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Flat Phantom Setup for the Performance Check and System Validation of Measurement Systems according to IEEE 1528 and IEC 62 209

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1 Introduction

According to the recommendations of the proposed IEEE 1528 Standard for determining the Specific Absorption Rate (SAR) in the human body due to mobile communications equipment (MTE) [1], the performance of the measurement system for compliance testing must be verified before it is used for the actual device testing. For this purpose, the standard suggests a simplified phantom setup which allows rapid validation that the measurement equipment is operating within its specifications with respect to, e. g., component drift or liquid parameters. The setup consists of a flat-bottomed vessel filled with tissue simulating liquid and a calibrated dipole antenna (see Section 3).

2 Objectives

Within the framework of this study the following open issues were investigated in order to provide reference data for [1]:

- determination of the length of the dipoles for the frequencies 300 MHz, 450 MHz, 2.0 GHz, 2.45 GHz and 3.0 GHz (Annex F of [1])
- calculation of the 1 g and 10 g averaged SAR maxima in the flat phantom for the frequencies specified in Table 7.1 of [1]
- verification of whether the necessary minimum phantom dimensions as assessed in [2] are valid for the frequency range from 300 MHz to 3 GHz
- validation of the simulation results with measurements

3 Flat Phantom Setup

3.1 Setup Configuration

The flat phantom setup consists of a a resonant half-wave dipole antenna placed underneath a dielectric vessel ($\epsilon_r = 3.7$) with a flat bottom filled with tissue simulating liquid. The setup is described in detail in [1]. Its main characteristics are summarized in Table 1 and Figure 1.

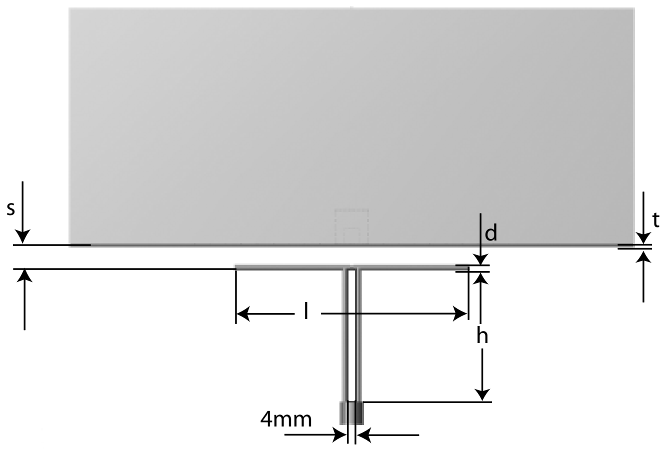

Figure 1: Dimensions of the flat phantom setup.

[1] recommends that the minimum dimensions of the surface be at least $0.6 \times 0.4\,\lambda_0$.[1] In [2], it is shown that the uncertainty of the averaged peak SAR can be kept below 1 % for a frequency of 835 MHz if the phantom size does not fall below these dimensions. Both a full size phantom whose surface size significantly exceeds the given limit and a phantom with dimensions reduced to the limit given in [1] were investigated. The surface dimensions of the two phantoms are given in Table 2.

Freq. [MHz]	ϵ_r	σ [S/m]	t [mm]	d [mm]	l [mm]	h [mm]	s [mm]
300	45.3	0.87	6	6.3	396	250	15
450	43.5	0.87	6	6.3	270	166.7	15
835	41.5	0.9	2	3.6	161	89.8	15
900	41.5	0.97	2	3.6	149	83.3	15
1 450	40.5	1.2	2	3.6	89.1	51.7	10
1 500	40.4	1.23	2	3.6	86.2	50	10
1 640	40.2	1.31	2	3.6	79	45.7	10
1 800	40	1.4	2	3.6	72	41.7	10
1 900	40	1.4	2	3.6	68	39.5	10
2 000	40	1.4	2	3.6	64.5	37.5	10
2 450	39.2	1.8	2	3.6	51.5	30.4	10
3 000	38.5	2.4	2	3.6	41.5	25	10

Table 1: Dielectric parameters of the tissue simulating liquid and geometric dimensions of the flat phantom setup.

