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Analysis and Optimization of Mobile Phone Antenna Radiation Performance in the Presence of Head and Hand Phantoms

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Abstract

A commercial clam shell phone CAD model is used to numerically investigate the effect of a hand phantom on mobile phone antenna radiation performance. The simulation results show that the grip of the hand phantom is the most important parameter to antenna performance. The antenna is converted into a parameterized form, then optimized to achieve the targeted multi-band performance in real-usage conditions.

Key Words: *Numerical simulation, hand phantom, antenna design, mobile device antennas, mobile communication, hardware acceleration, optimization.*

1. Introduction

Over-the-air (OTA) performance measurements of mobile phones with head phantoms are commonly performed in laboratories to simulate real world usage configurations. However, recent studies showed that the presence of the user hand also changes the RF performance of cellular phones [1–3]. Therefore, there is need to include a hand phantom in these tests, with repeatable hand positioning and support to predict mobile phone performance reliably. In order to define the hand phantom geometry and the position of the hand with respect to the head and the phone, detailed investigations of different setups have to be performed.

While the device performance in freespace or against the head can be measured according to standardized protocols (e.g. CTIA, IEEE 1529, etc.), influence from other parts of the body, e.g. the hand, are harder to characterize due to higher uncertainties and lower repeatability. Finite Difference Time Domain (FDTD) based Electromagnetic (EM) simulations tools, like SEMCAD X [4], offer more suitable environment for predicting the performance of mobile phones for realistic in-use conditions.

The objectives of this paper are to determine the effect of different hand models and use patterns on RF performance in terms of radiation parameters (efficiency, Total Radiated Power (TRP)). The RF dielectric properties and materials composition of the hand, the grip of the hand on the phone and the size of the hand and wrist will be investigated in detail. Finally, Genetic Algorithm based optimization technique will be applied to optimize the performance of the CAD derived model of the phone antenna in the presence of head and hand phantoms.

2. Method

The FDTD based electromagnetic simulation tool SEMCAD X was used to perform the evaluations. The software was explicitly developed for the analysis, optimization and synthesis of transceivers in the vicinity of lossy structures. The tool allows the simulation and optimization of CAD data based commercial phones which require grid resolutions of as low as 120 μm in significant regions to capture significant details [1]. In addition, the combined platforms SEMCAD X and DASY 5 allow a direct comparison of numerical and experimental data.

To compare different configurations such as different hand grips on the phone, simulation methods provide the most appropriate technique, since only relative values are compared (i.e., the difference of the radiated values between different configurations). The uncertainty for differences in radiation pattern including the positioning uncertainty is estimated to be less than 0.1 dB and thus considerably better than for measurements.

3. Numerical Models

In this study, a commercial clam shell phone with a stretched helix antenna is used, as shown in Figure 1. Highly detailed IGES CAD files were provided describing the geometry of the phone, which could be directly imported into SEMCAD X (Figure 1). The manufacturer also provided several devices for measurement and validation of CAD data.

The phone was simulated in the right side, 15 degrees tilted position, at homogeneous Specific Anthropomorphic Mannequin (SAM) head phantom according to standardized protocols. Two different hand models were developed for this study (Figure 2): inhomogeneous anatomical hand model with skin, muscle and significant finger and wrist bone tissues, and homogeneous anatomical hand model with homogeneous dielectric constant and conductivity. The material properties of the hand models are shown in Table 1. RF dielectric properties of the homogeneous hand phantom are based on the human tissue measurement data as described in [5]. In addition, a novel hand phantom modeling engine (Figure 2 (c)) has been also developed which allows the user to pose the hand model to obtain appropriate grips on any given phone models with different sizes.

Figure 1. Multiband phone used in this study: photograph of the actual phone (left) and the CAD derived model.

