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 regarding to antenna performance. The antenna is converted into a parameterized form and then optimized to achieve the targeted multi-band performance in real-usage conditions.

I. 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, a hand phantom has to be included 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. FDTD based 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.

II. 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 DASY4 allow a direct comparison of numerical and experimental data.

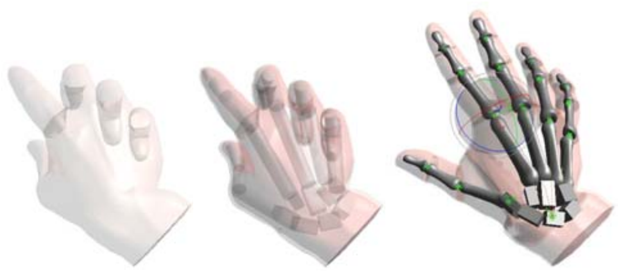
To compare different configurations such as different hand grips on the phone, simulation methods provide the most appropriate technique, since only relative values are compared (i.e., the difference of the radiated values between different configurations). The uncertainty for differences in radiation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

III. 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 purpose and validation of CAD data.

The phone was simulated in the right side 15 degrees tilted position at homogeneous 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

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

Table 1. Material properties of hand and head models

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).

	1750MHz		900MHz	
	H1	H2	H1	H2
Radiation Efficiency	0.109	0.113	0.112	0.113
TRP (dBm)	19.82	19.95	19.37	19.51
NHRP +/-30° (dBm)	16.50	16.79	16.20	16.55
NHRP +/-45° (dBm)	17.98	18.22	17.70	18.02

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

IV. 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 equipped with the latest probe technology. E- and H-Field scans were made on either side of the phone in planes 5mm behind the phone and 5mm above the keypad. Figure 3 shows the comparison between measured and simulated data for E- and H-Field distributions [1]. Good agreement was obtained for near-field comparisons.

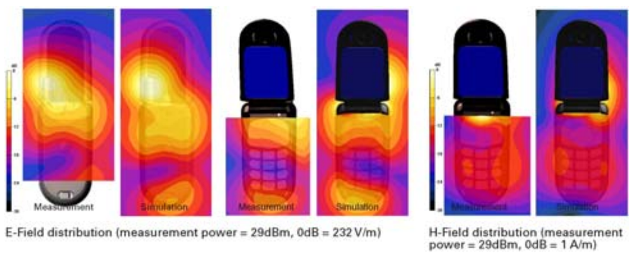


Figure 3. Freespace E- and H-field comparison between simulation and measurement of the mobile phone

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 4 shows five sets (M0 – M4) of different materials used in the simulations. As Figure 4 clearly demonstrates, the TRP value is not sensitive (<0.5dB difference) to tolerances in material properties of hand phantoms.

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%

Table 4. Variation of material properties of hand models

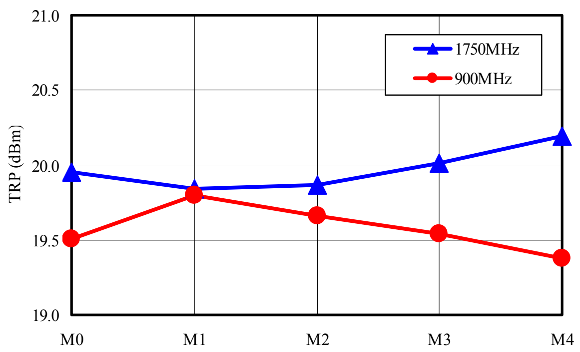


Figure 4. Effect of hand material properties on radiation performance

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 5 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.

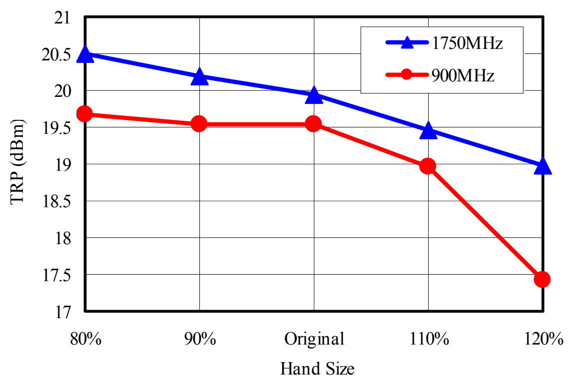


Figure 5. Effect of hand phantom size on radiation performance

D. Wrist Length and Position

Simulations for five head and hand setups with different wrist models (Figure 6) were also run to study the effect of the wrist on antenna radiation performance. Figure 7 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.