3.2 Simulations

All numerical simulations were carried out with SEMCAD V1.4. The phantom dimensions for the full size phantom were chosen such that they significantly exceeded the minimum surface dimensions given in [1]. The liquid level was 150 mm. The dielectric bottom of the shell ($\epsilon_r = 3.7$) was assumed to be lossless and the dipole material to be perfectly conducting. The accurate dimensions of the dipole were simulated including the $\lambda/4$-stub.

The flat phantom setups were discretized with nonuniform meshes. The maximum cell size was chosen such that the limit of $\lambda/15$ was never exceeded for all frequencies and dielectrics. In the regions of the antenna feedpoint, the antenna tips and the SAR maxima, the cell size was reduced to approximately $0.25\,\text{mm}^3$. Depending on the simulation frequency and the setup dimensions, this led to overall mesh

[1] λ_0 is the freespace wave length.

Freq. [MHz]	full size phantom x [mm]	y [mm]	reduced dimensions x [mm]	y [mm]
300	1000	800	600	400
450	700	600	400	267
835	360	300	216	144
900	360	300	200	133
1 450	240	200	124	83
1 500	240	200	120	80
1 640	240	200	110	73
1 800	220	200	100	67
1 900	220	200	95	63
2 000	160	140	90	60
2 450	180	120	73	49
3 000	200	160	60	40

Table 2: Dimensions of the flat phantom surface parallel (x) and normal (y) to the dipole.

sizes between three and twelve million cells. The mesh was truncated with PML absorbing boundary conditions.

3.3 Measurements

In order to verify the numerical results, the flat phantom setup was measured with the DASY 4 near-field scanner using the flat section in the center of the Generic Twin Phantom [3]. The frequencies 450 MHz, 835 MHz, 900 MHz, 1 450 MHz, 1 800 MHz and 1 900 MHz were evaluated. DASY4 applies a boundary error compensation algorithm which was not utilized in DASY3. The impedance was measured with the network analyzer Agilent HP8753E which was calibrated at the feedpoint of the dipole.

4 Results and Discussion

4.1 Numerical Results

4.1.1 Dipole Dimensions

According to the requirements of [1], the input reflection coefficient S_{11} of the dipole antennas must be -20 dB or better. The dipoles for the frequencies 300 MHz, 450 MHz, 2.0 GHz, 2 450 MHz and 3 GHz were matched to meet this condition by modifying their lengths. The assessed dipole lengths are given in Table 1. For all investigated frequencies, reflection coefficients of much better than the required -20 dB could be obtained. Figures 2 and 3 show the calculated reflection coefficients. The feedpoint impedances are given in Table 3.

4.1.2 SAR Distribution

The 1 g and 10 g averaged peak SAR were calculated in cubical volumes containing the respective masses of tissue simulating liquid. The volumes are located above the antenna feedpoint. In order to avoid uncertainties in determining the accurate averaging mass, the grid was discretized such that an integer number of cells fit into the volumes.

Table 4 shows the calculated averaged peak SAR values and the non-averaged SAR maxima normalized both to an antenna input power of 1 W and to a feedpoint current of 100 mA_{RMS}. Figure 4 shows the SAR inside the phantom immediately above the feedpoint as a function of the distance to the shell. In Figure 5, the SAR is displayed along an imaginary line normal to the shell surface with an offset of 20 mm to the antenna feedpoint. In both figures, the SAR is normalized to an input power of 1 W.

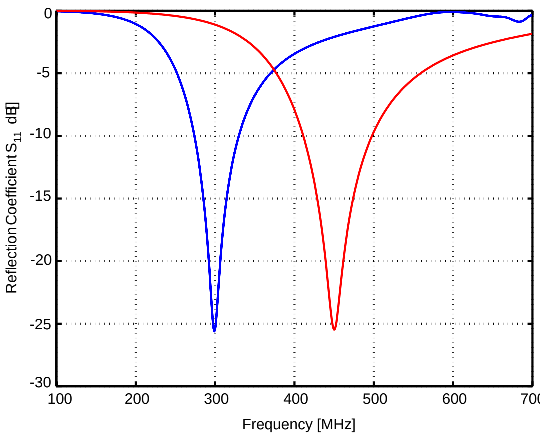

Figure 2: Simulated input reflection coefficient S_{11} for the 300 MHz (blue) and 450 MHz (red) dipole antennas.

