User's Hand Effect on TIS of Different GSM900/1800 Mobile Phone Models Using FDTD Method

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Abstract— This paper predicts the effect of the user's hand-hold position on the Total Isotropic Sensitivity (TIS) of GSM900/1800 mobile phone antennas of realistic in-use conditions, where different semi-realistic mobile phone models, i.e., candy bar and clamshell, as well as different antenna types, i.e., external and internal, are simulated using a FDTD-based platform. A semi-realistic hand model consisting of three tissues and the SAM head are used in simulations. The results show a considerable impact on TIS of the adopted mobile phone models owing to the user's hand presence at different positions, where a maximum level of TIS is obtained while grasping the upper part of the mobile phone against head. Maximum TIS levels are recorded in talk position for mobile phones with external antenna and maximum differences in TIS levels due to the hand-hold alteration are recorded for clamshell-type phones.

Keywords— FDTD, mobile phone, phantoms, TIS.

I. INTRODUCTION

THE total isotropic sensitivity (TIS) is the power that reaches the receiver through the antenna integrated over all directions. This sensitivity is affected by the sensitivity of the receiver, mismatch between the receiver and antenna, the efficiency of the antenna and objects in the vicinity to the antenna those contribute with losses, e.g., mobile phone chassis, hand, head, *etc*.

The TIS is a measure of the mobile phone receiving performance, where both TIS and TRP (total radiated power) together determine effectiveness of the phone as a piece of radio equipment, in particular the maximum range at which the phone can operate from the base station with some given level of performance. These parameters determine the performance that will be experienced by a user in network service, where many network operators establish standards of TRP/TIS performance which must be met by phones before they are permitted to be used on their network. The standard test methods are described in [1].

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Based on the type of the field applied to the mobile phone antenna, several test methods have been proposed to measure the performance of the mobile phone including the antenna [2]; measurement in an anechoic chamber with plane waves [3], [4], measurement in a normal environment for mobile terminals with real scattered fields [5], [6] and measurement in reverberating chamber with artificial scattered fields [7], [8].

In [4] the antenna performance including the TIS of a series of ten commercially available GSM900/1800 mobile phones were measured in an anechoic chamber at different setups, i.e., in free space and against a Torso phantom, whereas, in [8] the sensitivity of a commercially available GSM900 mobile phone in receiving mode was measured in reverberation chamber at different setups, i.e., in free space and against head phantom.

Using a FDTD-method, the hand position effect on the TIS was computed in [10] for a novel mobile phone with different antenna positions and in [11] for different candy-bar phone models with different antenna types/positions.

In this paper, the total isotropic sensitivity of the GSM900/1800 mobile phone including the antenna due to the hand-hold alteration is computed using a FDTD-based platform, *SEMCAD X* [9]. A series of four different phone models with internal and external antennas operating at 900 and 1800 MHz are used for the TIS measurement in free space and in hand at different positions against human head.

II. NUMERICAL METHOD

The Finite-Difference Time-Domain (FDTD) method proposed by Yee in 1966 [12] is a direct solution of Maxwell's curl equations in the time domain. Maxwell's curl equations are discretized using a 2nd order finite-difference approximation both in space and in time in an equidistantly spaced mesh [9].

Although FDTD technique has some limitations [13]; its robustness, suitability for handling complex problems composed of any number of sub-volumes and general independence of material compositions make it more popular than other techniques and the most applied in EM solver platforms. *SEMCAD X* (ver. 12.4 JUNGFAU) simulation platform [9] is selected for simulating the proposed work cases due to its handling, functionality and features for highly detailed CAD models as well as efficient FDTD solver for simulating advanced applications.

A. Mobile Phone Models

In this paper semi-realistic four mobile phone models are simulated to achieve the commercially available modern designs and used to evaluate the TIS under a usage pattern of different hand-hold positions. The simulated mobile phone models are; candy bar-type with external antenna [14] (model-A), candy bar-type with internal antenna [11] (model-B), clamshell-type with external antenna (model-C) and clamshell-type with internal antenna (model-D). Each mobile phone model is designed with two different tuned frequencies, i.e., 900 and 1800 MHz.