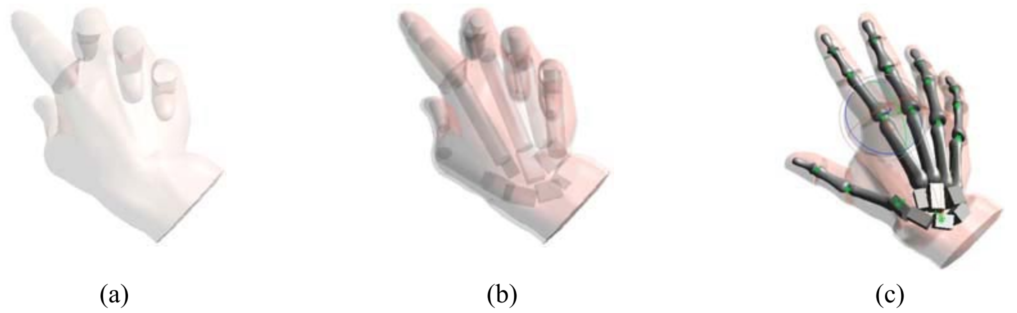

(a) (b) (c)

Figure 2. (a) Homogeneous (H1), and (b) inhomogeneous (H2) hand models; (c) illustration of hand phantom modeling engine.

Table 1. Material properties of hand and head models.

1750MHz	H1	H2-Skin	H2-Muscle	H2-Bone	H2-Head
ϵ	32.6	38.75	53.4	11.7	39
σ	1.26	1.22	1.39	0.29	1.42
900MHz	H1	H2-Skin	H2-Muscle	H2-Bone	H2-Head
ϵ	36.2	41.41	55.03	12.45	41.5
σ	0.79	0.867	0.943	0.143	0.97

Initial investigations with homogeneous and inhomogeneous hands have shown negligible differences in terms of antenna radiation parameters (Table 2). Therefore, the rest of the study was carried out using the homogeneous hand phantom (H1).

Table 2. Comparison of radiation performance of the phone with inhomogeneous and homogeneous hand models.

	1750MHz		900MHz	
	H1	H2	H1	H2
Radiation Efficiency	0.109	0.113	0.112	0.113
TRP (dBm)	19.82	19.95	19.36	19.51
NHRP +/-30° (dBm)	16.50	16.79	16.20	16.55
NHRP +/-45° (dBm)	17.98	18.22	17.70	18.02

4. Results: Hand Phantom

A. Freespace Near-Field Comparison

In order to validate the mobile phone model and the simulation results, freespace near-field measurements were made using the high precision DASY5 [6] scanning system (see Figure 3) equipped with the latest probe technology. E- and H-field scans were made on either side of the phone in planes 5 mm behind the phone and 5 mm above the keypad. Figure 4 shows the comparison between measured and simulated data for E- and H-Field distributions [1]. Good agreement was obtained for near-field comparisons.

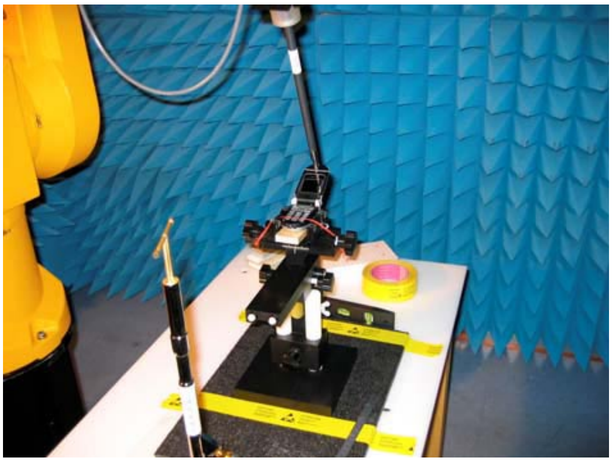


Figure 3. Automated dosimetric assessment system DASY5: free-space measurement of mobile phone.

