Investigation of Mobile Phone Antennas with Regard to Power Efficiency and Radiation Safety

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Abstract: *Numerical calculations using the finite-difference time-domain method and phantom measurements have shown that the exposure of the brain of an operator using a 900 MHz GSM mobile phone is by a factor of 4 or more below the most strict limits (IEEE C95.1). A novel, durable heterogeneous phantom of the human head has been developed. It allows repeatable measurements of the so-called specific absorption rate over years. The SAR of 7 commercial available GSM 900 mobile phones were evaluated. Also typical antennas of mobile phones were simulated and compared to new developed antennas in that project. One of those antennas reduces the amount of maximum SAR values produced in the human head by a factor of 3 in comparison to the conventional helical design. Thus, power efficiency and radiation safety are improved.*

1. Introduction

Operation of a mobile phone close to the human head results in a power absorption in the tissue of about 60 %. This stresses the human body and wastes energy of the battery. Therefore, the design goal for mobile phone antennas is maximum efficiency at lowest possible specific absorption rate (SAR; power absorbed per mass unit). The goal of this project was both to investigate the SAR occur with the operation of present commercial mobile phones and to design optimized antennas.

The SAR can be determined by numerical calculations or phantom measurements. We have implemented the finite-difference time-domain method using the commercial computer program XFDTD. Furthermore, we built a novel heterogeneous phantom. In the first step, we measured the SAR in our phantom of 7 different commercial mobile phones. Then, models of mobile phones equipped with antennas of typical commercial construction were built and analysed. We also designed optimized antennas and verified their performance by measurements.

2. Methods of Investigation

2.1 Construction of a Novel, Heterogeneous Phantom

We compiled published scientific data [1, 2, 3, 4, 5, 6, 7, 8, 9] on the relevant material parameters (electrical conductivity, permittivity, specific heat and density) of human tissue. In addition, we made measurements on fresh muscle and brain tissue and eyes. Using these data, we designed a novel, heterogeneous phantom based on a human skull. The composition of our phantom materials are based on [4, 5]. Most phantom materials age quickly and change their characteristics. Therefore, brain, muscle and eye materials of our phantom consist of exchangeable liquids. The facial muscle is made of semisolid material and can also be replaced without changing the characteristics of the phantom.

2.2 SAR Measurement

We used the measurement system DASY3mini including an isotropic E-field probe ET3DV5R with three orthogonal dipoles of 6 mm total length [10]. The measurement data are transferred to a PC via an optical fibre.

For the E-field probe we built a plastic support frame with x-y-z positioning. The mobile phone can be placed at the ear of the head phantom in a characteristic angle (rotated 60° from upright). The probe is directly inserted into the brain simulating liquid respectively via plastic cannulas into the right eye. So we can test in any position in the brain and in several positions (along the cannula axis) in one eye. E-field measurements were made in the left half of the brain (148 points). The E-field maximum were found by coarse scans of the probe position in the area of highest SAR. They were always found right beside the antenna. The used probe position in the eye was 2 mm behind the anatomical position of the lens. All measurements were made in an anechoic chamber of 180 cm x 145 cm x 145 cm and 12´´ pyramidal absorbers.