Fig. 1 shows the CAD models of the proposed mobile phones, where;

1) The maximum physical dimensions of model-A (excluding the antenna) are 104 mm × 43 mm × 16.5 mm (length × width × thickness), whereas, the multilayer PCB dimensions are 97 mm × 37 mm × 1 mm.
2) The maximum physical dimensions of model-B are 110 mm × 44 mm × 13 mm, whereas; the multilayer PCB dimensions are 97 mm × 37 mm × 1 mm.
3) The maximum physical dimensions of model-C (excluding the antenna) when closed are 89 mm × 50 mm × 19 mm, whereas; the base-multilayer PCB dimensions are 67.5 mm × 43 mm × 1 mm.
4) The maximum physical dimensions of model-D when closed are 90 mm × 45 mm × 18.5 mm, whereas; the base-multilayer PCB dimensions are 77 mm × 37 mm × 1 mm.

The dielectric components of the mobile phone models are represented within the FDTD simulation using the material parameters summarized in Table I [10], [11], [13], [14].

The proposed external antenna is a single-band short-whip top loaded with a small cylinder [11], [14], whereas, the proposed internal antenna is a single-band probe-fed rectangular patch with shorting plate at the edge [11]. The patch antenna in model-B is mounted on the back-side of the upper part of the PCB, whereas, in model-D the patch is mounted on the back-side of the upper part of the base-PCB, as shown in Fig. 2.

TABLE I
THE DIELECTRIC PARTS OF THE MOBILE PHONES MECHANICAL CAD DATA SETS AND THE CORRESPONDING MATERIAL PARAMETERS

Part	ε_r	σ (S/m)
Antenna cover and bushing	2.5	0.003
PCB dielectric	4.5	0.07
LCD glass	4.5	0.01
LCD dielectric	3.0	0.01
Housing and covers	3.5	0.02
Keypad/buttons	3.5	0.02
Battery case	3.5	0.02

B. Hand Model

A semi-realistic hand model consisting of three tissues (skin, muscle and bone) [10], [11], [14] is designed with two common different holding positions referred later as hand1 and hand2. Hand1 grasping the lower part of the phone, whereas, hand2 grasping the upper part of the phone. These proposed hand-holds represent the two applicable extremes of hand holding. The electrical properties of the hand tissues are given in Table II.
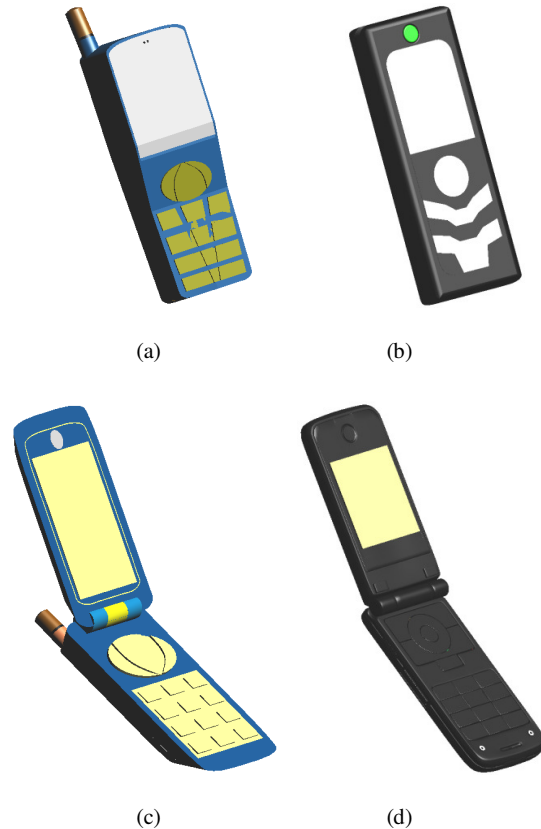