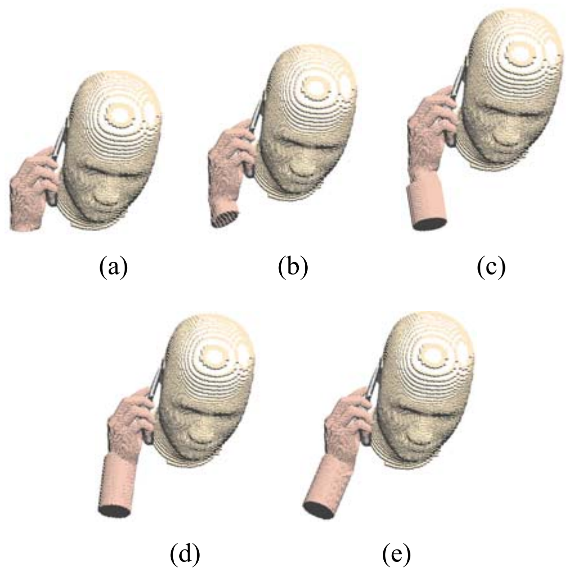


Figure 6. Hands with different wrists: (a) no wrist, (b) 3cm long wrist, (c) 10cm long wrist (d) 10cm long 15 degrees tilted wrist, and (e) 10cm long 30 degrees tilted wrist

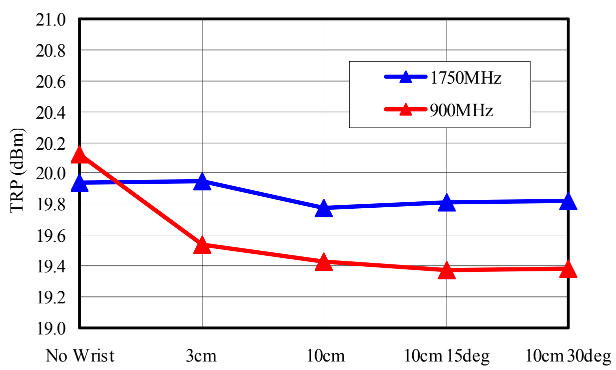


Figure 7. Effect of wrists with different sizes and positions on radiation performance

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 8). Figure 9 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 the index finger. The simulated TRP values presented in Figure 9 shows that there is up to 8dB difference due to different positioning of the index finger on the mobile phone. The difference of TRP is more than 4dB if the index finger is only shifted in 9mm vertically and 15mm horizontally.

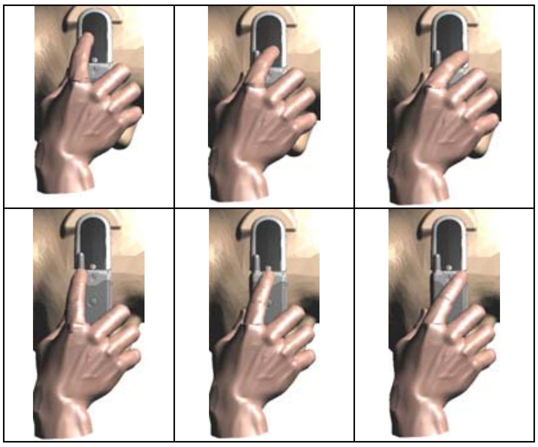


Figure 8. Index finger positioning on the mobile phone

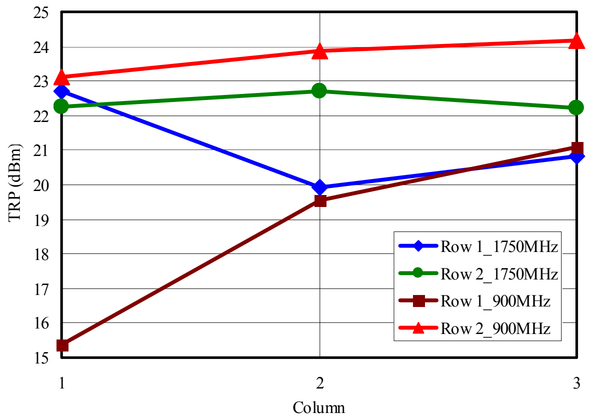


Figure 9. Effect of different index finger positioning on radiation performance

V. 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 resulting grid for free space phone optimization contained about 4.5 million FDTD cells, while the grid for the phone, head and hand simulations contained about 14.1 million cells.

