMCAD-X and consists of two dielectric materials, shell and liquid. The SAM was developed by the IEEE Standards Coordinating Committee 34, Subcommittee 2, Working Group 1 (SCC34/SC2/WG1) as a lossless plastic shell, filled with a homogeneous liquid, and a thin lossless ear spacer, whereas (SCC34/SC2/WG2) suggested the same SAM but with different plastic shell parameters [14]. Fig. 3 shows the handset in hand proximity to SAM at cheek position for different hand-hold positions, where the hand-bones grasping the handset are also shown.

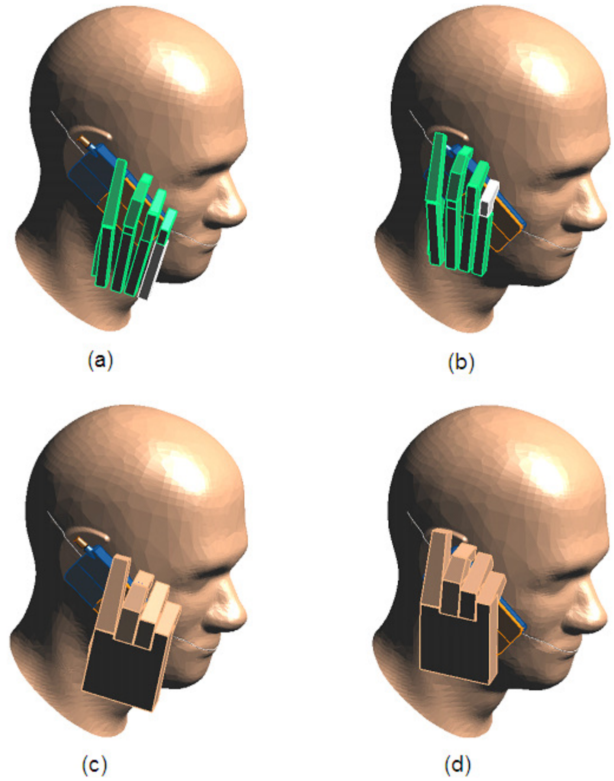

Fig. 3 Different CAD representations of the handset in hand close to head at check-position; (a) Hand1-bones holding the handset, (b) Hand2-bones holding the handset, (d) Hand1-tissues holding the handset and (d) Hand2-tissues holding the handset.

IV. GRID GENERATION

To align the simulated handset components to the FDTD grid accurately (in free space) a minimum spatial resolution of 0.5x0.5x0.5 mm^3 and maximum spatial resolution of 5x5x5 mm^3 in the x, y, and z directions are chosen with grading ratio of 1.2. This FDTD-grid setting is also applied in cases of the handset held in free space and the handset held proximity to head at both cheek and tilt-positions. During the simulation processes, the absorbing boundary conditions (ABC) are set as a Perfectly Matched Layer (PML) mode with a very high strength thickness [12]. Table II lists the generated grid properties of the handset in all conditions.

TABLE II
THE GENERATED GRID PROPERTIES OF THE HANDSET IN ALL CONDITIONS

			Mesh cells amount (Mcells)
No head	Handset in free-space		103*81*179 = 1.49340
	Handset in hand1 only		209*149*254 = 7.90981
	Handset in hand2 only		212*145*227 = 6.97798
SAM	Cheek	No hand	191*134*263 = 6.73122
		In hand1	273*296*315 = 16.8550
		In hand2	277*195*307 = 16.5826
	Tilt	No hand	192*134*265 = 6.81792
		In hand1	275*197*318 = 17.2277
		In hand2	277*195*304 = 16.4206

V. SIMULATION RESULTS

A. Antenna Performance

Referred to the IEEE-standard C95.1b-2004 [15] (for low power devices, uncontrolled environment), the antenna input power is set to 0.6 W at 900 MHz.

Fig. 4 illustrates the value of $|S_{11}|$ in (dB) versus frequency for the handset in free-space and in both hand1 and hand2 close to head at cheek-position, whereas Fig. 5 illustrates the value of $|S_{11}|$ in (dB) versus frequency for the handset in free-space and the handset in both hand1 and hand2 close to head at tilt-position.