Fig. 1 The numerical *SEMCAD X* models of the adopted mobile phones used in simulations; (a) Phone model-A, (b) Phone model-B, (c) Phone model-C, and (d) Phone model-D
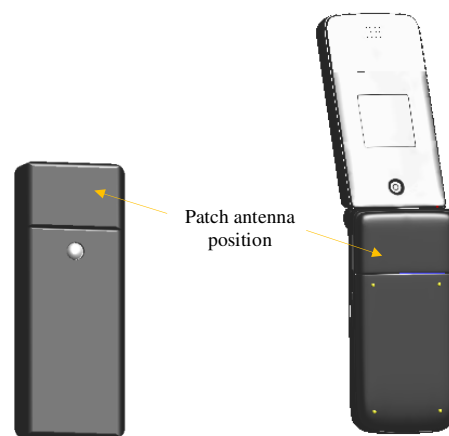

Fig. 2 The patch antenna position in mobile phone model-B (left) and model-D (right)

C. Human Head Model

A Specific Anthropomorphic Mannequin (SAM) developed by different standard committees [15] – [19] and represents the world-wide standard phantom for compliance testing is used to simulate the human head. The electrical properties of the SAM materials are defined in [15], [20] and given in Table II.

TABLE II
THE ELECTRICAL PROPERTIES OF THE SAM MATERIALS AND HEAD TISSUES USED FOR SIMULATIONS

	900 MHz		1800 MHz	
Hand Tissue	ε_r	σ (S/m)	ε_r	σ (S/m)
hand skin	41.41	0.87	38.87	1.18
hand muscle	55.03	0.94	53.55	1.34
hand bone	12.45	0.14	11.78	0.28
SAM Material	ε_r	σ (S/m)	ε_r	σ (S/m)
SAM shell	5.0	0.0016	5.0	0.0016
SAM liquid	41.5	0.97	40.0	1.4

III. FDTD-Grid Generation

To align the simulated mobile phone components to the FDTD grid accurately a minimum spatial resolution of $0.5 \times 0.5 \times 0.5$ mm^3 and a maximum spatial resolution of $10 \times 10 \times 10$ mm^3 in the *x*, *y*, and *z* directions are chosen for simulating the phone in hand close to head. Depending on the case complexity, a refining factor of (5 - 20) with grading ratio of (1.2 - 1.3) is used for the solid regions during the simulations. The simulations assume a steady state voltage at 900 and 1800 MHz, with a feed point of 50 Ohm voltage source of 0.5 mm physical gap. The absorbing boundary conditions (ABC) are set as a Uniaxial Perfectly Matched Layer (UPML) mode with a very high strength thickness, where a minimum level of absorption at the outer boundary is (> 99.9%) [9].

Fig. 3, Fig. 4, Fig. 5 and Fig. 6 demonstrate the mobile phone models-A, B, C and D, respectively, under the adopted usage patterns; in hand1 against SAM at cheek position and in hand2 against SAM at cheek position in compliance with the IEEE-Std. 1528 [15].

Tables III and IV list the total number of FDTD-grid cells required according to the above setting to simulate the mobile phone models in free space, in hand and in hand close to head operating at 900 and 1800 MHz, respectively.

IV. RESULTS AND INFERENCES

Referred to the IEEE-Std. C95.1b-2004 [21] (for low power devices, uncontrolled environment), the antenna input power is set as 0.6 W at 900 MHz and 0.125 W at 1800 MHz, for all phone setups. Table V and Table VI show the antenna parameters, i.e., $|S_{11}|$ dB, radiation efficiency (η_{rad}) and total radiated power (*TRP*), at 900 and 1800 MHz, respectively. *TRP* is defined as:

$$TRP = \eta_{tot} \times input\ power \qquad (1)$$

Where η_{tot} is the total efficiency and defined as:

$$\eta_{tot} = \eta_{rad} \times \eta_{mis} \qquad (2)$$

and the mismatch efficiency (η_{mis}) is given by:

$$\eta_{mis} = (1 - |S_{11}|^2) \qquad (3)$$

Fig. 7 illustrates the distortion of the reactive near-field, $E(x,y,z,f_o)$, of the simulated phone-antenna systems by the presence of hand (hand1 and hand2) at 900 and 1800 MHz.