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 -10dB. The same bands with -15dB 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 optimizations were run using SEMCAD X and hardware accelerated workstations (CIB Dual) [8], achieving simulation speeds of more than 350 million cells/s which allows to solve the 14 million cells problems in less than 15 minutes. For free space phone optimization, the maximum number of evaluations was 320 (16 generations), achieving convergence in less than 3 days.

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 10. The achieved antenna matching for this configuration is better than -10dB in the two specified bands. Higher TRP values in both frequency bands are also obtained after optimization (Table 5).

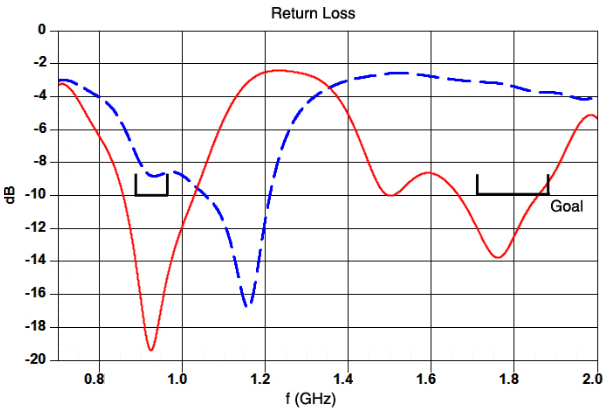


Figure 10. Return loss performance of the mobile phone in free space before (dashed line) and after (solid line) optimization

The optimized antenna geometry is initially simulated with SAM head phantom and homogeneous hand phantom. The return loss performance shown in Figure 11 (dashed line) and Table 5 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 11 (solid line)) and increased TRP values (Table 5).

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.

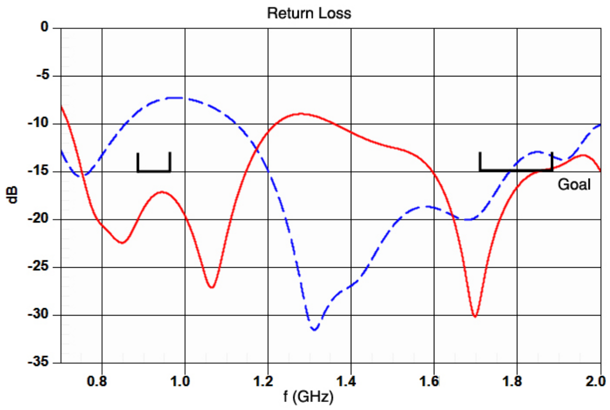


Figure 11. Return loss performance of the mobile phone with head and hand phantoms before (dashed line) and after (solid line) optimization

	η_{rad} (%)		η_{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

Table 5. Simulated mobile phone antenna performance for different setups

VI. 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.

REFERENCES

1. P. Futter, N. Chavannes, R. Tay, M. Meili, A. Klingenboeck, K. Pokovic, N. Kuster, Reliable prediction of mobile phone performance under real usage conditions using the FDTD method, Proceedings of International Symposium on Antenna and Propagation, pp. 355 – 358, 2005.
2. G.F. Pedersen, M. Tartiere, M.B. Knudsen, Radiation efficiency of handheld phones, Vehicular Technology Conference Proceedings, pp. 1381 – 1385, 2000.
3. K.R. Boyle, The performance of GSM 900 antennas in the presence of people and phantoms, Proceedings of International Conference on Antennas and Propagation, pp. 35 – 38, 2003.
4. SEMCAD X: EM/T Simulation Platform. http://www.semcad.com.
5. C. Gabriel, Tissue equivalent material for hand phantoms, Phys. Med. Biol. 52, pp. 4205 – 4210, 2007.
6. DASY Systems. http:\\www.speag.com.
7. T.M. Greiner, Hand anthropometry of U.S. army personnel, United States Army Natick Research, Development and Engineering Center, 1991.
8. Acceleware. http:\\www.acceleware.com.