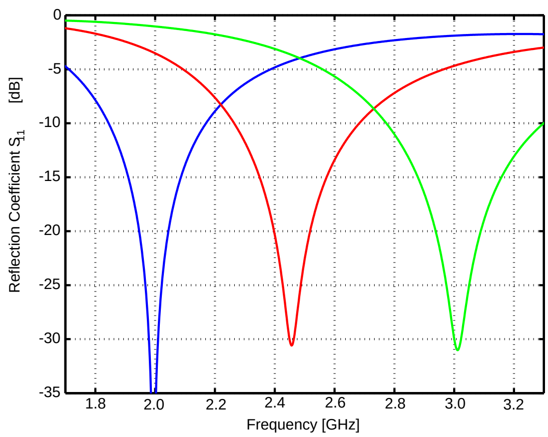

Figure 3: Simulated input reflection coefficient S_{11} for the 2.0 GHz (blue), 2.45 GHz (red) and 3.0 GHz (green) dipole antennas.

	full size phantom			reduced dimensions		
Freq. [MHz]	Re{Z} [Ω]	Im{Z} [Ω]	S_{11}[dB]	Re{Z} [Ω]	Im{Z} [Ω]	S_{11}[dB]
300	55.1	-2.2	-25.5	54.8	-2.3	-25.9
450	54.9	-3.1	-25.2	54.5	-2.1	-26.4
835	51.0	1.4	-35.4	50.1	1.3	-38.0
900	49.9	2.3	-32.8	49.0	2.0	-33.0
1 450	50.2	-2.4	-32.2	50.2	-2.6	-31.2
1 500	50.1	-2.4	-32.3	49.1	-2.6	-31.2
1 640	50.3	-0.5	-44.6	49.1	-0.8	-38.6
1 800	50.6	1.1	-38.1	49.2	0.7	-39.2
1 900	50.6	0.7	-40.7	49.0	0.3	-39.5
2 000	50.9	0.9	-38.1	49.2	0.4	-40.4
2 450	51.0	-3.4	-29.1	48.8	-2.6	-30.8
3 000	53.4	-4.0	-26.0	51.5	-4.4	-26.7

Table 3: Calculated antenna feedpoint impedance.

4.1.3 Flat Phantom with Reduced Dimensions

The 1 g and 10 g averaged peak SAR and the SAR maximum for the phantom with reduced dimensions (see Section 3) are given in Table 5, normalized to both 1 W antenna input power and 100 mA_{RMS} feedpoint current. Figures 6 and 7 show the deviations of the averaged peak SAR compared to the full size phantom. Up to a frequency of 900 MHz, the deviations are smaller than 1 %, which confirms the findings of [2]. For frequencies above 900 MHz, the distance between the dipole and the phantom increases in terms of wavelength, resulting in greater sensitivity to the feedpoint impedance which in turn affects the SAR distribution as well. This effect is clearly demonstrated in Figure 7 when the values normalized to the feedpoint current are compared. The 1 g spatial peak SAR are constant whereas the deviation of the 10 g spatial peak SAR increases with frequency. The 1% criteria can be kept if the minimal dimensions of the flat phantom for frequencies above 835 MHz correspond to 180×120 mm.

4.2 Measurement Results

Table 6 summarizes the measured feedpoint impedances and SAR values. The dielectric parameters of the tissue simulating liquid used in the measurements are given as well.

Figure 8 shows the deviations of the measured SAR from the simulation results. For all 1 g and 10 g averaged SAR values the agreement is better than 6 %. The maximum deviation of the peak SAR is

	SAR 1 W forward power [W/kg]			SAR 100 mA_{RMS} feedpt. current [W/kg]		
Freq. [MHz]	1 g av.	10 g av.	peak	1 g av.	10 g av.	peak
300	3.02	2.04	4.40	1.68	1.14	2.45
450	4.91	3.27	7.17	2.70	1.80	3.95
835	9.56	6.22	14.2	4.87	3.17	7.21
900	10.9	7.00	16.4	5.45	3.49	8.16
1 450	29.2	16.2	50.3	14.7	8.15	25.3
1 500	30.5	16.8	52.8	15.3	8.43	26.5
1 640	34.2	18.4	60.4	17.2	9.25	30.4
1 800	38.4	20.1	68.9	19.4	10.2	34.9
1 900	39.8	20.7	71.5	20.1	10.5	36.2
2 000	41.2	21.2	73.9	21.0	10.8	37.6
2 450	52.5	24.2	103.3	26.8	12.3	52.7
3 000	63.4	25.6	141.9	33.9	13.7	75.9

Table 4: Calculated averaged peak SAR of the full size setup.

