SAR COMPLIANCE TESTING OF ASKEY COMPUTER CORPORATION 802.11 a/b CARDBUS CARD (FCC ID# H8NWLC221-D4) INSERTED INTO A LAPTOP COMPUTER

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I. Introduction

The U.S. Federal Communications Commission (FCC) has adopted limits of human exposure to RF emissions from mobile and portable devices that are regulated by the FCC [1]. The FCC has also issued Supplement C (Edition 97-01) to OET Bulletin 65 [2] and a more recent version of the same [3] defining both the measurement and the computational procedures that should be followed for evaluating compliance of mobile and portable devices with FCC limits for human exposure to radiofrequency emissions.

We have used the measurement procedure for SAR compliance testing of the Askey Computer Corporation 802.11 a/b Cardbus Card inserted into the laptop computer. A photograph of the unit with the Cardbus Card inserted into the laptop computer is given in Fig. 1. A picture of the Cardbus Card placed on the laptop is given in Fig. 2. The Askey Computer Corporation 802.11 a/b Cardbus Card operates over the frequency band 5.18 to 5.825 GHz in normal or turbo modes with average conducted power levels as high as 15.6 dBm (36.3 mW).

For SAR measurements, two configurations of the wireless PC relative to the experimental phantom have been used:

a. Since the wireless PC may possibly be placed on a user's lap where the RF antennas would be the closest to the body, a planar phantom model with inside dimensions 12" x 16.5" (30.5 x 41.9 cm) and a base thickness of 2.0 ± 0.2 mm (recommended in [3]) was used for SAR measurements and the wireless PC card mounted in a portable computer (as in Fig. 1) pressed against the bottom of this phantom (see Fig. 5).
b. For a bystander, the "end-on" SAR value is obtained for the PC and the card edge at 90° to the flat phantom with a spacing of 0 cm (see Fig. 6). The SARs measured for the end-on configuration of the PC Card were extremely low close to the noise level for the FCC-

recommended spacing of 2.5 cm, hence the PC Card edge in contact with the base of the planar phantom was used instead for the SAR measurements given in Figs. 15 a-d and Tables 7-10, respectively.

II. The SAR Measurement System

The University of Utah SAR Measurement System has been described in peer-reviewed literature [Ref. 4 -- attached here as Appendix A]. A photograph of the SAR Measurement System is given in Fig. 3. This SAR Measurement System uses a computer-controlled 3-D stepper motor system (Arrick Robotics MD-2A). A triaxial Narda Model 8021 E-field probe is used to determine the internal electric fields. The positioning repeatability of the stepper motor system moving the E-field probe is within ±0.1 mm. Outputs from the three channels of the E-field probe are dc voltages, the sum of which is proportional to the square of the internal electric fields $\left(|E_i|^2\right)$ from which the SAR can be obtained from the equation SAR = $\sigma\left(|E_i|^2\right)/\rho$, where σ and ρ are the conductivity and mass density of the tissue-simulant materials, respectively [5]. The dc voltages for the three channels of the E-field probe are read by three HP 34401A multimeters and sent to the computer via an HPIB interface. The setup is carefully grounded and shielded to reduce the noise due to the electromagnetic interference (EMI). A cutout in a wooden table of dimensions 38.1 × 21.6 cm allows placement of a plastic holder (shown in Fig. 4) on which the laptop computer with the Cardbus Card (see Fig. 1) is supported. The plastic holder can be moved up or down so that the base of the PC is pressed against the base of the flat phantom for determination of SAR for above-lap position (see Fig. 5). Similarly, for the "end-on" SAR determination, the laptop computer with the Askey Corporation Cardbus Card is mounted sideways on the plastic holder and moved up so that the white plastic-covered end of the Cardbus Card is touching the base of the flat phantom (see Fig. 6).

The Flat Phantom

As recommended in Supplement C Edition 01-01 to OET Bulletin 65 [3], a planar phantom model with inside dimensions 12" × 16.5" (30.5 × 41.9 cm) and base thickness

2.0 ± 0.2 mm was used for SAR measurements (see Figs. 5, 6). As seen both in Figs. 5 and 6, a one-inch thick Styrofoam block was used under the base of the phantom to prevent bending of the 2 mm thin base.