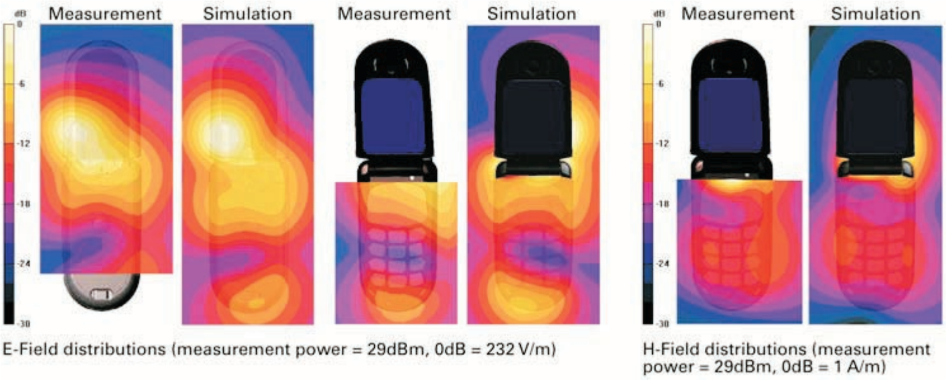


Figure 4. Freespace E- and H-field comparison between simulation and measurement of the mobile phone.

B. Hand Material Properties

The effects of tolerances in dielectric parameters of hand phantom material were investigated by using different permittivity and conductivity to simulate dry and wet hands. Table 3 shows five sets (M0–M4) of different materials used in the simulations. As Figure 5 clearly demonstrates, the TRP value is not sensitive ($<$ 0.5 dB difference) to tolerances in material properties of hand phantoms.

Table 3. Variation of material properties of hand models.

1750MHz	M0	M1	M2	M3	M4
ϵ	32.6	32.6 * 115%	32.6 * 115%	32.6 * 85%	32.6 * 85%
σ	1.26	1.26 * 115%	1.26 * 85%	1.26 * 115%	1.26 * 85%
900MHz	M0	M1	M2	M3	M4
ϵ	36.2	36.2 * 115%	36.2 * 115%	36.2 * 85%	36.2 * 85%
σ	0.79	0.79 * 115%	0.79 * 85%	0.79 * 115%	0.79 * 85%

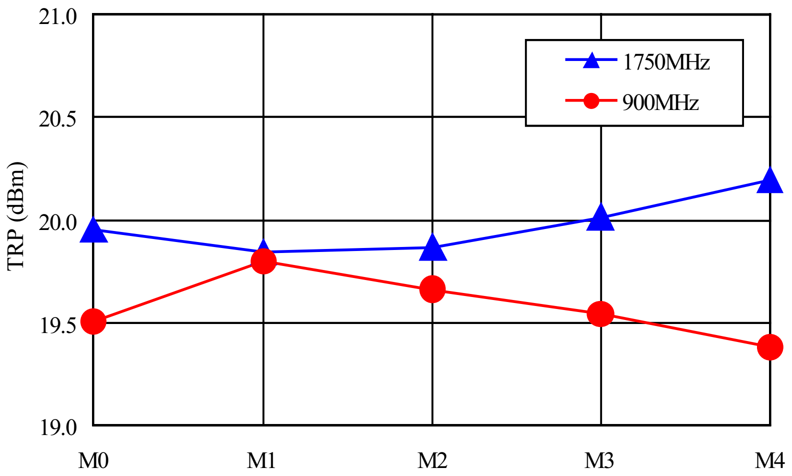


Figure 5. Effect of hand material properties on radiation performance.

C. Hand Size

The original size of the hand phantom model used in this paper is chosen to be close to the average of female and male hand sizes [7]. The smallest female hand and the largest male hand reported in [7] are about 20% different from the average hand size. Therefore, five different hand models have been used to illustrate the effects of human hand size and the palm-phone distance on antenna performance. The simulation results shown in Figure 6 demonstrate that an external antenna is sensitive to hand size. Larger hands do not always result in lower TRP since the antenna performance is also sensitive to the palm-phone distance.