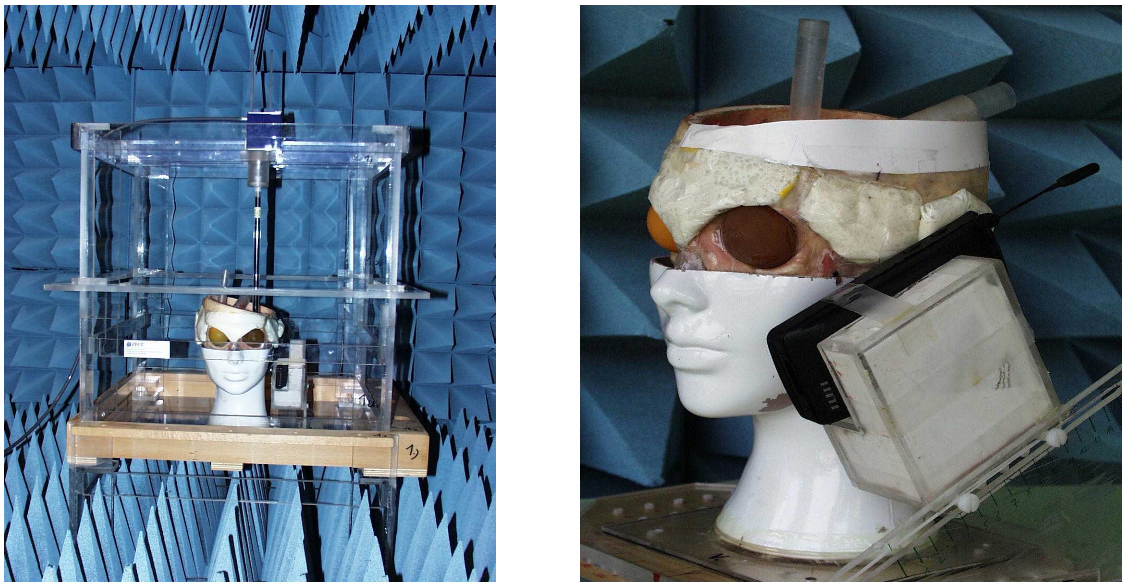

Figure 1: Arrangement for SAR-measurements in a heterogeneous phantom with support frame (left) and head and hand phantom with a phone (right)

2.3 Simulations

Simulations were made using the finite-difference time-domain method FDTD [11]. A commercial head model based on NMR (nuclear magnetic resonance imaging) was used. The arrangement of head, mobile phone and hand is divided in 4.9 million cubic cells of 3 mm. Subgrids (cubic cells of 0.6 mm, up to 0.9 million elements) are superimposed for the relevant parts of the mobile phone (antenna, parts of the chassis). The head is modelled from 6 different kinds of tissue: brain, muscle, bone, eye humor, cartilage and dry skin. The hand is modelled from bone, cartilage and fat and dry skin. Material parameters are given in [11].

For excitation, an electromagnetic force is defined in the feedpoint of the antenna. The program calculates electric and magnetic fields, currents, electric potentials and SAR in small time increments. Antenna input impedance over frequency, return loss, radiation pattern and radiation efficiency were calculated using FFT (fast fourier transformation) and near-zone to far-zone transformation [11]. The radiation efficiency η is usually defined as formula 1 [12], where P_{rad} is the amount of power radiated into the space and P_{absorb} is the amount of power absorbed in the tissue.

$$\eta = \frac{P_{rad}}{P_{rad} + P_{absorb}} \cdot 100 = \frac{P_{rad}}{P_{delivered,i}} \cdot 100 \quad [\%], \qquad (1)$$

2.4 Radiation Pattern Measurements

The whole setup consisting of mobile phone and the head and hand phantom as used for the SAR-measurements was rotated around the vertical axis through the center of the head. Measurements were made in a horizontal plane at the height of the inner ear of the phantom in a radius of 85 cm. Referring to a sherical coordinate system, E_φ and E_ϑ were measured with a precision reference dipole PRD3100 from Seibersdorf and a spectrum analyzer HP 8591 EM.

3. Investigation of Commercial Mobile Phones

We have tested 7 different mobile GSM 900 phones of 3 manufacturers. The measurements were conducted in a shielded anechoic chamber of the EMC Test Laboratory Seibersdorf. The operation of the mobile phones was controlled via a Rohde & Schwarz CMD 55 GSM Tester that simulated a base station. The mobile phones were operated at their highest power level of approximately 250 mW (average). The position of the mobile phones at the phantom was as shown in right side of Figure 1.

Table 1 shows measurement results of peak SAR in the brain and in the eye for 7 different GSM mobile phones (M1 - M7). The numbers are calculated based on the measured peak values of E_{rss}. Due to very different antenna and case designs, we observe variations of more than a factor of 4 in the brain and a factor of 20 in the eye.

SAR [W/kg]	M1	M2	M3	M4	M5	M6	M7
Brain	0.245	0.181	0.407	0.098	0.120	0.282	0.379
Eye	0.142	0.168	0.077	0.026	0.008	0.169	0.132

Table 1: Peak SAR with real mobile phones for the brain and the eye

If the results are compared with the standard safety limits of IEEE, CENELEC or ICNIRP, we must account for the fact, that standards limits are averaged over 1 g, 10 g, or even 100 g of tissue. Thus, in terms of standard safety limits, our measurement values represent worst-case estimations and are always on the safe side. Nevertheless, all peak values are more than a factor of 4 below the most stringent limit (IEEE C95.1, 1.6 W/kg averaged over 1 g).