III. Calibration of the E-Field Probe

The IEEE Draft Standard P1528 [4] suggests a recommended procedure for probe calibration (see Section 4.4.1 of [4]) for frequencies above 800 MHz where waveguide size is manageable. Calibration using a rectangular waveguide is recommended. As in some previously reported SAR measurements at 6 GHz [5], we have calibrated the Narda Model 8021 Miniature Broadband Electric Field Probe of tip diameter 4 mm (internal dipole dimensions on the order of 2.5 mm) using a rectangular waveguide WR 159 (of internal dimensions 1.59 x 0.795 inches) that was filled with the tissue-simulant fluid of composition given in Section V. The triaxial (3 dipole) E-field probe shown in Fig. 7 was originally developed by Howard Bassen and colleagues of FDA and has been manufactured under license by Narda Microwave Corporation, Hauppage, New York. The probe is described in detail in references 6 and 7. It uses three orthogonal pick up dipoles each of length about 2.5 mm offset from the tip by 3 mm, each with its own leadless zero voltage Schottky barrier diode operating in the square law region. The sum of the three diode outputs read by three microvoltmeters [8] gives an output proportional to E^2. By rotating the probe around its axis, the isotropy of the probe was measured to be less than ± 0.23 dB and the deviation of the probe from the square law behavior was less than ± 3%.

As suggested in the Draft Standard P1528, the waveguide (WR 159) filled with the tissue-simulant fluid was maintained vertically. From microwave field theory [see e.g. ref. 9], the transverse field distribution in the liquid corresponds to the fundamental mode (TE_{10}) with an exponential decay in the vertical direction (z-axis). The liquid level was 15 cm deep which is deep enough to guarantee that reflections from the top liquid surface do not affect the calibration. By comparing the square of the decaying electric fields expected in the tissue from the analytical expressions for the TE_{10} mode of the rectangular waveguide, we obtained a calibration factor of 2.98 (mW/kg)/μV with a variability of less than ±2% for measurement frequencies of 5.2, 5.3, 5.7 and 5.8 GHz, respectively. This is no doubt due to a fairly limited frequency band of only 0.6 GHz out of a recommended bandwidth of 2.2 GHz for the TE_{10} mode for the WR159 waveguide (recommended band of 4.9-7.1 GHz -- see e.g. ref. 9).

The data for the calibration of the E-field probe closest to the SAR tests given here was November 19, 2002.

IV. SAR System Verification

Since we do not have a dipole for the 5 GHz band, a half wave dipole at 1900 MHz was used instead for SAR system verification. This dipole of length 76.0 mm and diameter 1.5 mm and h = 39.5 mm is shown in Fig. 8. As recommended in OET65 Supplement C [3], we used a spacing of 10 mm from the dipole to the tissue-simulant fluid composed of 40.4% water, 58.0% sugar, 0.5% salt (NaCl), 1% HEC, and 0.1% bactericide. The microwave circuit arrangement used for system verification is sketched in Fig. 9. The dielectric properties for this body-simulant fluid were measured using the Hewlett Packard (HP) Model 85070 B Dielectric Probe (rated frequency band 200 MHz to 20 GHz in conjunction with HP Model 8720C Network Analyzer (50 MHz-20 GHz) using a procedure detailed in Section V. The measured dielectric parameters of the body-simulant fluid at 1900 MHz are $\varepsilon_r = 53.1 \pm 1.3$ and $\sigma = 1.44 \pm 0.09$ S/m. The measured properties are close to the values of $\varepsilon_r = 54.0$ and $\sigma = 1.45$ S/m given in OET Supplement C [3].

The two measured SAR distributions for the peak 1-g SAR region using this system verification dipole for each day of SAR measurements November 19, 20, 2002 are given in Appendix B. Also given in Appendix B are the dipole SAR plots for each date of device testing. The two peak 1-g SARs are 36.189 and 36.626 W/kg which is a variability of only 1.2%. Furthermore, both of the measured 1-g SARs are in excellent agreement with the FDTDcalculated 1-g SAR of 35.8 W/kg for this dipole. Also as expected, the measured SAR plots are quite symmetric.