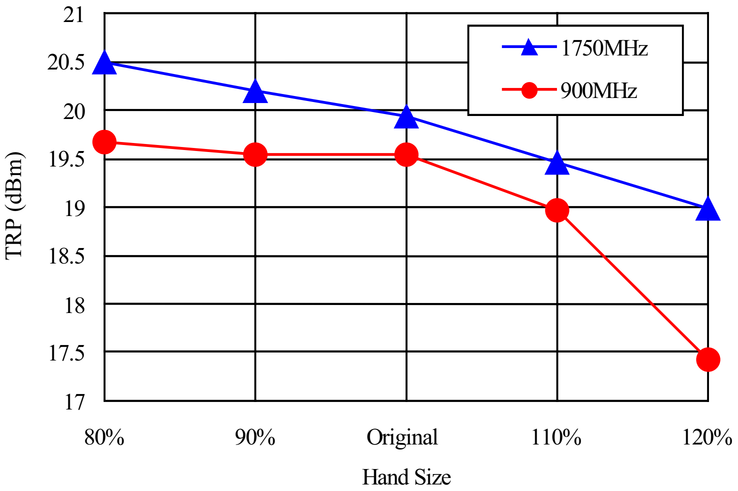
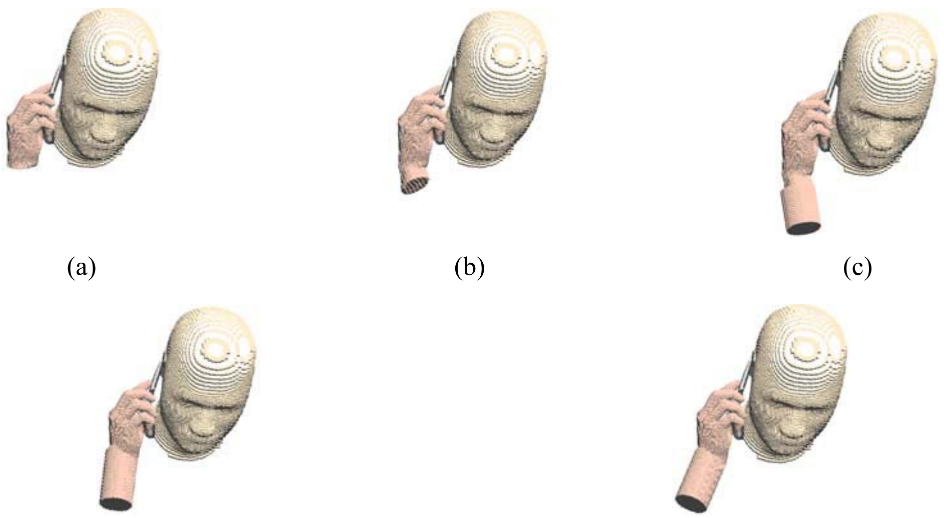


Figure 6. Effect of hand phantom size on radiation performance.

D. Wrist Length and Position

Simulations for five head and hand setups with different wrist models (Figure 7) were also run to study the effect of the wrist on antenna radiation performance. Figure 8 shows that the existence of wrist has no significant influence on TRP. This is due to that the wrist is further away from the antenna and the most of the radiated energy in the direction of wrist is already absorbed by the palm.



(a) (b) (c)

(d) (e)

Figure 7. Hands with different wrists: (a) no wrist, (b) 3 cm long wrist, (c) 10 cm long wrist (d) 10 cm long 15 degrees tilted wrist, and (e) 10 cm long 30 degrees tilted wrist.