Although the interference of the external noisy components, i.e., display and camera, and their associated feed circuits is not considered in simulation, the drop in TIS specification of mobile phones while in-use, as shown in Fig. 8 and Fig. 9, is caused by antenna total efficiency decrease due to hand and head presence in the vicinity to the antenna. The relation between the TIS level and the mobile phone setup in both Fig. 8 and Fig. 9 demonstrates the following:

1) Hand2 shows more impact on TIS than hand1 in the different phone setups, where a maximum TIS level of -95.4 dBm is recorded for model-A in hand2 against head at 900 MHz and -93.1 dBm is recorded for model-C in hand2 against head at 1800 MHz.

2) Under realistic usage, mobile phones with external antenna, i.e., model-A and model-C, exhibit more variation in their TIS level due to hand-hold alteration (from hand1 to hand2) at 1800 MHz than at 900 MHz, whereas, phones with internal antenna, i.e., model-B and model-D exhibit more variation in their TIS level due to hand-hold alteration at 900 MHz than at 1800 MHz.

3) Maximum differences in TIS levels due to hand-hold alteration are recorded for clamshell-type phones; 4.4 dBm for model-D at 900 MHz and 7.1 dBm for model-C at 1800 MHz.

4) As compared with the sensitivity of the mobile phone models at GSM900 frequency in free-space, the TIS level is around 10 dBm higher in talk positions. This difference may cross over 12 dB at 1800 MHz. These results coincide with the measured sensitivities at GSM850/900 obtained in [22].

TABLE III
TOTAL NUMBER OF GRID-CELLS OF THE SIMULATED PHONE MODELS AT DIFFERENT SETUPS, OPERATING AT 900 MHz

FDTD-Grid Cell Size (Mcells)				
Phone model-	A	B	C	D
in free-space	0.73372	1.176	3.70881	2.3408
in hand1	3.11798	5.2733	9.09321	7.6079
in hand2	2.75059	4.71229	8.17021	6.72184
in hand1+SAM	16.855	13.7325	18.0854	17.1054
in hand2+SAM	16.5826	13.272	16.4359	15.6194

TABLE IV
TOTAL NUMBER OF GRID-CELLS OF THE SIMULATED PHONE MODELS AT DIFFERENT SETUPS, OPERATING AT 1800 MHz

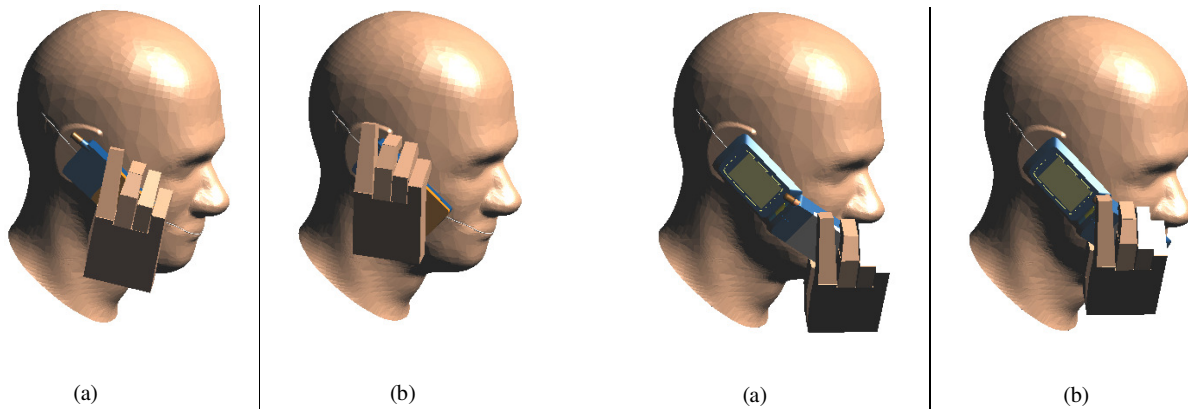| FDTD-Grid Cell Size (Mcells)				
Phone model-	A	B	C	D
in free-space	0.47925	1.04378	2.69568	0.73372
in hand1	2.5454	5.0616	7.30759	7.48995
in hand2	2.25283	4.35153	6.76944	6.72184
in hand1+SAM	14.4537	13.2165	15.2807	16.8889
in hand2+SAM	14.7094	12.4616	14.2586	15.6194