V. Tissue Simulant Fluid for the Frequency Band 5.2 to 5.8 GHz

In OET 65 Supplement C [3], the dielectric parameters suggested for body phantom are given only for 3000 and 5800 MHz. These are listed in Table 1 here. Using linear interpolation, we can obtain the dielectric parameters to use for the frequency band between 5.2 to 5.8 GHz. The desired dielectric properties thus obtained are also given in Table 1. From Table 1, it can be noticed that the desired dielectric constant ε_r varies from 48.2 to 49.0 which is a variation of less than ± 1% from the average value of 48.6 for this band. Also the conductivity σ varies linearly with frequency from 5.3 to 6.00 S/m. For the SAR measurements given in this report, we have used a tissue-simulant fluid developed at the University of Utah which consists of 68.0% water, 31.0% sugar and 1% HEC. For this composition, we have measured the dielectric properties using a Hewlett Packard (HP) Model 85070B Dielectric Probe in conjunction with HP Model 8720C Network Analyzer (50 MHz-20 GHz). The measured dielectric properties at a mid band frequency of 5.30 GHz are as follows: $\varepsilon_r = 48.5 \pm 1.7$ and $\sigma = 5.40 \pm 0.08$ S/m. From Table 1, we obtain the desired dielectric properties to simulate the body tissue at the midband frequency of 5.30 GHz to be $\varepsilon_r = 48.9$ and $\sigma = 5.42$ S/m. Thus, the measured properties for the body-simulant fluid are close to the desired values. Also as expected, the conductivity of this fluid varies linearly with frequency rising to 6.03 ± 0.09 S/m at 5.8 GHz, while the dielectric constant ε_r is nearly the same as the measured value at 5.3 GHz.

The procedure is as follows: The HP Model 95070B Dielectric Probe (see Fig. 10) is an open-circuited transmission-line (coaxial line) probe similar to that described in Section B.1.2 of the Draft IEEE Standard 1528 [4]. The theory of the open-circuited coaxial line method has been described in scientific literature [10-12]. We have previously used this method in determining the dielectric properties of tissue-simulant materials at 6 GHz [5]. In this method, the complex reflection coefficient Γ^* measured for the open end of the coaxial line can be used to calculate the complex permittivity ε^* from the following equation [5]

$$\varepsilon^* = \frac{1-\Gamma^*}{j\omega Z_o C_o\left(1+\Gamma^*\right)} - \frac{C_f}{C_o} \tag{1}$$

where Z_o is the characteristic impedance (50 Ω) for the coaxial line, C_o is the capacitance when the line is in air and C_f is the capacitance that accounts for the fringing fields in the dielectric of the coaxial line.

For the HP85070B Dielectric Probe with diameters of the outer and inner conductors 2b = 3.00 mm and 2a = 0.912 mm, respectively, the following capacitances were obtained using deionized water and methanol as the calibration fluids. The following capacitances were obtained:

$$C_o = 0.022 \text{ pF}$$

$$C_f = 0.005 \text{ pF}$$

Using the network analyzer HP8720C, we measured the reflection coefficient Γ^* for the open end of the coaxial line that was submerged in the tissue-simulant fluid. Using Eq. 1, the complex permittivity of the fluid was measured at various frequencies 5.2-5.8 GHz. From the imaginary part of the complex permittivity $\mathrm{Im}(\varepsilon^*)$, we can obtain the conductivity σ from the relationship

$$\sigma = \frac{\mathrm{Im}(\varepsilon^*)}{\omega\varepsilon_o} \tag{2}$$

VI. The Measured SAR Distributions

Using a Hewlett Packard Model 436A Power Meter, the maximum power output of the Askey Computer Corporation 802.11 a/b Cardbus Card was measured for both normal and turbo modes at a number of frequencies through the coaxial connector provided for this purpose on the Cardbus Card (see Figs. 11 and 12). The RF power output thus measured is given in Table 2. Recognizing that the power outputs were the highest at 5.26 and 5.785 GHz for the normal mode and at 5.25 and 5.80 GHz for the turbo mode (see Table 2), the SAR measurements were conducted for these four power output conditions of the Askey Cardbus Card. Also as recommended in Supplement C, Edition 01-01 [3], the conducted power was measured before and after each SAR measurement and found to be within ±0.1 dB (±2.5%) of the values given in Table 2.

