Mobile Handset Radiation Efficiency as a Function of the Antenna Position Relative to the Human Head

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Abstract: - The radiation efficiency of a mobile handset as a function of its relative position to the user's head, has been investigated. The study was based on theoretical results taken through electromagnetic modelling using MoM and on experimental results obtained by a measuring procedure using a mock-up handset and a phantom head in an anechoic chamber. The distance between antenna and the head as the handset is moving away from the head in the horizontal direction is found to be the main factor affecting the radiation efficiency in comparison with the movement of the handset vertically or horizontally on the "ear to nose" direction.

Key-Words: - radiation efficiency, mobile handset, phantom head, method of moments

1. Introduction

The big proliferation of mobile communication systems has caused an increased concern about the interaction between the human body and the antennas of mobile handsets. A lot of research studies have been carried out based on this interaction [1],[2], dealing generally with two aspects. The first aspect is the deposition of the microwave energy in the user's body in order to establish precise safety standards. The second aspect is the influence of the user's body on radiation properties of the mobile phone, which is significant from the antenna design point of view. Antenna characteristics that are mostly affected by the presence of the human body are radiation pattern, input impedance and radiation efficiency [3].

The presence of the human body (and more specifically of the head) close to the handset causes (generally) degradation of its performance in comparison with the operation of the handset alone. The measure of this performance is the radiation efficiency of its antenna. The aim of this work is to study the radiation efficiency of a handset antenna near the human head. We have studied the dependence of the efficiency on the antenna position with respect to a phantom head. We have theoretically calculated and experimentally measured the radiation efficiency of a mobile handset model by moving it on the X, Y and Z-axis of an orthogonal coordination system fixed on the phantom head. The three-dimensional far-field measurements of mobile handset near the phantom head were performed inside an anechoic chamber while they were accurately modeled in a PC using the MoM (Galerkin method).

In section 2, the theoretical models of the handsets and a phantom head are described and the EM modeling of the structure is presented, In section 3 the measurement procedure is described and the results are presented in section 4. Finally, conclusions of the work are shown in section 5.

2. Theoretical Model

In order to analyze the radiation efficiency of the handset's antenna in the presence of the human head in relation with its position, an accurate geometrical model of a phantom head and a handset were made using a dedicated software package WIPL-D [4] (Fig. 1). This model simulates the real model (Fig. 2) that has been constructed in order to be used in measurements procedure. The handset had a monopole antenna attached on the top with 41 mm length (~ $\lambda/4$ at 1800 MHz) and 1 mm radius. In order to model the human head, a 2 mm thick spherical glass shell has been used. The shell had 90 mm outer radius and it was cut by two parallel planes at a distance of 150 mm (Fig. 2). It was filled in by a liquid mixture of electric parameters $\varepsilon_r = 40$,

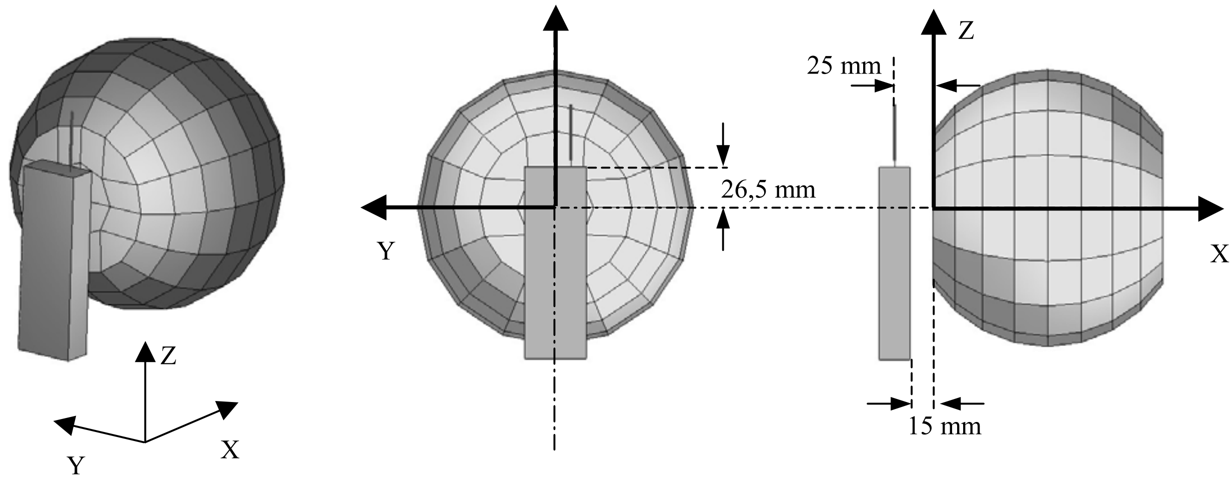

Fig. 1. The theoretical model.