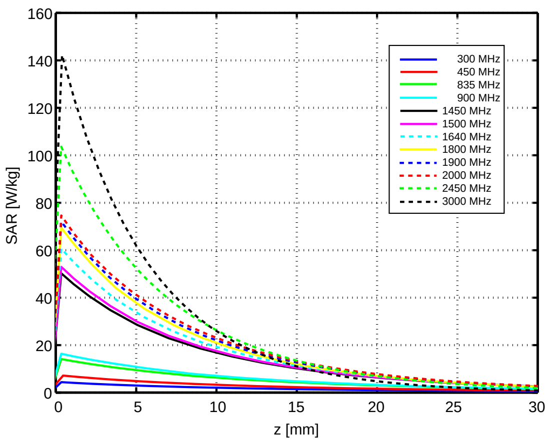

Figure 4: SAR above the antenna feedpoint as a function of the distance to the shell surface. (normalized to 1 W antenna input power)

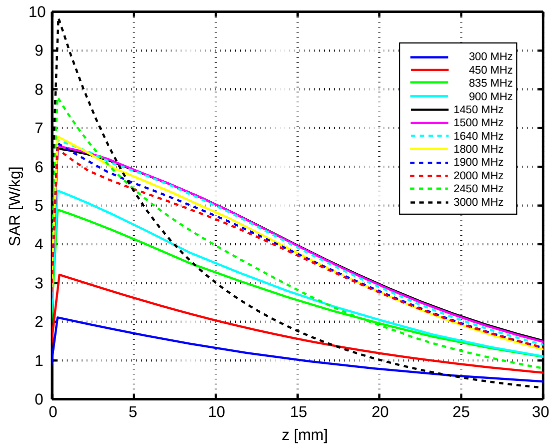

Figure 5: SAR 20 mm beside the antenna feedpoint as a function of the distance to the shell surface. (normalized to 1 W antenna input power)

8.2 %. The deviations are well within the uncertainty of the measurement and would be considerably smaller if the deviations of the tissue simulating liquids would be taken into account.

5 Conclusions

The open issues in Annex F and Table 7.1 of [1] have been investigated. The dimensions of the dipole antennas for the frequencies given in Section 4.1.1 have been determined such that a matching of better than -20 dB can be achieved. Reference values for the 1 g and 10 g SAR have been calculated for all frequencies of interest.

The minimum surface dimensions of the flat phantom as proposed in [2] for a frequency of 835 MHz are valid for the frequencies below 900 MHz. The minium dimensions for frequencies above 900 MHz should be 180 x 120 mm.

The agreements between measurement of DASY4 and the simulation are well within the uncertainties of the applied techniques. Further measurements will be performed to complete the evaluation for the whole frequency range proposed in [1].

Freq. [MHz]	SAR 1 W forward power [W/kg] 1 g av.	10 g av.	peak	SAR 100 mA$_{RMS}$ feedpt. current [W/kg] 1 g av.	10 g av.	peak
300	3.02	2.04	4.41	1.67	1.13	2.44
450	4.91	3.28	7.24	2.70	1.79	3.96
835	9.61	6.28	14.2	4.82	3.15	7.13
900	11.0	7.07	16.5	5.39	3.46	8.07
1 450	29.5	16.5	50.5	14.5	8.12	24.9
1 500	30.9	17.1	53.1	15.2	8.38	26.1
1 640	34.8	18.7	60.7	17.1	9.17	29.8
1 800	39.2	20.3	69.4	19.3	10.0	34.1
1 900	40.9	20.9	72.1	20.1	10.2	35.3
2 000	42.5	21.3	74.6	20.9	10.5	36.7
2 450	55.1	24.2	105.6	26.9	11.8	51.6
3 000	65.4	25.3	144.4	33.8	13.1	74.5

Table 5: Calculated averaged peak SAR of the setup with reduced phantom dimensions.