Table III demonstrates the antenna parameters including; input impedance, S_{11} in (dB), radiation efficiency and total efficiency of the handset antenna in different conditions.

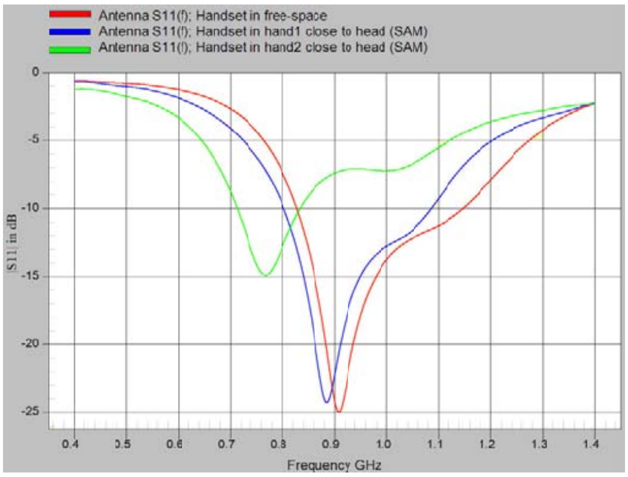

Fig. 4 $|S_{11}|$ in (dB) versus frequency of the antenna on top of the handset at cheek-position and different conditions.

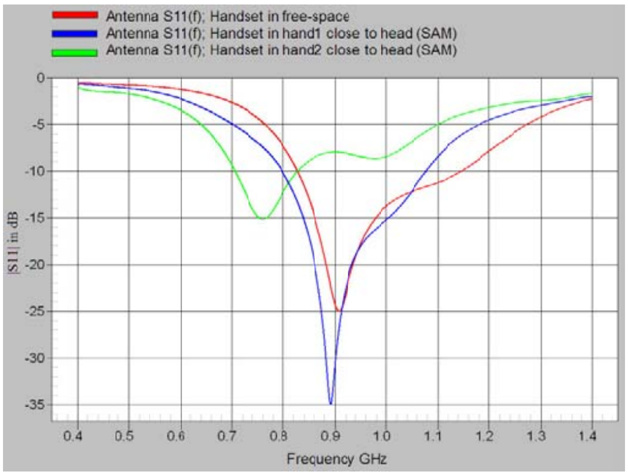

Fig. 5 $|S_{11}|$ in (dB) versus frequency of the antenna on top of the handset at tilt-position and different conditions.

TABLE III
HANDSET ANTENNA PARAMETERS IN DIFFERENT CONDITIONS

Frequency		900 MHz			
Parameter		Z_{in}	$\|S_{11}\|$ (dB)	η_{rad}	η_{total}
No head	No hand	44.5 +j0.86	-24.4	77.8%	77.6%
	In hand1	49.2 - j8.17	-21.6	89.8%	87.2%
	In hand2	78.5 + j37.4	-9.08	30.7%	26.9%
SAM/Cheek	No hand	39 + j 11.5	-15.02	15.1%	14.6%
	In hand1	46.6 + j7.07	-21.9	14.6%	14.5%
	In hand2	59.3 + j52.1	-7.19	7.3%	5.9%
SAM/Tilt	No hand	45.3 + j15.2	-15.65	32.5%	31.8%
	In hand1	50.6 + j2.68	-31.24	27.5%	27.5%
	In hand2	69.7 + j53.6	-7.22	14.6%	11.8%

B. SAR and Power Loss Computation

The SAR is defined as the amount of EM energy absorption in the unit mass as follow [16]:

$$SAR = \frac{\sigma_E}{\rho}|\mathbf{E}|^2 \qquad (1)$$

where σ_E (S/m) is the electric conductivity, **E** (V/m) is the induced electric field vector, and ρ (kg/m^3) is the mass density of the tissue.

Using SEMCAD-X platform, an algorithm based on SCC34/SC2/WG2 computational dosimetry, IEEE-1529 [17], the spatial peak SAR(x, y, z, f_o) can be computed over any required mass.