The example shown in Figure 2 gives the equivalent antenna gain over an isotropic radiator (dBi) on the basis of an average transmitted power of 250 mW. We can see that the presence of the head reduces the field strength available for communication significantly. The field-strength in the direction of the head is reduced by more than 10 dB.

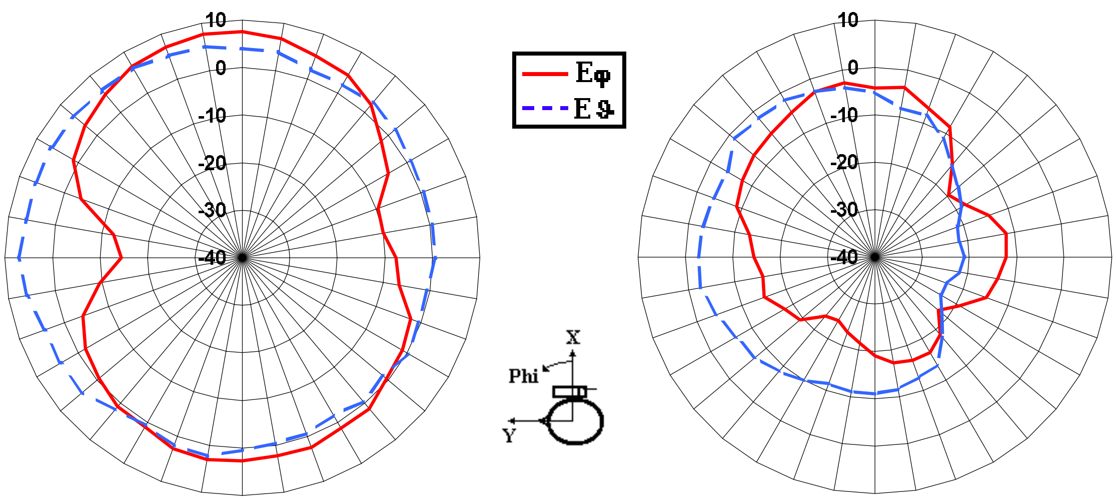

Figure 2: Measured radiation pattern of mobile phone M4 only with hand model (left side) and with the presents of the hand and the head phantom (right side).

4. Investigation of Different Kinds of Antennas

We investigated both some usual antenna types employed in commercial mobile phones and some new designs, developed in this project. For all antennas the case is a metallic box of 24 mm x 48 mm x 120 mm, covered with a 3 mm thick layer of plastic. After extensive simulations, we selected the most promising types for further optimization. In the figure below 6 different antennas are shown (S1-S6). Models S5 and S6 are optimized antennas developed in this project. These two showed the lowest SAR in the brain and good efficiency.