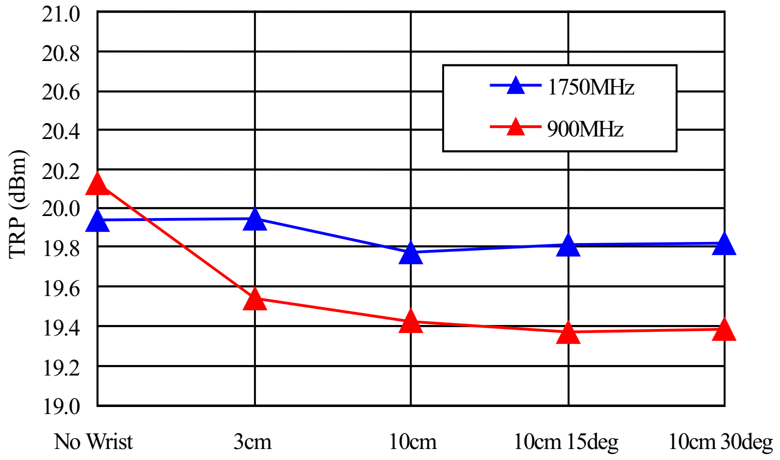


Figure 8. Effect of wrists with different sizes and positions on radiation performance.

E. Index Finger Positioning

Six different index finger positioning scenarios are simulated to investigate the performance of the mobile phone's interaction with a realistic, in-use environment (Figure 9). Figure 10 highlights the effect of the absorbing index finger in the vicinity of the close near-field of the phone in terms of decreased radiated power. Both mismatch and radiation efficiency significantly changes due to presence of the index finger. Very low TRP values are obtained at 900MHz when the index finger is placed on antenna tip. In this case, it mainly changes the mismatch efficiency of the antenna. Due to different E-field distributions on the helical antenna at 900MHz and at 1750MHz, the influence of index finger on TRP is also different. The simulated TRP values presented in Figure 10 shows that there is up to 8 dB difference due to different positioning of the index finger on the mobile phone. The difference of TRP is more than 4 dB if the index finger is only shifted in 9 mm vertically and 15 mm horizontally.

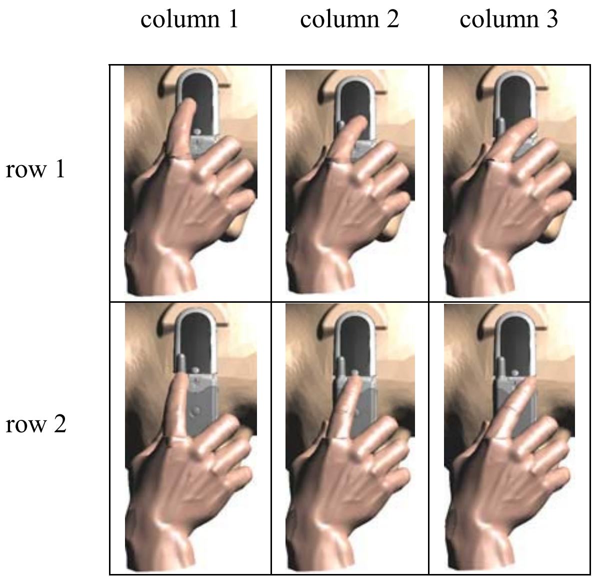


Figure 9. Index finger positioning on the mobile phone.