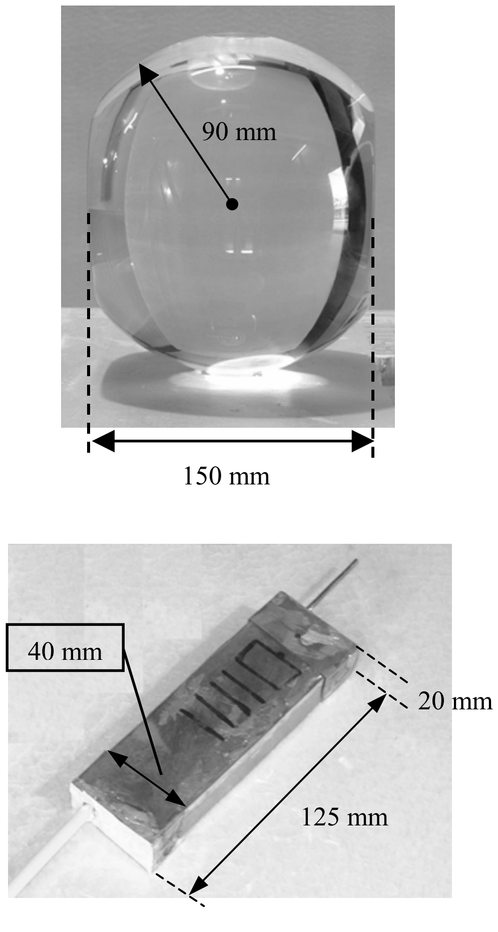

Fig. 2. The real model.

σ = 1.40 S/m, according to the recommended standards for 1800 MHz [5].

Radiation efficiency is the full quality factor of an antenna and can be defined as the ratio of the total radiated power to the total power accepted by the antenna:

$$e = \frac{P_{rad}}{P_g} \quad (1)$$

where P_{rad} is the radiated power of the antenna and P_{g} is the input power. The WIPL-D calculates the radiated power over the pre-specified dense 3D mesh.

The head model consists of 320 bilinear hexahedra in which have been assigned the same electrical parameters as those of the real model. The handset model consists of metal rectangular plates and a cylindrical wire (for the antenna). A point-like (delta-function) generator is assumed to be attached at the plate-to-wire junction, while we assume that all conductors are perfect.

Basic numerical task is the obtaining of the electric surface currents distribution over the plates and the wire of the handset and equivalent electric and magnetic currents over hexahedra surfaces. Surface currents distribution is approximated by polynomial functions that automatically satisfy continuity equation across junctions. Current distribution is obtained by solving the electric field integral equation (EFIE) by the Method of Moments (Galerkin method). The complete methodology [6] results in an accurate and efficient numerical method for analysis of wire/plate/dielectric structures and is extremely well suited for EM modeling of the handset and the phantom head.

The aim of our work is to calculate the radiation efficiency, *e*, for several shifts in relation to the initial position. The initial position of the handset can be seen in Fig. 1. Therefore, *e* was calculated for the following cases:

a) Movement along the X- axis (handset constant along the Y- and Z- axis in the initial position). This situation corresponds with antenna moving away from the head in horizontal direction.

b) Movement along the Y- axis while the handset was staying in a fixed distance from the phantom and constant along the Z- axis.

c) Movement along the Z- axis with the handset constant along the other two axis.

3. Measurements

Measurements were taken inside of a RF shielded anechoic chamber 10 m long, 5 m wide and 5 m high, fully lined with 0.9 m high absorbing pyramids. The phantom head and the handset were placed inside a box made of styrofoam and mounted on the RF transparent stand situated on a remote controlled turntable. The turntable was connected to the positioning controller via an optical fiber. At the opposite side of the chamber a calibrated reference horn antenna (EMCO-3115) was sited 4.75 m away of the handset. A vector network analyzer (VNA) was used for the measurements. The handset's antenna was connected at its one port and the horn antenna at the other. Full two-port s-parameters measurements at the frequency of 1.8 GHz were performed using the VNA calibrated at the antennas' ports. All the devices were controlled by a PC through an IEEE bus with an appropriate software (HP-VEE). The complete measurement setup is presented in Fig. 3.