The highest SAR region for each of the measurement frequencies was identified in the first instance by using a coarser sampling with a step size of 8.0 mm over three overlapping areas for a total scan area of 8.0 × 9.6 cm. The data thus obtained is resolved into a 4 x 4 times larger grid i.e. a grid involving 40 x 28 points by linear interpolation using a 2 mm step size. After thus identifying the region of the highest SAR, the SAR distribution was then measured with a resolution of 2 mm in order to obtain the peak 1 cm^3 or 1-g SAR. The SAR measurements are performed at 4, 6, 8, 10, 12 mm height from the bottom surface of the body-simulant fluid. The SARs thus measured were extrapolated using a second-order least-square fit to the measured data to obtain values at 1, 3, 5, 7 and 9 mm height and used to obtain 1-g SARs. The uncertainty analysis of the University of Utah SAR measurement system is given in Appendix C. The combined standard uncertainty is ± 8.3%.

The coarse scans for the four measurements for the Above-lap position are shown in Fig. 13a-d, respectively. In these figures, the two axes are marked in units of the step size of 8 mm. The highest SAR region shown in maroon color is immediately above the region of the radiating antenna as illustrated in Fig. 14. Given in Tables 3-7 are the SAR distributions for the peak SAR region of volume 10 ×10 ×mm for which the coarse scans are given in Figs. 13a-d, respectively. The SARs are given for xy planes at heights z of 1, 3, 5, 7, and 9 mm for the Askey Cardbus Card inserted in the laptop computer which is pressed against the bottom of the flat phantom. The individual SAR values for this grid of 5 × 5 × 5 or 125 points are averaged to obtain peak 1-g SAR values (for a volume of 1 cm^3). The temperature variation of the tissue-simulant fluid measured with a Bailey Instruments Model BAT 8 Temperature Probe over the 80-minute period needed for measurements at the four frequencies was $23.7 \pm 0.2^{\circ}C$.

The coarse scans measurements for the four measurements for the End-on position are shown in Fig. 15a-d, respectively. The corresponding SAR distributions for the peak 1-g SAR are given in Tables 7-10, respectively. The z-axis scan plots taken at the highest SAR locations for each set of tests are given in Fig. 16 and 17, respectively.

For the measurements in Tables 3-6, the separation between the Askey Cardbus Card and the bottom of the experimental phantom is on the order of 1 cm. For the "end-on" position, the SARs for an FCC-recommended separation of 2.5 cm to the bottom of the flat phantom were extremely low close to the noise level. Therefore, the PC Card edge at 90° in contact with the base of the phantom was used instead for the SAR measurements given in Figs. 15a-d and Tables 7-10, respectively. The peak 1-g SARs for the various configurations of the Cardbus Card are summarized in Table 11. All of the measured 1-g SARs are less than the FCC 96-326 guideline of 1.6 W/kg.

VII. Comparison of the Data with FCC 96-326 Guidelines

According to the FCC 96-326 Guideline [1], the peak SAR for any 1-g of tissue should not exceed 1.6 W/kg. For the Askey Computer Corporation 802.11 a/b Cardbus Card, the measured peak 1-g SARs vary from 0.11 to 0.32 W/kg which are smaller than 1.6 W/kg.

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Table 1. Dielectric parameters for body phantom for the frequency band 5.2 to 5.8 GHz [3].

Frequency GHz	ε_r	σ S/m	Reference
3.0	52.0	2.73	Ref. 3
5.8	48.2	6.00	Ref. 3
5.2	49.0	5.30	Interpolated
5.3	48.9	5.42	Interpolated
5.4	48.7	5.53	Interpolated
5.6	48.5	5.77	Interpolated
5.7	48.3	5.88	Interpolated

Table 2. Average conducted RF power outputs measured at various frequencies for the Askey Corporation Cardbus Card for normal and turbo modes.

Frequency GHz	Average Power dBm
Normal Mode	
5.18	13.02
5.26	15.21
5.32	13.04
5.745	15.52
5.785	15.63
5.825	15.28
Turbo Mode	
5.21	15.66
5.25	15.56
5.29	14.86
5.76	15.47
5.80	15.61

Table 3. **Above-lap position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the normal mode at 5.26 GHz.