The computed peaks SAR averaged over 1g &10g with the absorbed power in both head and hand are listed in Table IV and Table V for the handset at cheek and tilt-positions, respectively.

TABLE IV
PEAK SAR, POWER ABSORPTION IN TISSUES, AND THE COMPUTATION ERROR FOR THE HANDSET AT CHEEK-POSITION AND DIFFERENT CONDITIONS

Frequency	900 MHz		
Head phantom type	SAM		
Hand position	No Hand	Hand1	Hand2
Input power (mW)	600	600	600
SAR_{1g} in head (W/Kg)	4.67	3.67	3.31
SAR_{10g} in head (W/Kg)	3.13	2.51	2.20
SAR_{1g} in hand (W/Kg)	---	1.60	5.31
SAR_{10g} in hand (W/Kg)	---	0.83	1.84
Absorbed power in head (mW)	362.00	288.60	237.60
Absorbed power in hand (mW)	---	93.20	201.70
Absorption rate in head (%)	60.33	48.10	39.60
Radiated power (mW)	87.57	87.25	35.42
Dielectric loss (mW)	143.05	125.80	113.90
Computation error (%)	1.23	0.86	1.90

TABLE V
PEAK SAR, POWER ABSORPTION IN TISSUES, AND THE COMPUTATION ERROR FOR THE HANDSET AT TILT-POSITION AND DIFFERENT CONDITIONS

Frequency	900 MHz		
Head phantom type	SAM		
Hand position	No Hand	Hand1	Hand2
Input power (mW)	600	600	600
SAR_{1g} in head (W/Kg)	2.66	1.84	1.64
SAR_{10g} in head (W/Kg)	1.81	1.26	1.07
SAR_{1g} in hand (W/Kg)	---	1.98	5.40
SAR_{10g} in hand (W/Kg)	---	1.03	2.18
Absorbed power in head (mW)	191.1	164.9	70.92
Absorbed power in hand (mW)	277.6	194.6	165.0
Absorption rate in head (%)	46.27	32.43	27.50
Radiated power (mW)	---	121.6	246.8
Dielectric loss (mW)	123.70	116.0	103.7
Computation error (%)	1.27	0.48	2.26

Fig. 6 shows the far-field 3-D radiation pattern of the handset in hand1 and hand2 close to SAM at cheek-position, whereas Fig. 7 shows the radiation pattern of the handset in hand1 and hand2 close to SAM at tilt-position.

Fig. 8 and Fig. 9 show the sliced-distribution of the averaged peak SAR_{1g} in the SAM phantom exposed to EM radiation of handset antenna at cheek and tilt-positions, respectively.

C. Computation Error

The computation error is defined as [18]:

$$\text{Comp. error} = |P_{in} - (P_{rad} + P_{abs} + P_{Loss})| \,/\, P_{in} \quad (2)$$

$$P_{Loss} = P_d + P_c \quad (3)$$

Where P_{in} is the input power, P_{rad} is the radiation power, P_{abs} is the absorbed power in hand and head and P_{Loss} is the total power loss. P_{Loss} includes the dielectric-loss (P_d) and the metallic ohmic-loss (P_c). Table IV and Table V are both list the computation error for the handset simulation in all conditions.

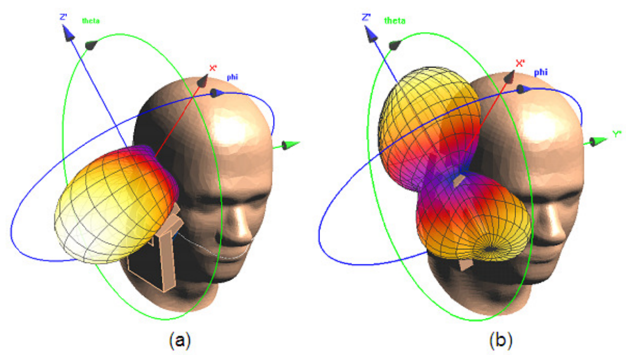

Fig. 6 The 3-D far-field radiation pattern; (a) handset in hand1 close to SAM at cheek-position and (b) handset in hand2 close to SAM at cheek-position..