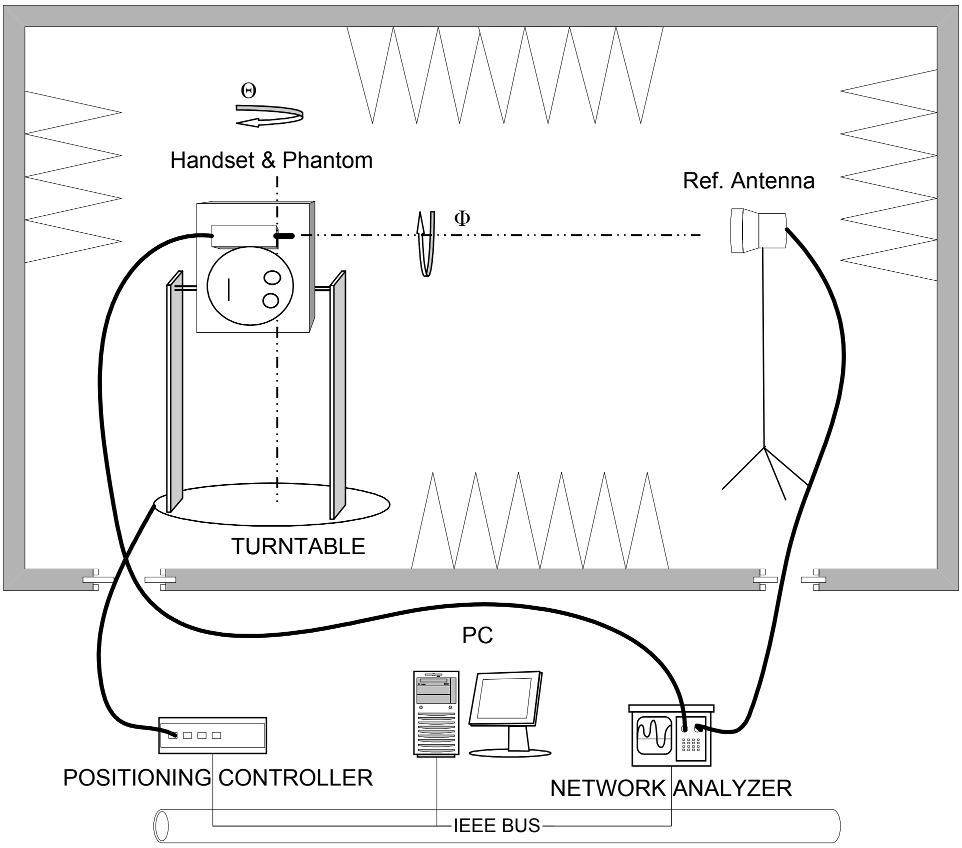

Fig. 3. Measurement setup.

Assuming free space conditions inside the anechoic chamber, and considering the whole measurements setup as a 2-port system with reference planes at the two antennas' ports we have the following formula for the calculation of the gain from the measured s-parameters:

$$\frac{|S_{21}|^2}{\left(1-|S_{22}|^2\right)\left(1-|S_{11}|^2\right)} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2)$$

where G_T is the power gain of the transmitting device, G_R is the power gain of the reference antenna and d is the distance between the reference antenna and the handset.

In the measurements setup, (Fig. 3) angle theta (θ) of a spherical coordinate system is the turntable angle and angle phi (φ) is the inclination angle of the supporting styrofoam box. Three-dimensional radiation diagrams are obtained using $\theta_{step} = 5°$ (by automatic turntable scan) and $\varphi_{step} = 10°$ (by manual positioning). Both θ and φ polarizations were measured in separate measurement cycles and the total gain obtained as:

$$G_T = G_{T\theta} + G_{T\varphi} \quad (3)$$

For suppression of possible unbalanced currents on the feeding cable of a handset ferrite rings are put around the cable at mutual distances of λ/4. Using the above measuring procedure, we measure the gain of the handset alone (G_{HS}) and the gain of the handset with the presence of the phantom (G_{PH}).