Frequency [MHz]	Liquid parameters ϵ_r	σ [S/m]	Feedpoint Impedance Re{Z} [Ω]	Im{Z} [Ω]	S_{11}[dB]	Meas. SAR [W/kg] 1 g av.	10 g av.	peak
450	44.5	0.86	56.6	-5.5	-21.9	4.81	3.19	7.28
835	41.9	0.89	48.5	-2.8	-29.8	9.40	6.20	13.8
900	41.3	0.94	48.0	-3.0	-28.7	10.3	6.64	15.4
1450	41.6	1.25	50.3	-1.2	-38.2	29.1	16.4	48.8
1800	40.5	1.35	48.4	-8.0	-21.7	36.3	19.6	63.2
1900	39.1	1.47	45.0	-8.4	-19.8	40.4	21.2	71.2

Table 6: Measurement results, SAR normalized to 1 W input power.

References

[1] IEEE, *Std. 1528-200X, Recommended Practice for Determining the Spatial-Peak Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communications Devices: Experimental Techniques*, June 2000.

[2] Nicolas Chavannes and Andreas Christ, "Assessment of the minimum dimensions of a flat phantom for the simualtion of an infinitely extended lossy half space", Tech. Rep., Institut für Feldtheorie und Höchstfrequenztechnik, ETH Zürich, 8092 Zürich, Switzerland, Jan. 1999.

[3] Niels Kuster, Ralph Kästle, and Thomas Schmid, "Dosimetric evaluation of mobile communications equipment with known precision", *IEICE Transactions on Communications*, vol. E80-B, no. 5, pp. 645–652, May 1997.

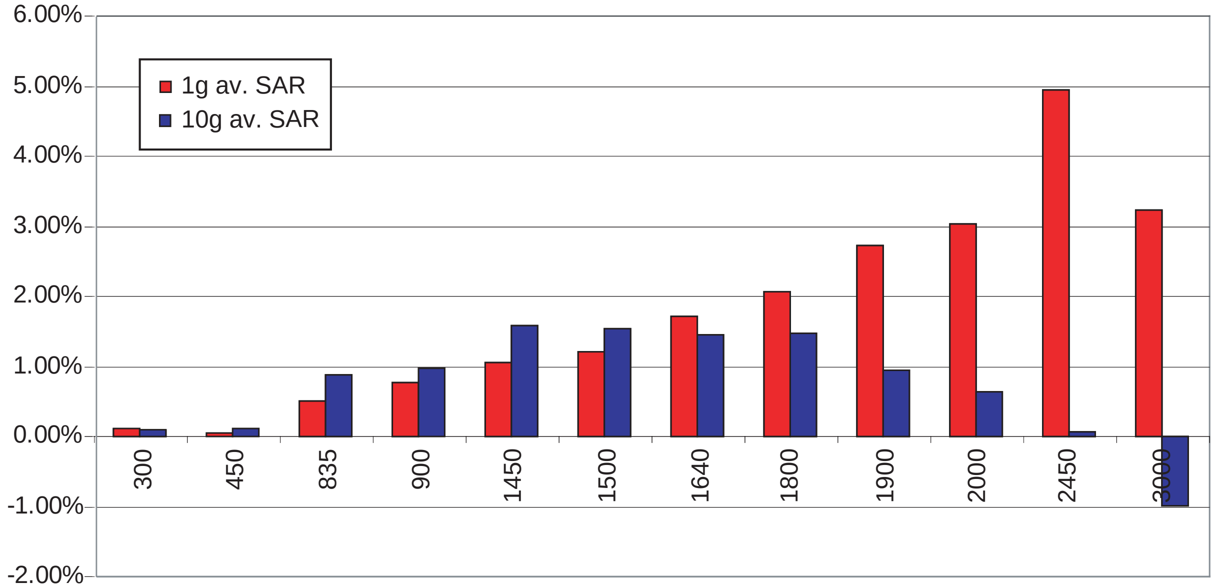

Figure 6: Deviation of the averaged peak SAR of the setup with reduced dimensions compared to the full size phantom. (SAR normalized to forward power, frequencies in MHz)