1-g SAR = 0.317 W/kg

a. At depth of 1 mm

0.604	0.616	0.600	0.587	0.572
0.613	0.605	0.623	0.596	0.570
0.623	0.624	0.609	0.602	0.590
0.581	0.594	0.600	0.611	0.565
0.554	0.583	0.593	0.564	0.570

b. At depth of 3 mm

0.430	0.441	0.424	0.418	0.411
0.432	0.431	0.432	0.424	0.410
0.438	0.440	0.427	0.414	0.411
0.413	0.419	0.422	0.430	0.397
0.386	0.409	0.412	0.400	0.405

c. At depth of 5 mm

0.292	0.302	0.287	0.284	0.282
0.289	0.292	0.283	0.287	0.281
0.288	0.294	0.282	0.267	0.270
0.279	0.282	0.281	0.287	0.265
0.254	0.273	0.271	0.271	0.274

d. At depth of 7 mm

0.191	0.199	0.186	0.185	0.186
0.184	0.189	0.176	0.185	0.184
0.180	0.186	0.174	0.162	0.168
0.180	0.180	0.177	0.182	0.167
0.159	0.173	0.168	0.175	0.179

e. At depth of 9 mm

0.126	0.132	0.123	0.122	0.123
0.116	0.122	0.111	0.118	0.118
0.114	0.116	0.104	0.097	0.103
0.115	0.116	0.111	0.113	0.105
0.099	0.109	0.104	0.115	0.118

Table 4. **Above-lap position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the normal mode at 5.785 GHz.

1-g SAR = 0.195 W/kg

a. At depth of 1 mm

0.352	0.359	0.359	0.346	0.342
0.364	0.378	0.376	0.377	0.360
0.378	0.383	0.369	0.381	0.344
0.327	0.349	0.368	0.349	0.354
0.319	0.343	0.337	0.357	0.358

b. At depth of 3 mm

0.254	0.258	0.262	0.253	0.246
0.264	0.272	0.269	0.268	0.256
0.264	0.269	0.260	0.269	0.241
0.230	0.245	0.258	0.246	0.244
0.225	0.243	0.238	0.256	0.258

c. At depth of 5 mm

0.177	0.179	0.186	0.179	0.172
0.186	0.188	0.186	0.182	0.174
0.175	0.180	0.175	0.180	0.160
0.155	0.164	0.171	0.164	0.158
0.151	0.165	0.161	0.176	0.180

d. At depth of 7 mm

0.119	0.121	0.129	0.125	0.118
0.128	0.127	0.125	0.121	0.115
0.112	0.117	0.115	0.114	0.102
0.100	0.105	0.108	0.104	0.097
0.099	0.107	0.105	0.119	0.126

e. At depth of 9 mm

0.082	0.085	0.093	0.090	0.086
0.091	0.088	0.086	0.083	0.078
0.074	0.079	0.078	0.072	0.066
0.067	0.068	0.068	0.066	0.061
0.068	0.070	0.071	0.082	0.095

Table 5. **Above-lap position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the turbo mode at 5.25 GHz.

1-g SAR = 0.242 W/kg

a. At depth of 1 mm

0.359	0.374	0.366	0.350	0.341
0.391	0.371	0.368	0.360	0.337
0.397	0.385	0.384	0.380	0.358
0.379	0.386	0.386	0.358	0.358
0.375	0.371	0.363	0.340	0.354

b. At depth of 3 mm

0.294	0.310	0.292	0.277	0.274
0.306	0.297	0.292	0.287	0.272
0.308	0.301	0.301	0.296	0.277
0.292	0.300	0.298	0.281	0.277
0.284	0.282	0.273	0.269	0.269

c. At depth of 5 mm

0.240	0.245	0.234	0.220	0.221
0.239	0.238	0.232	0.229	0.220
0.237	0.234	0.235	0.229	0.214
0.224	0.233	0.229	0.220	0.214
0.212	0.211	0.202	0.212	0.201

d. At depth of 7 mm

0.200	0.199	0.191	0.178	0.182
0.192	0.193	0.187	0.186	0.181
0.186	0.186	0.185	0.181	0.169
0.174	0.183	0.177	0.174	0.168
0.161	0.159	0.152	0.169	0.152

e. At depth of 9 mm

0.172	0.171	0.162	0.153	0.158
0.163	0.164	0.156	0.157	0.156
0.153	0.156	0.151	0.150	0.142
0.143	0.152	0.144	0.144	0.139
0.130	0.126	0.123	0.140	0.121

Table 6. **Above-lap position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the turbo mode at 5.8 GHz.