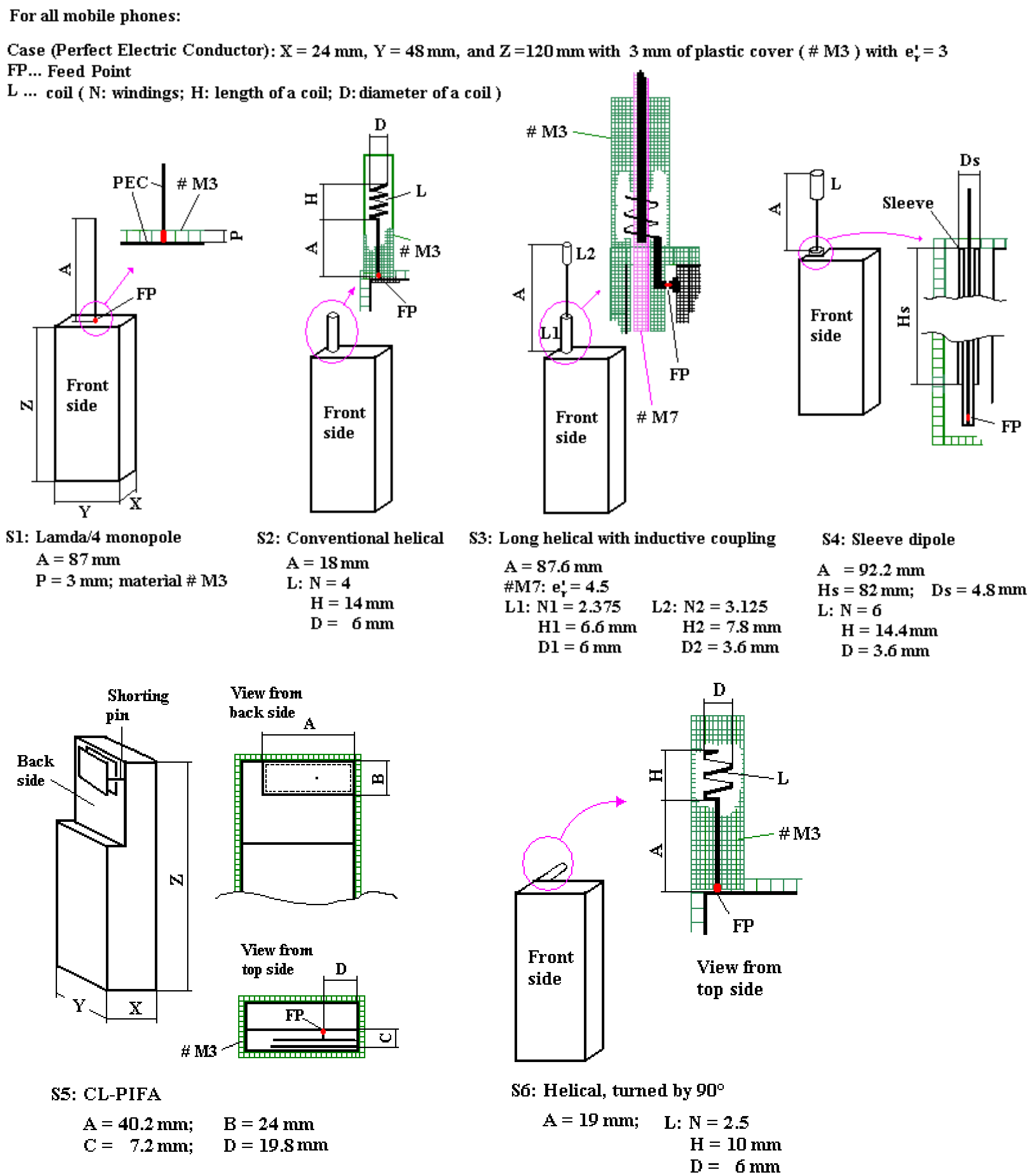

Figure 3: Mobile phone antennas used for the investigations of SAR and radiation efficiency

For experimental verification, we constructed models of S5, S6 and S2 for measurements named as B5, B6 and B2. S5 respectively B5 is a "capacitively loaded - planar inverted folded antenna" (CL-PIFA) [13]. It is integrated in the plastic case of the mobile phone. Antenna Nr. 6 has a helix which is slightly longer than the conventional design and it is turned by 90°. We tried to make the practical construction and the numerical model as identical as possible.

For the measurements of B2, B5 and B6 the case with the antenna was fed from a signal generator and power amplifier via a 120 cm long coaxial cable. The influence of the cable on the field distribution was less than 0.3 dB (investigated by various experiments). The cable position remained unchanged for all measurements. The transmitter power was 250 mW average. Both the forward and backward power were measured by HP 436A power meters.

4.1 Results of SAR and Radiation Efficiency

Figure 4 compares the calculated maximum values of SAR in the brain, in the whole head and in the hand. The calculated results refer to volume elements of 3 mm x 3 mm x 3 mm, corresponding to approximately 0.03 g of tissue. For the models S2/B2, S5/B5 and S6/B6, the numbers achieved by phantom measurements are also shown. The coincidence is amazingly good. In comparison to the measurement results with the standard helix, our optimized antennas reduce the peak SAR by 49 % (CL-PIFA) and 55 % (90°-helix). The maximum averaged SAR (based on the simulations) is reduced by 54 % (CL-PIFA) and 65 % (90°-helix).