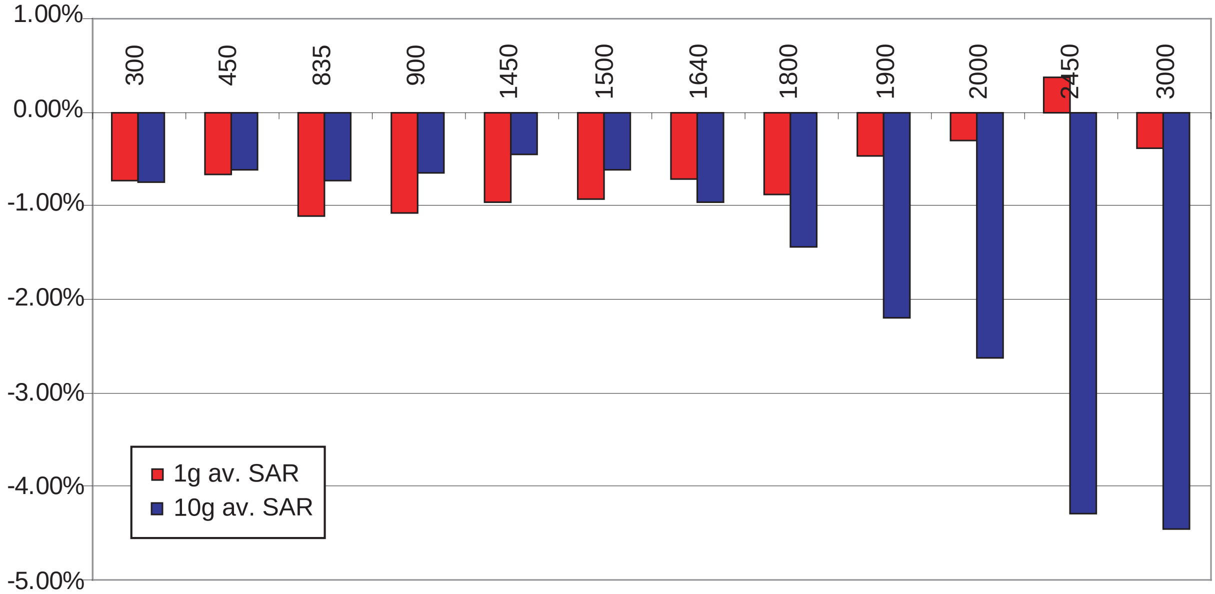

Figure 7: Deviation of the averaged peak SAR of the setup with reduced dimensions compared to the full size phantom when normalized to the feepoint current.

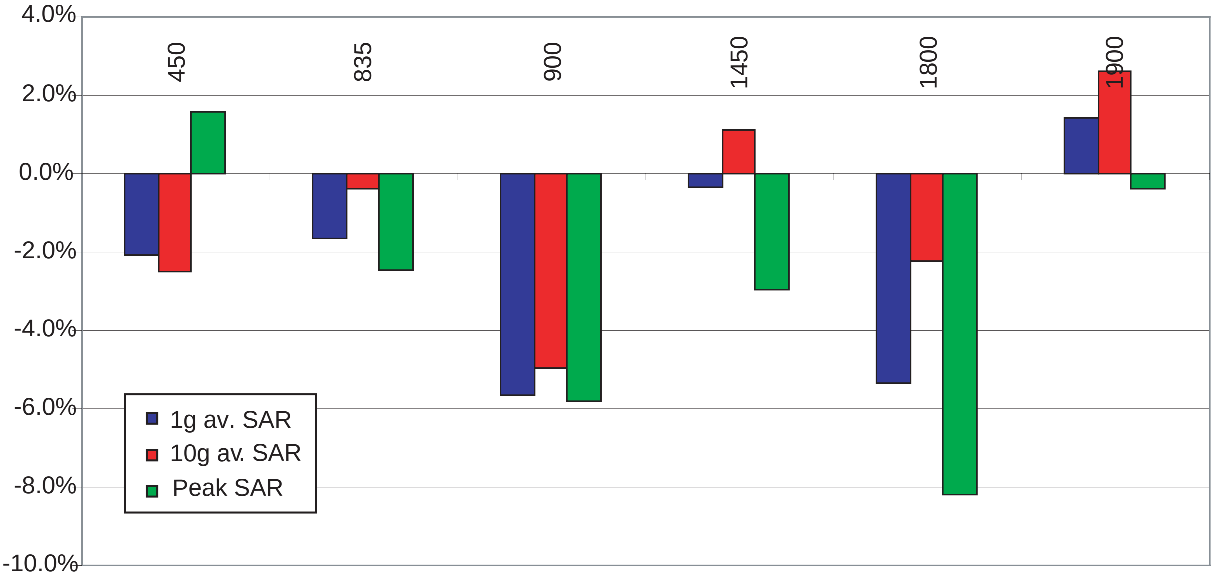

Figure 8: Deviation of the measurement results compared to the simulations. (SAR normalized to forward power, frequencies in MHz)