(a)　　　　　　　　　(b)

Fig. 3 The *SEMCAD X* representation of; (a) Model-A in hand1 against SAM at check position, (b) Model-A in hand2 against SAM at check position

(a)　　　　　　　　　(b)

Fig. 5 The SEMCAD X representation of; (a) Model-C in hand1 against SAM at check position, (b) Model-C in hand2 against SAM at check position
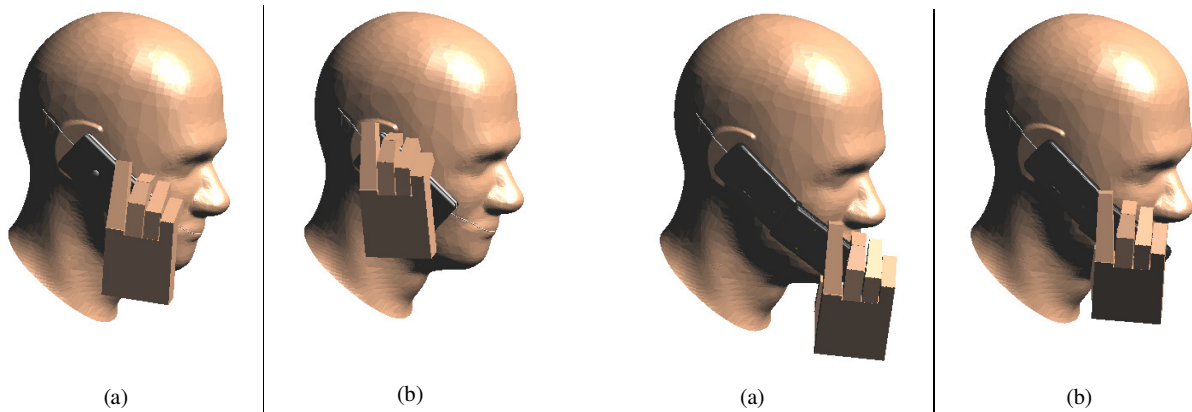

(a)　　　　　　　　　(b)

Fig. 4 The *SEMCAD X* representation of; (a) Model-B in hand1 against SAM at check position, (b) Model-B in hand2 against SAM at check position

(a)　　　　　　　　　(b)

Fig. 6 The *SEMCAD X* representation of; (a) Model-D in hand1 against SAM at check position, (b) Model-D in hand2 against SAM at check position

TABLE V
ANTENNA PARAMETERS OF THE PROPOSED MOBILE PHONE MODELS IN FREE-SPACE AT 900 MHZ; $|S_{11}|$ dB, RADIATION EFFICIENCY (η_{rad}) AND TOTAL RADIATED POWER (*TRP*) NORMALIZED TO 0.6 W INPUT POWER

Antenna Parameters	Frequency/900 MHz		
	$|S_{11}|$ dB	η_{rad}(%)	*TRP* (mW)
model-A	-24.4	77.8	465.6
model-B	-18.7	83.2	492.6
model-C	-14.5	74.0	427.8
model-D	-14.2	75.0	433.3