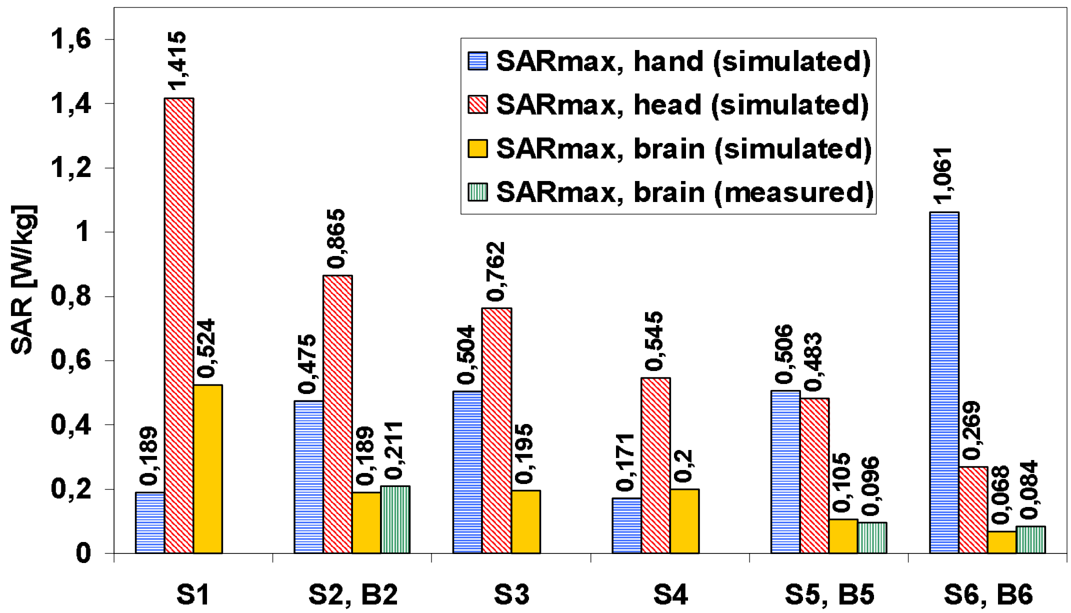

Figure 4: Maximum values of peak SAR in the hand, the whole head and the brain

Figure 5 shows the SAR-values in the brain averaged over 1 g of tissue. This representation corresponds to the safety limits of IEEE. We can see that there is a safety factor of more than 10 for all commercial antenna designs, for our optimzed constructions (S5, S6) the factor is more than 25. Figure 6 accounts for the radiation efficiency achieved with each kind of antenna: The left bar is again peak SAR in the brain when the transmitter power is at 250 mW. However, when comparing different mobile phones, we must also take into account the radiation efficiency of their antennas: In mobile telephone networks, the base station controls the transmitter power of the mobile stations depending on the field-strengths they generate at the receiving antenna of the base station. If a phone has a more efficient antenna, it only needs to transmit less power. If this is taken into account, the right bars in Figure 7 result. They compare the yielded SAR for equivalent radiated power (that is the amount of power, which can be used for communication) normalised with the efficiency of S2 to 94 mW (delivered power for S2 is 250 mW and different for the other phones).