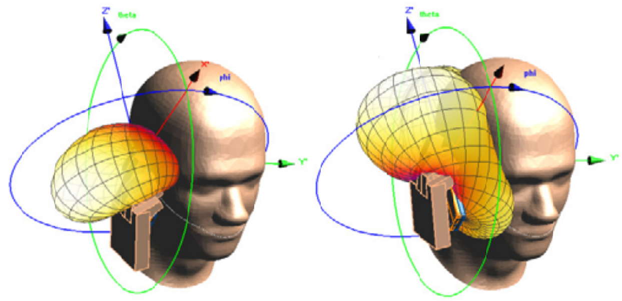

Fig. 7 The 3-D far-field radiation pattern; (a) handset in hand1 close to SAM at tilt-position and (b) handset in hand2 close to SAM at tilt-position.

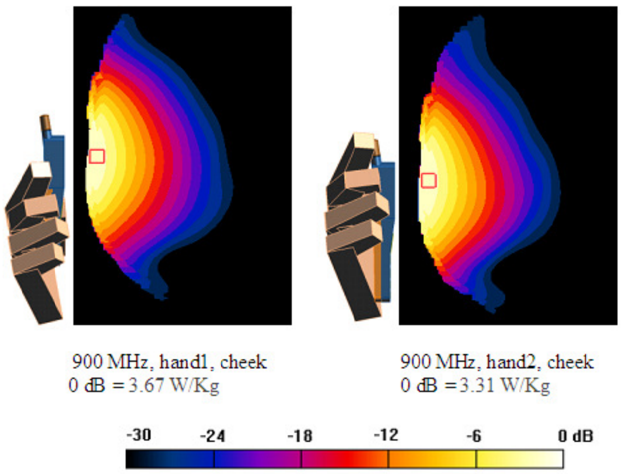

Fig. 8 The peak SAR_{1g} sliced-distribution (yz- plane) in SAM due to the EM radiation of the handset antenna at cheek-position.

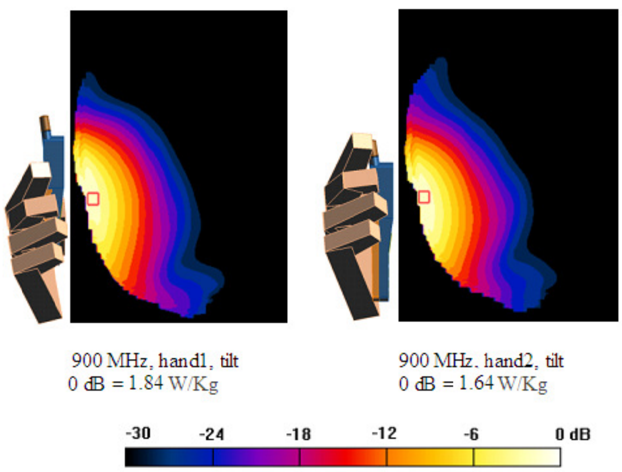

Fig. 9 The peak SAR_{1g} sliced-distribution (yz- plane) in SAM due to the EM radiation of the handset antenna at tilt-position.

VI. Discussion

1. Fig. 4 and Fig. 5 has shown that holding the handset with either hand1 or hand2 decreases both the tuning frequency and the input reflection coefficient, except in case of handset in hand1 at tilt-position, where the input reflection coefficient gets increased.
2. According to the simulation results shown in Table III, the antenna total efficiency gets increased when holding the handset with hand1 in free-space, whereas it gets decreased when holding the handset with hand2 in free-space. Holding the handset close to head decreases the antenna total efficiency dramatically, whereas the worst is the case with the hand2-hold at cheek-position.
3. The computed SAR and the absorbed power in both head and hand, listed in Table IV and Table V, has shown that the head close to handset in hand2 gets less induced SAR and less absorbed power, as compared with the head close to handset in hand1. In contrast, more SAR and absorbed power in hand have been induced in case of the handset in hand2 close to head.
4. As shown in Table IV and Table V, the simulation computation errors are less than 2% in all simulation cases, except in case of the handset in hand2 close to head at tilt-position, where it is equal to 2.26%.