Assuming perfect matching of the handset antenna, we can consider that the radiated power when the handset is operating without the presence of the head (P_{HS}) is equal to the input power (P_g):

$$P_{\mathrm{HS}} = P_{\mathrm{g}} \quad (4)$$

while for the case of operation with the presence of the phantom head, the radiated power (P_{PH}) is:

$$P_{\mathrm{PH}} = P_{\mathrm{g}} - P_{\mathrm{abs}} \quad (5)$$

where P_{abs} is the power absorbed in the head. The radiated power is calculated from the total gain by the classical formula [7],

$$P_{\mathrm{rad}} = \frac{P_{\mathrm{g}}}{4\pi} \oint_{4\pi} G \mathrm{d}\Omega \quad (6)$$

which can be approximated in:

$$P_{rad} \approx P_g \frac{\sum G}{N} \quad (7)$$

where the summation symbol represents summation of the N measured gain values, G. The aim is the calculation of the antenna's radiation efficiency when the phantom head is present. So we can change the terms in equation (1) using (4),(5) as:

$$e = \frac{P_{PH}}{P_{HS}} \quad (8)$$

or in terms of the gain and using equations (6),(7):

$$e\ \% = \frac{\sum G_{PH}}{\sum G_{HS}} \cdot 100\ \% \quad (9)$$

where G_{PH} and G_{HS} are the total gain of the handset with and without the phantom head, respectively.

4. Results

As it is described in section 2, the radiation efficiency of the handset antenna was investigated as the handset was moving in different positions along the three axis of the orthogonal coordination system fixed on the head (Fig. 1). The obtained results are given below in three different cases:

a) The handset antenna was moving away from the head along the X- axis from the initial position (25 mm distance from the head) to 35 mm from it (60 mm distance from the head). The obtained theoretical and experimental results are presented in Fig. 4. We can notice a significant increment of the radiation efficiency as the distance between head and handset is getting larger. By moving the handset 15 mm away from the initial position, we have about 20% relative increment of the efficiency. While at the end of the range (35 mm) the efficiency is more than 90%. Note that we consider that 100% is the efficiency of the handset transmitting alone. In the same figure it can be seen that the derived experimental results are close to the theoretical justifying the correctness of model simulation.

b) The handset antenna was moving along Y- axis in the "noise-to-ear" direction and vice versa, from the Y initial position to 50 mm away. The obtained theoretical results for two different antenna-head distances are presented in Fig. 5.

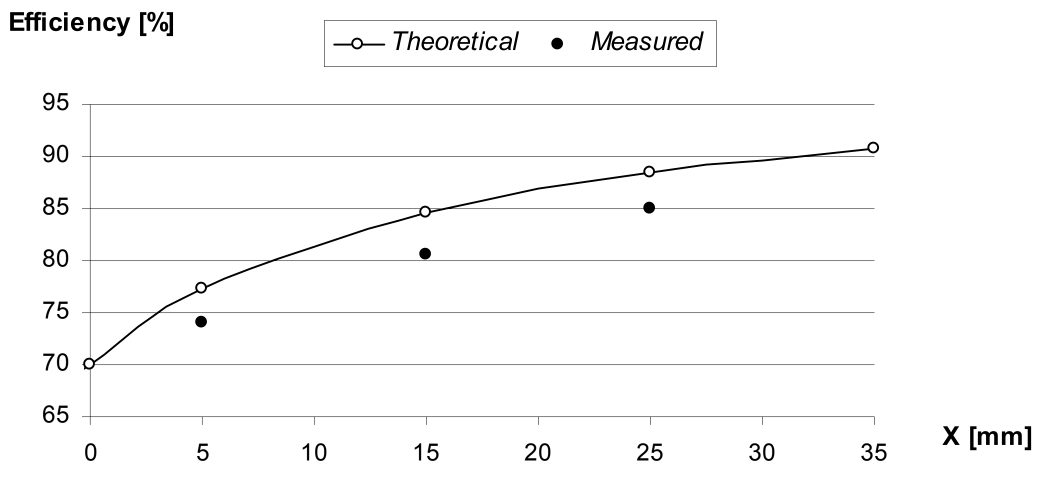

Fig. 4. Radiation efficiency vs movement on X- axis.