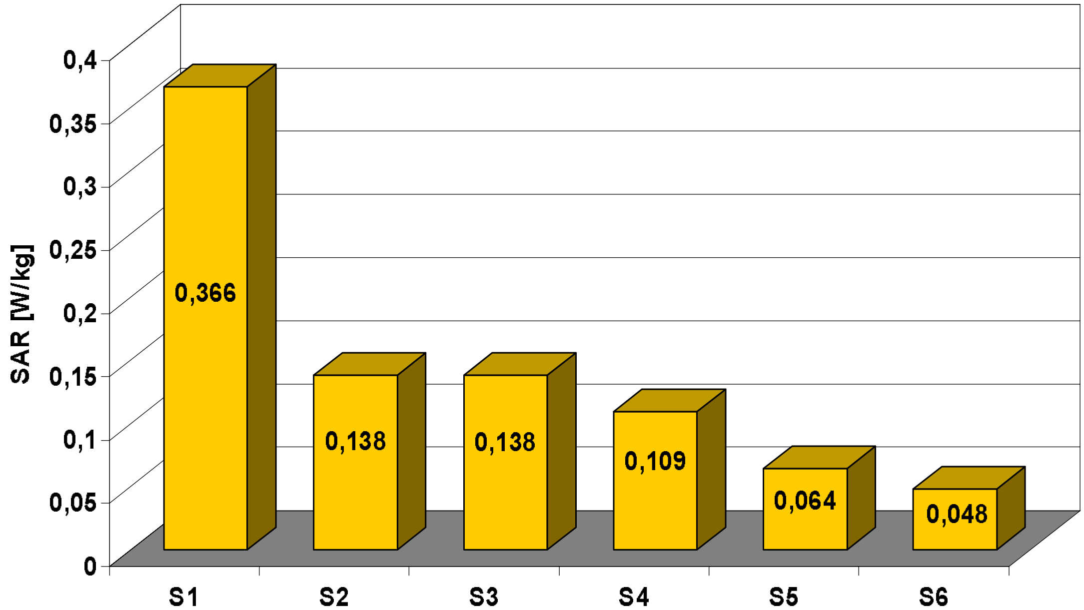

Figure 5: Calculated maximum values of SAR in the brain, averaged over 1 g of tissue

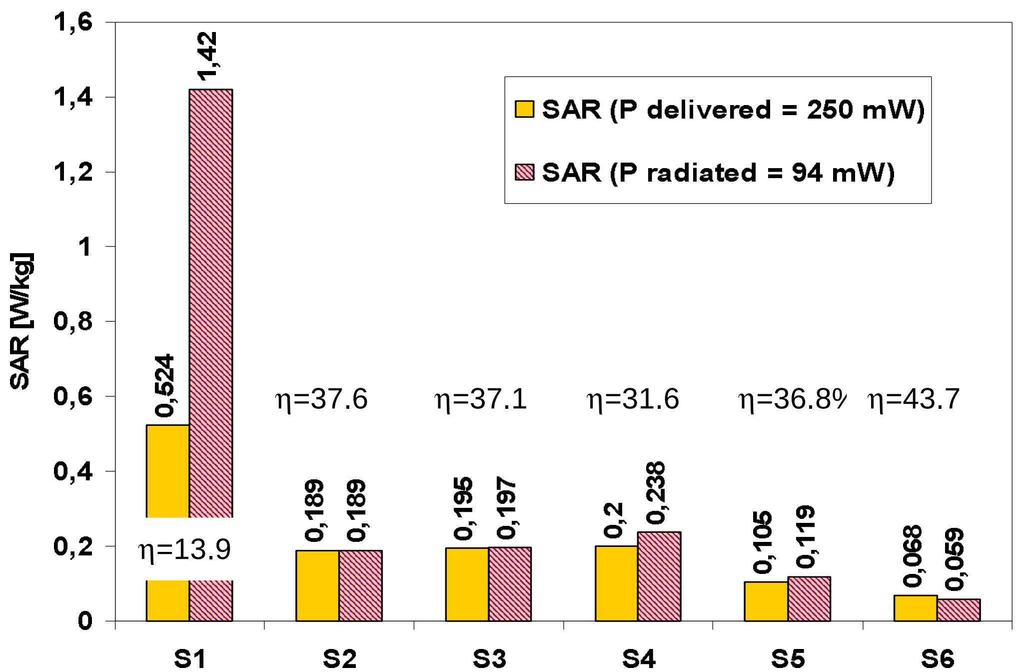

Figure 6: Calculated efficiency and calculated peak SAR in the brain for equivalent delivered power and equivalent radiated power

4.2 Radiation Patterns

Figure 7 and Figure 8 are showing the calculated and measured radiation patterns of the new developed antennas S5/B5 and S6/B6 including head and hand phantom. The coincidence is acceptable. We can see that the antennas still have good omnidirectional pattern while the SAR in the head is significantly reduced in comparison to the conventional helix design.