TABLE VI
ANTENNA PARAMETERS OF THE PROPOSED MOBILE PHONE MODELS IN FREE-SPACE AT 1800 MHZ; $|S_{11}|$ dB, RADIATION EFFICIENCY (η_{rad}) AND TOTAL RADIATED POWER (*TRP*) NORMALIZED TO 0.125 W INPUT POWER

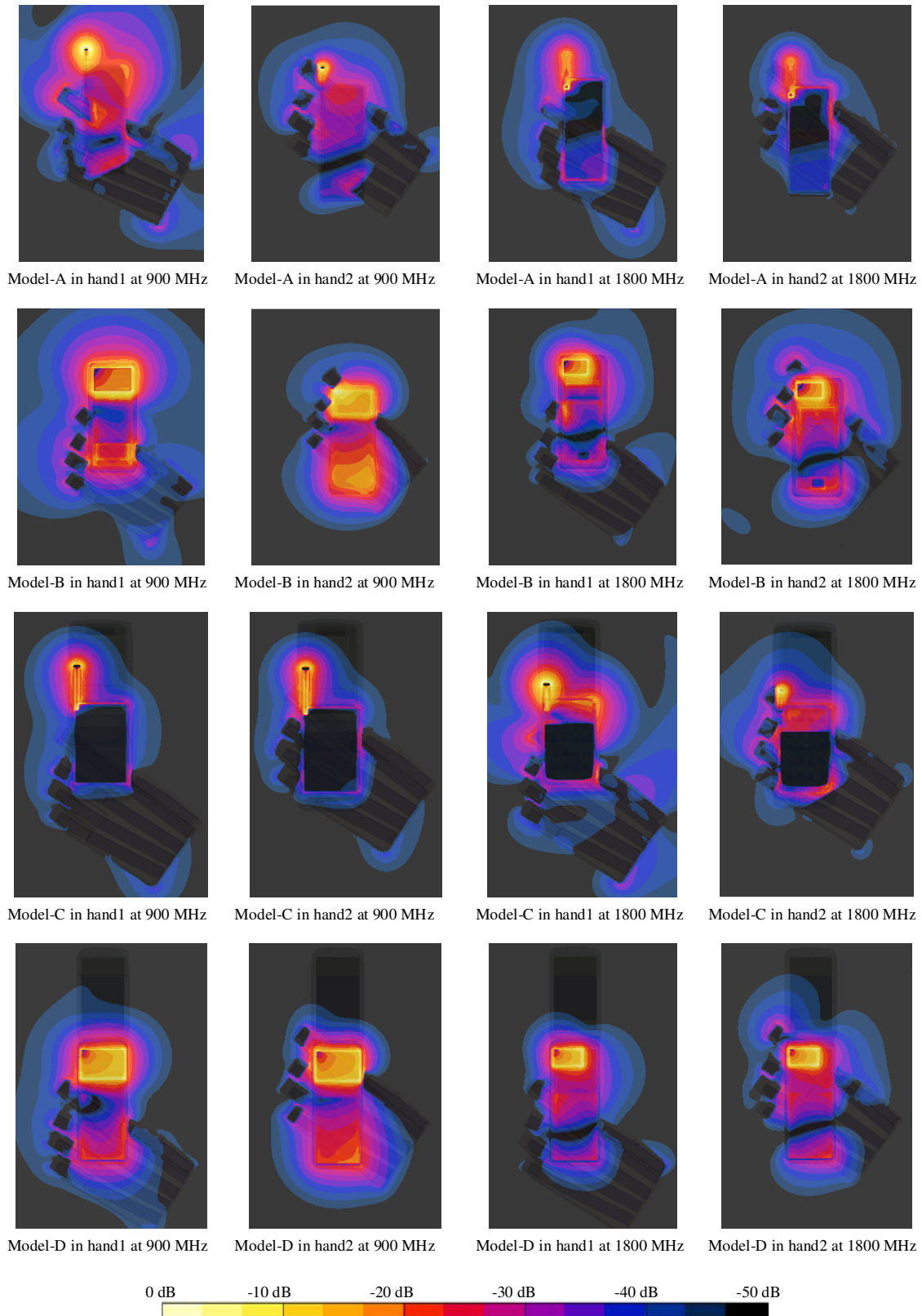| Antenna Parameters	Frequency/1800 MHz		
	$|S_{11}|$ dB	η_{rad}(%)	*TRP* (mW)
model-A	-15.5	89.8	109.1
model-B	-12.7	90.0	106.4
model-C	-17.4	90.4	110.9
model-D	-17.3	90.2	110.7