1-g SAR = 0.136 W/kg

a. At depth of 1 mm

0.246	0.236	0.240	0.247	0.205
0.255	0.243	0.268	0.238	0.228
0.238	0.247	0.247	0.243	0.246
0.224	0.231	0.215	0.238	0.219
0.193	0.207	0.218	0.239	0.220

b. At depth of 3 mm

0.179	0.176	0.173	0.182	0.156
0.183	0.183	0.188	0.172	0.171
0.178	0.180	0.184	0.174	0.170
0.165	0.170	0.154	0.168	0.159
0.143	0.153	0.163	0.177	0.175

c. At depth of 5 mm

0.127	0.128	0.122	0.133	0.117
0.128	0.135	0.127	0.120	0.125
0.130	0.127	0.133	0.120	0.112
0.119	0.121	0.107	0.114	0.112
0.103	0.110	0.120	0.130	0.139

d. At depth of 7 mm

0.090	0.092	0.087	0.097	0.088
0.090	0.099	0.085	0.082	0.090
0.095	0.088	0.093	0.081	0.072
0.086	0.084	0.074	0.076	0.078
0.074	0.078	0.089	0.095	0.113

e. At depth of 9 mm

0.066	0.068	0.068	0.075	0.069
0.068	0.075	0.061	0.059	0.066
0.072	0.063	0.066	0.059	0.050
0.066	0.059	0.056	0.054	0.057
0.055	0.058	0.070	0.074	0.097

Table 7. **End-on position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the normal mode at 5.26 GHz.

1-g SAR = 0.279W/kg

a. At depth of 1 mm

0.522	0.516	0.519	0.537	0.544
0.520	0.537	0.554	0.554	0.560
0.522	0.545	0.537	0.507	0.525
0.512	0.525	0.535	0.524	0.518
0.517	0.527	0.519	0.516	0.522

b. At depth of 3 mm

0.357	0.358	0.366	0.378	0.383
0.364	0.381	0.387	0.384	0.389
0.372	0.376	0.375	0.359	0.368
0.360	0.369	0.378	0.372	0.362
0.361	0.367	0.365	0.369	0.370

c. At depth of 5 mm

0.229	0.234	0.244	0.252	0.255
0.242	0.257	0.254	0.250	0.249
0.251	0.243	0.246	0.241	0.243
0.239	0.246	0.254	0.249	0.238
0.237	0.241	0.244	0.252	0.250

d. At depth of 7 mm

0.136	0.143	0.154	0.157	0.161
0.153	0.166	0.156	0.153	0.150
0.160	0.147	0.150	0.151	0.151
0.150	0.154	0.161	0.156	0.148
0.147	0.150	0.155	0.163	0.161

e. At depth of 9 mm

0.080	0.086	0.095	0.095	0.101
0.098	0.107	0.092	0.091	0.089
0.100	0.086	0.088	0.091	0.091
0.093	0.095	0.101	0.093	0.090
0.089	0.094	0.100	0.104	0.103

Table 8. **End-on position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the normal mode at 5.785 GHz.

1-g SAR = 0.203 W/kg

a. At depth of 1 mm

0.362	0.406	0.419	0.452	0.405
0.419	0.445	0.455	0.440	0.421
0.432	0.455	0.466	0.440	0.400
0.388	0.418	0.428	0.404	0.383
0.364	0.366	0.387	0.369	0.319

b. At depth of 3 mm

0.244	0.272	0.285	0.306	0.272
0.286	0.306	0.302	0.301	0.289
0.296	0.308	0.315	0.294	0.271
0.264	0.283	0.294	0.268	0.265
0.246	0.245	0.260	0.248	0.234

c. At depth of 5 mm

0.151	0.168	0.181	0.191	0.169
0.181	0.196	0.183	0.192	0.185
0.189	0.192	0.196	0.179	0.169
0.166	0.177	0.188	0.163	0.171
0.153	0.151	0.16	0.154	0.164

d. At depth of 7 mm

0.084	0.094	0.107	0.106	0.096
0.104	0.115	0.097	0.112	0.108
0.111	0.109	0.108	0.097	0.093
0.094	0.100	0.109	0.090	0.101
0.086	0.084	0.090	0.088	0.110

e. At depth of 9 mm

0.042	0.048	0.063	0.052	0.053
0.056	0.063	0.045	0.061	0.059
0.062	0.059	0.051	0.048	0.043
0.049	0.052	0.058	0.048	0.055
0.044	0.045	0.049	0.048	0.072

Table 9. **End-on position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the turbo mode at 5.25 GHz.