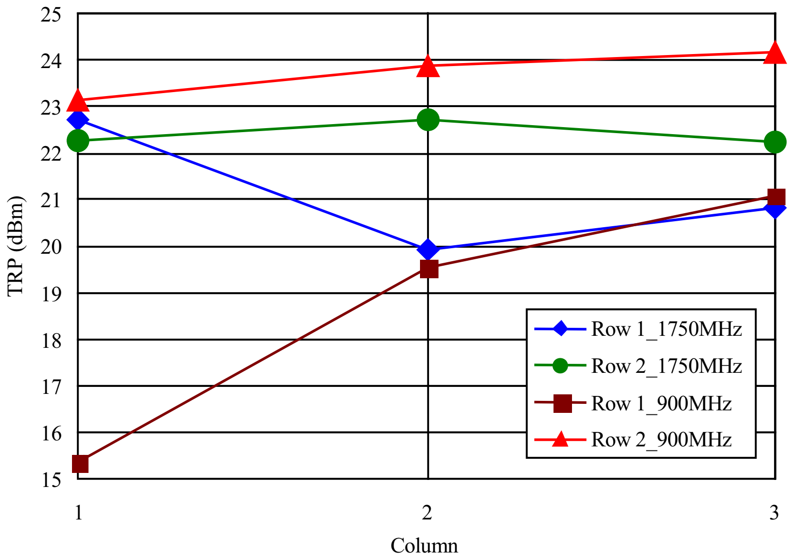


Figure 10. Effect of different index finger positioning on radiation performance.

The effect of index finger positioning on TRP is clearly observed when the index finger in row 1 is moved form left (column 1) to middle (column 2) position (Figure 9). The E-field at the top of the antenna is stronger at 900 MHz than that of at 1750 MHz. Thus, the antenna experiences severe detuning at 900 MHz when the index finger is placed on top of the antenna. The detuning effect of the index finger is illustrated in Figure 11. The index finger changes the resonant frequencies and the input impedances of the antenna.

F. Palm-Phone Distance

Three hand grips with different palm-phone distances are used to illustrate the effect of palm-phone distance on radiation performance of the antenna (Figure 12). In each grip, the index finger is placed on the side of the mobile phone model to isolate the effect of index finger positioning. The simulation results shown in Figure 13 demonstrate that the antenna radiation performance at 1750 MHz is more sensitive to that at 900 MHz.

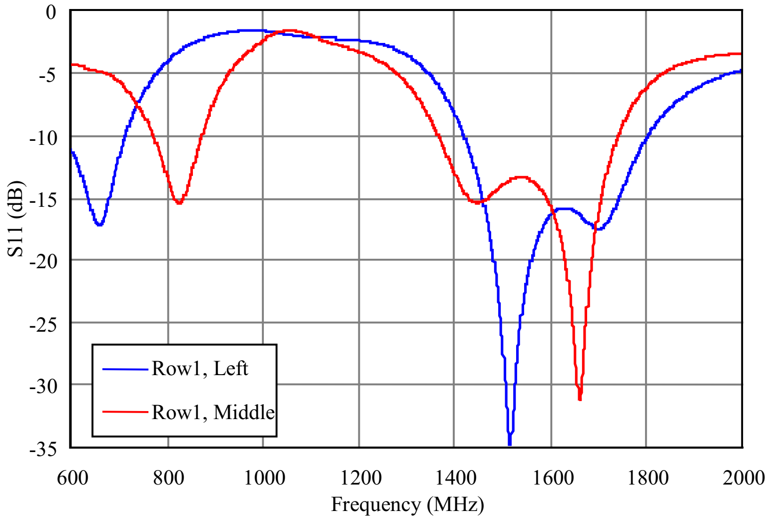


Figure 11. The return loss performance of the mobile phone antenna for different index finger locations.

Figure 12. Three grips with different palm-phone distances: (a) 13 mm, (b) 30 mm, and (c) 45 mm.