Fig. 7 Slice view of the reactive near-field (E-field) distortion of the simulated phone-antenna systems by the presence of the hand only at different positions, i.e., hand1 and hand2, at 900 and 1800 MHz
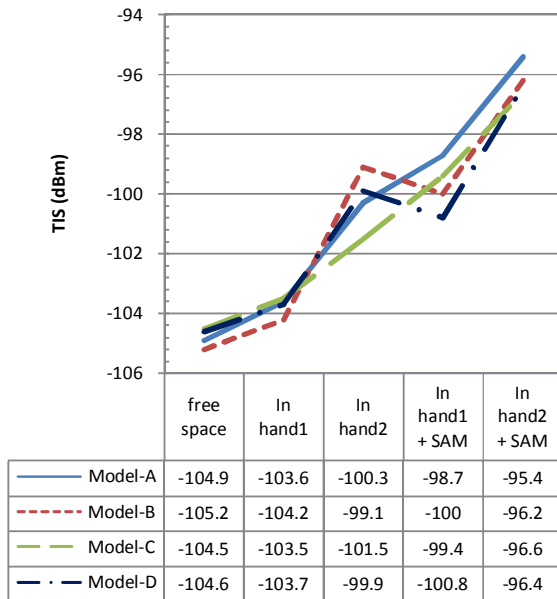
	free space	In hand1	In hand2	In hand1 + SAM	In hand2 + SAM
Model-A	-104.9	-103.6	-100.3	-98.7	-95.4
Model-B	-105.2	-104.2	-99.1	-100	-96.2
Model-C	-104.5	-103.5	-101.5	-99.4	-96.6
Model-D	-104.6	-103.7	-99.9	-100.8	-96.4

Fig. 8 TIS versus mobile phone setup for the different adopted models at 900 MHz

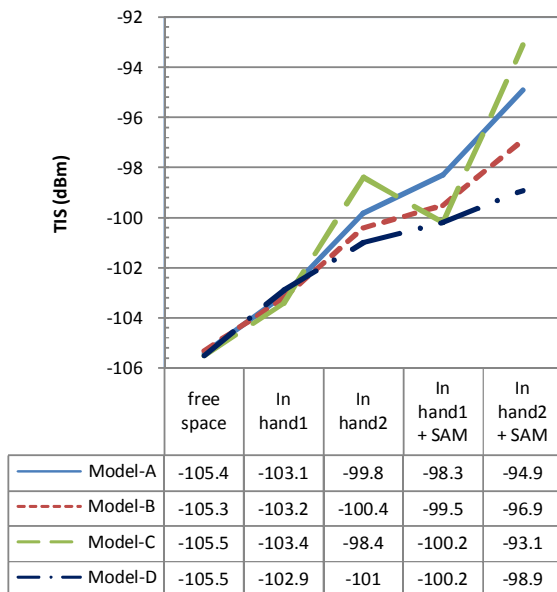|	free space	In hand1	In hand2	In hand1 + SAM	In hand2 + SAM
Model-A	-105.4	-103.1	-99.8	-98.3	-94.9
Model-B	-105.3	-103.2	-100.4	-99.5	-96.9
Model-C	-105.5	-103.4	-98.4	-100.2	-93.1
Model-D	-105.5	-102.9	-101	-100.2	-98.9

Fig. 9 TIS versus mobile phone setup for the different adopted models at 1800 MHz

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