References

[1] *Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices – Measurement Techniques*, IEEE Standard 1528, 2003.

[2] *Product Standard to Demonstrate the Compliance of Mobile Phones with the Basic Restrictions Related to Human Exposure to Electromagnetic Fields (300 MHz – 3 GHz),* EN 50360, 2001.

[3] *Basic Standard for the Measurement of Specific Absorption Rate Related to Exposure to Electromagnetic Fields from Mobile Phones (300 MHz – 3 GHz),* EN 50361, 2001.

[4] *Procedure to Measure the Specific Absorption Rate (SAR) in the Frequency Range of 300 MHz to 3 GHz – Part 1: Hand-held Mobile Wireless Communication Devices*, IEC 62209.

[5] *Specific Absorption Rate (SAR) Estimation for Cellular Phone*, ARIB Standard-T56, 2002.

[6] *Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields*, supplement C to OET Bulletin 65 (Edition 9701) FCC, 1997.

[7] *Electromagnetic Radiation - Human Exposure*, ACA Radio communications Standard, Schedules 1 and 2, 2003.

[8] S. I. Al-Mously and M. M. Abousetta, "Study of both antenna and PCB positions effect on the coupling between the cellular hand-set and human head at GSM-900 standard," *iWAT IEEE-2008, International Workshop on Antenna Technology 2008, Chiba, Japan, March 4-6, 2008,* to be published.

[9] J. Graffin, N. Rots and G. F. Pedersen, "Radiations phantom for handheld phones," *Vehicular Technology Conference, 2000, IEEE VTS-Fall VTC 2000, 52nd*, Volume 2, pp. 853 – 866, 24-28Sept. 2000

[10] N. Chavannes, P. Futter, R. Tay, K. Pokovic and N. Kuster, "Reliable prediction of MTE performance under real usage conditions using FDTD," *in Proc. of Applied Electromagnetics and Communications 18th Int. Conf., 2005*

[11] Chin-Ming Su, Chin-Hsien Wu, Kin-Lu wong, Shin-Huang Yeh and Chia-Lun Tang, "User's hand effects on EMC internal GSM/DCS mobile phone antenna," *Antennas and Propagation Society International Symposium 2006, IEEE*, 9-14 July 2006.

[12] *SEMCAD-X Reference Manual*, SEMCAD Simulation Platform for Electromagnetic Compatibility, Antenna Design and Dosimetry," SPEAG - Schmid&Partner Engineering AG. (http://www.semcad.com)

[13] K. Ogawa and T. Uwano, "A diversity Antenna for very small 800-MHz band portable telephones," *IEEE Trans. Antenna and Propagation*, vol. 42, No. 9, September 1994.

[14] B. B. Beard, W. Kainz, T. Onishi, T. Iyama, S. Watanabe, O. Fujiwara, J. Wang, G. Bit-Babik, A. Faraone, J. Wiart, A. Christ, N. Kuster, A. Lee, H. Kroeze, M. Siegbahn, J. Keshvari, H. Abrishamkar, W. Simon, D. Manteuffel, and N. Nikoloski, "Comparisons of computed mobile phone induced SAR in the SAM phantom to that in anatomically correct models of the human head," *IEEE Trans. Electromagnetic Compatibility*, vol. 48, No. 2, MAY 2006.

[15] *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*, *Amendment 2: Specific Absorption Rate (SAR) Limits for the Pinna*, IEEE Standard C95.1b-2004, Dec. 2004.

[16] H. Arai, *Measurement of Mobile Antenna Systems*, Artech House Inc, 2001.

[17] *Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) Associated with the Use of Wireless Handsets – Computational Techniques*, IEEE draft Standard-1529.

[18] L. Kuo, Y. Kan and H. Chuang, "Analysis of A 900/1800-MHz dual-band gap loop antenna on a handset with proximate head and hand model," *Journal of Electromagnetics Waves and Applications*, vol. 21, No. 1, pp. 107–122, 2007.