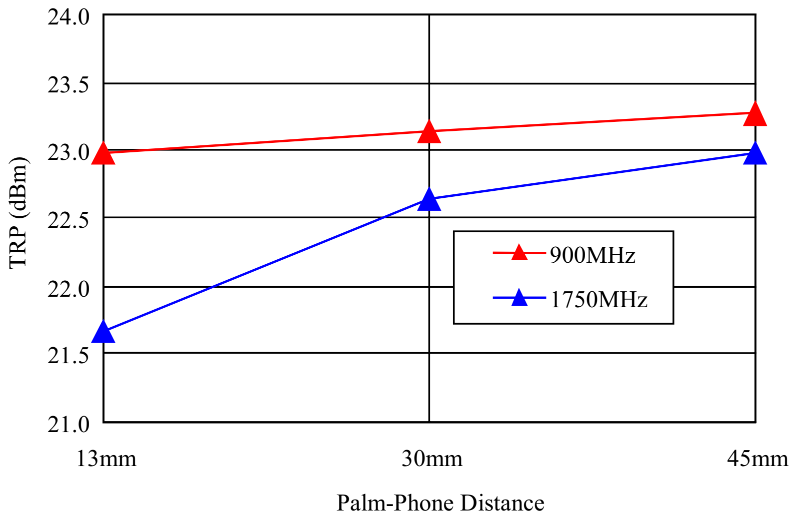


Figure 13. Effect of different palm-phone distance on radiation performance at (a) 900 MHz and (b) 1750 MHz.

5. Genetic Algorithm Based Optimization

The mobile phone antenna can be redesigned to be insensitive to the significant influences of the hand and head phantoms by optimizing it in real-usage conditions. To illustrate the CAD derived mobile phone antenna optimization, the stretched helix antenna was subsequently converted into a parameterized form leading to a total of 4 parameters. The optimization is then performed in two steps: In the first step, a suitable and robust antenna design was developed for free-space. In the second step, this antenna design was the initial solution to optimize the return loss performance when the phone was operated next to the SAM head including homogeneous hand phantom.

The optimization goal is to obtain a dual-band antenna which covers the bands from 890 MHz to 960 MHz and from 1710 MHz to 1880 MHz with a return loss better than -10 dB. The same bands with -15 dB return loss was considered as the goal in the second optimization step, and the previous optimized structure was used as a starting point (forcing it to be a member of the first population).

The optimization process ends if either the maximum number of iterations is reached or the optimization goal is achieved. The return loss of the antenna before and after optimization is shown in Figure 14. The achieved antenna matching for this configuration is better than -10 dB in the two specified bands. Higher TRP values in both frequency bands are also obtained after optimization (cf. Table 4).

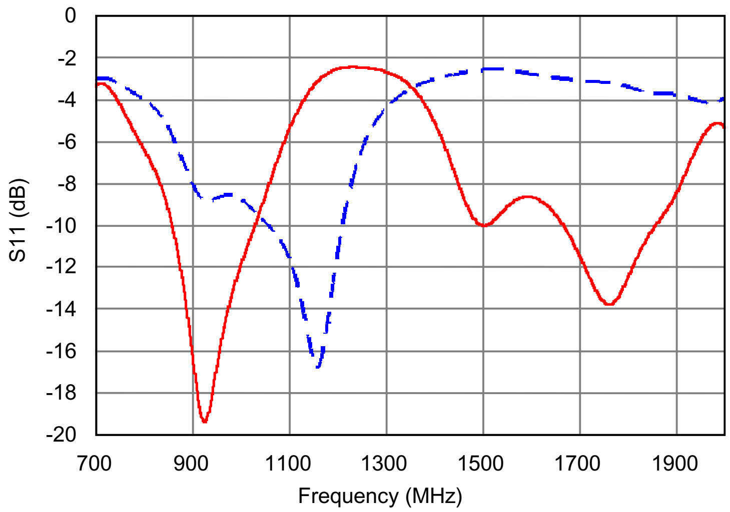


Figure 14. Return loss performance of the mobile phone in free space before (dashed line) and after (solid line) optimization.

The optimized antenna geometry is initially simulated with SAM head phantom and homogeneous hand phantom. The return loss performance shown in Figure 15 (dashed line) and Table 4 clearly demonstrates the detuning effects due to the phantoms. The last step of the optimization procedure enabled us to obtain better return loss performance (Figure 15, solid line) and increased TRP values (Table 4).