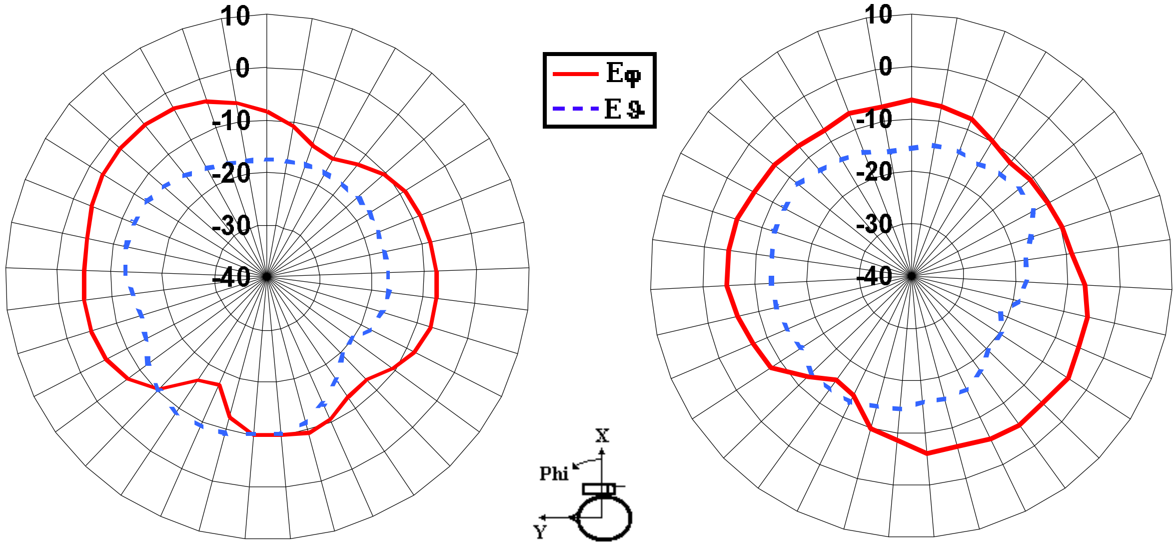

Figure 7: Calculated (left) and measured (right) radiation patterns of the CL-PIFA (S5/B5)

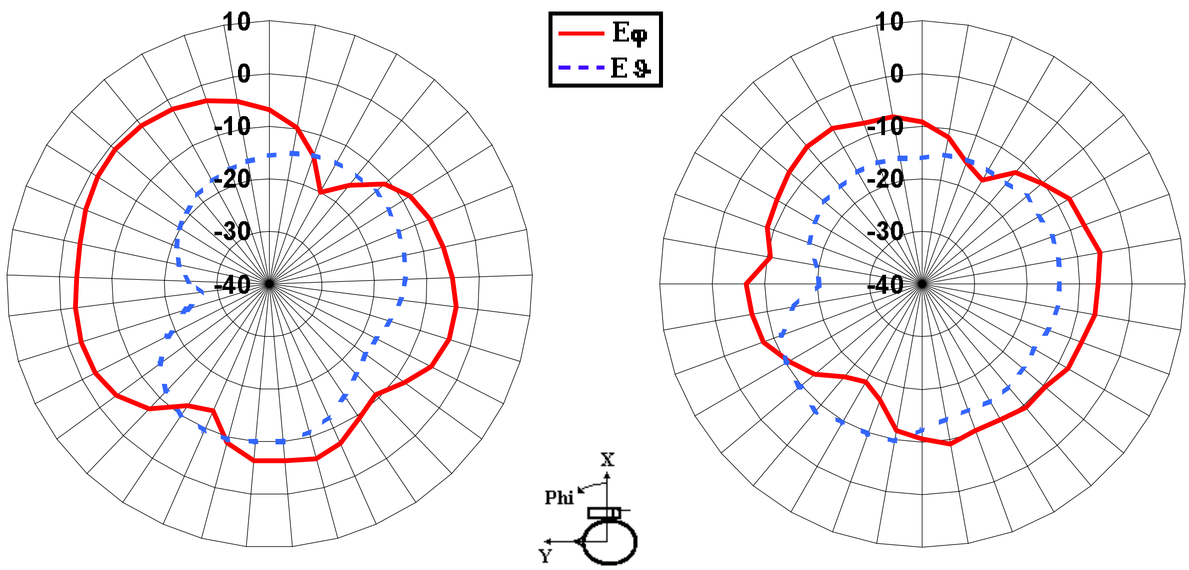

Figure 8: Calculated (left) and measured (right) radiation patterns of the 90° turned Helical antenna (S6/B6)

5. Conclusion

All the tested GSM 900 phones did not exceed the limits of IEEE C95.1 and ÖNORM S1120 and can therefore be considered safe according to these standards. Maximum SAR in the users head can be significantly reduced by implementing optimised antennas. The power efficiency of mobile phones can be improved also, but only by a few percent. However, while constructing new type of antennas one has to take into account the SAR in the head and in the hand of the user.

6. Acknowledgement

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7. References

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