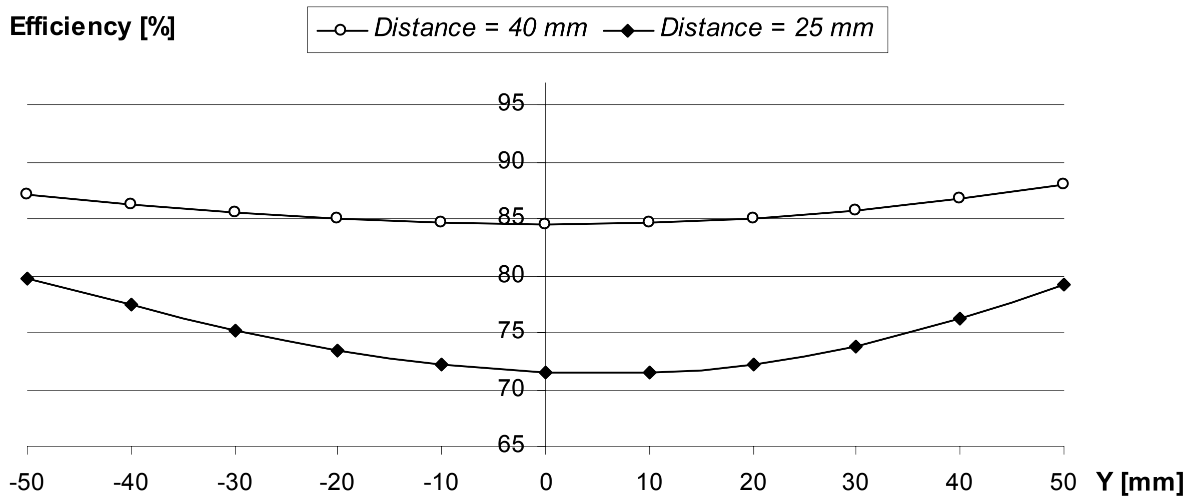

Fig. 5. Radiation efficiency vs movement on Y- axis.

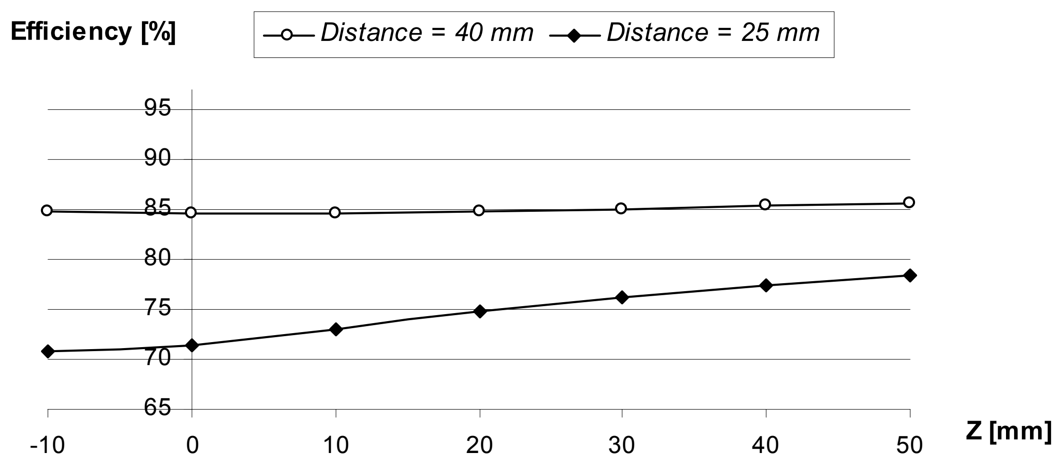

Fig. 6. Radiation efficiency vs movement on Z- axis.

The increment of the radiation efficiency as the antenna is moving away from the head along the Y- axis is relatively small in comparison with that of the movement on the X- axis. If head-antenna distance along X- axis is 40 mm, the efficiency is nearly constant at almost 85% as it is moving along the Y- axis.

c) The handset antenna was moving along Z- axis ranging from -10 mm to 50 mm from the initial position. The obtained theoretical results for two different antenna-head distances (25 mm and 40 mm) are presented in Fig. 6. The increment of the radiation efficiency as the antenna is moving away from the head along the Z- axis is relatively small in comparison with that of the movement on the X- axis and Y- axis as well. If the antenna is 40 mm away from the handset along X- axis, the efficiency is nearly constant at almost 85% as it is moving along the Z- axis.

5. Conclusions

Comparing the influence on radiation efficiency that the position of the handset antenna along the three axis has, we can conclude that the dominant factor affecting the efficiency is the position of the handset along the X-axis. As the distance between head and antenna is getting larger the absorbed power on the head is decreased and the radiation efficiency is proportionally increased. On the other hand moving the handset vertically (along Z-axis) or horizontally (along Y-axis) we have theoretically proved that the influence on the radiation efficiency is significantly smaller.

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