It is possible to further improve the return loss performance and reduce the initially obtained SAR and farfield back radiation values in the multi-goal optimization by including other parts of the mobile phone such as PCB, shields, pins, etc. as additional optimization variables.

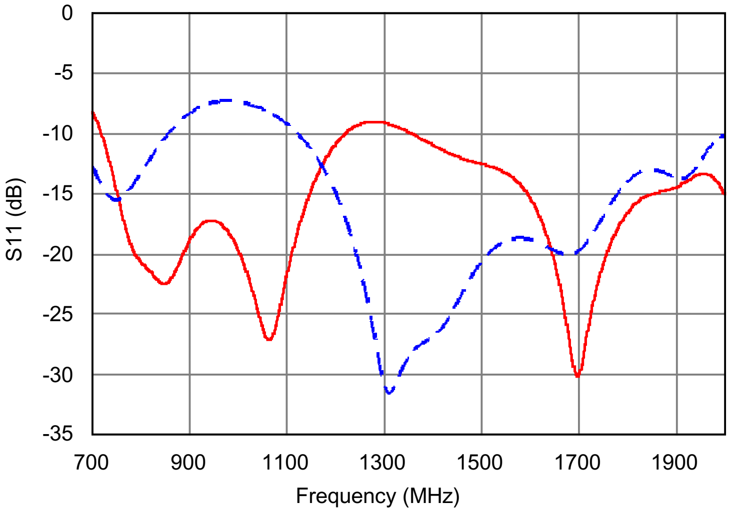


Figure 15. Return loss performance of the mobile phone with head and hand phantoms before (dashed line) and after (solid line) optimization.

Table 4. Simulated mobile phone antenna performance for different setups.

	$\eta_{rad}(\%)$		$\eta_{mis}(\%)$		TRP (dBm)	
Frequency (MHz)	900	1800	900	1800	900	1800
Freespace (before opt.)	57.3	23.5	84.6	54.2	26.8	21.0
Freespace (after opt.)	70.4	29.6	97.6	94.3	28.4	24.5
SAM + H1 (before opt.)	7.4	4.8	85.0	96.1	17.9	16.6
SAM + H1 (after opt.)	8.0	5.5	98.7	97.8	18.9	17.3

6. Computational Requirements

The simulations and optimizations were run using the combination of high performance FDTD and hardware accelerated FDTD solvers [8]. Initial stage of modeling (data import, modifications, source modeling, and simulation settings) required about 3 hours. The hardware acceleration allowed us to perform simulations for free-space and with head/hand phantoms platforms in as little as 7 min (phone only) to 15 min (phone, head and hand phantoms). Table 5 gives an overview of the grid sizes for these simulations and the performance of SEMCAD X.

Table 5. Computational requirements for simulations and optimizations of phone in free-space and under loaded conditions.

SEMCAD X Computation Performance		
	Hand factor study	optimization
min. grid size (μm)	250	300
computational domain	25.5 Mcells	14.2 Mcells
simulation time	54 min	$<$ 15 min
simulation speed	430 Mcells/s	300 Mcells/s
total number of simulation	-	320
total simulation time	-	$<$ 3 days

7. Conclusion

This study shows that numerical methods and enhanced FDTD tools are suitable techniques for supporting engineers in the analysis, design and optimization of transmitters in real-world usage conditions. The influence of the hand on the overall performance of mobile phone antenna is investigated in detail. Hand grip, i.e., positions of fingers on the phone and palm-phone distance, strongly affects the radiation performance of the device. The effect of wrist length and positioning as well as the acceptable deviation of the hand phantom's dielectric properties are negligible in terms of radiation performance. The return loss performance of the entire mobile phone next to the head and hand phantoms is then redesigned using Genetic Algorithms based optimization combined with enhanced parameterization and hardware accelerated FDTD. The straight-forward application of the presented approach demonstrated its robust integration into industrial R&D processes ranging from device optimization to virtual prototyping.

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