1-g SAR = 0.254 W/kg

a. At depth of 1 mm

0.479	0.498	0.508	0.507	0.507
0.515	0.509	0.464	0.524	0.493
0.506	0.517	0.520	0.507	0.511
0.497	0.496	0.485	0.493	0.497
0.444	0.433	0.450	0.414	0.431

b. At depth of 3 mm

0.341	0.350	0.356	0.354	0.352
0.357	0.355	0.336	0.359	0.345
0.355	0.356	0.362	0.358	0.351
0.345	0.348	0.340	0.346	0.339
0.311	0.300	0.312	0.291	0.303

c. At depth of 5 mm

0.231	0.233	0.235	0.234	0.229
0.231	0.232	0.232	0.229	0.228
0.234	0.229	0.236	0.239	0.224
0.225	0.229	0.224	0.229	0.216
0.205	0.195	0.203	0.194	0.202

d. At depth of 7 mm

0.148	0.145	0.146	0.146	0.140
0.138	0.141	0.151	0.136	0.140
0.144	0.137	0.144	0.152	0.131
0.136	0.140	0.139	0.140	0.127
0.125	0.117	0.122	0.123	0.128

e. At depth of 9 mm

0.093	0.088	0.088	0.090	0.083
0.079	0.081	0.094	0.078	0.082
0.085	0.079	0.084	0.095	0.072
0.078	0.082	0.083	0.081	0.073
0.073	0.067	0.069	0.079	0.081

Table 10. **End-on position.** The SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer for the turbo mode at 5.8 GHz.

1-g SAR = 0.109 W/kg

a. At depth of 1 mm

0.215	0.234	0.222	0.221	0.210
0.228	0.217	0.210	0.208	0.187
0.217	0.237	0.217	0.218	0.184
0.193	0.233	0.232	0.211	0.212
0.200	0.199	0.205	0.174	0.159

b. At depth of 3 mm

0.151	0.164	0.157	0.157	0.144
0.155	0.149	0.145	0.144	0.132
0.148	0.163	0.151	0.148	0.133
0.137	0.161	0.164	0.150	0.142
0.142	0.136	0.138	0.124	0.124

c. At depth of 5 mm

0.101	0.107	0.104	0.106	0.092
0.098	0.095	0.094	0.093	0.088
0.094	0.105	0.099	0.093	0.091
0.092	0.103	0.110	0.101	0.088
0.095	0.087	0.085	0.086	0.097

d. At depth of 7 mm

0.065	0.065	0.066	0.068	0.054
0.057	0.055	0.058	0.054	0.055
0.055	0.062	0.061	0.053	0.058
0.058	0.062	0.070	0.064	0.050
0.059	0.052	0.046	0.057	0.076

e. At depth of 9 mm

0.042	0.038	0.041	0.042	0.030
0.031	0.029	0.035	0.028	0.034
0.030	0.034	0.035	0.028	0.039
0.036	0.036	0.044	0.039	0.027
0.035	0.030	0.021	0.040	0.061

Table 11. The peak 1-g SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer.

1-g SAR in W/kg

PC position relative To the flat phantom	Spacing to the bottom of the phantom	5.26 GHz normal mode	5.785 GHz normal mode	5.25 GHz turbo mode	5.80 GHz turbo mode
"Above-lap": bottom of PC pressed against bottom of the flat phantom	1 cm	0.317	0.195	0.242	0.136
"End-on": card edge at 90° pressed against the bottom of the flat phantom	0 cm	0.279	0.203	0.254	0.109

Fig. 1. Photograph of the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer.

Fig. 2. A picture of the Askey Corporation 802.11 a/b Cardbus Card placed on the laptop computer.

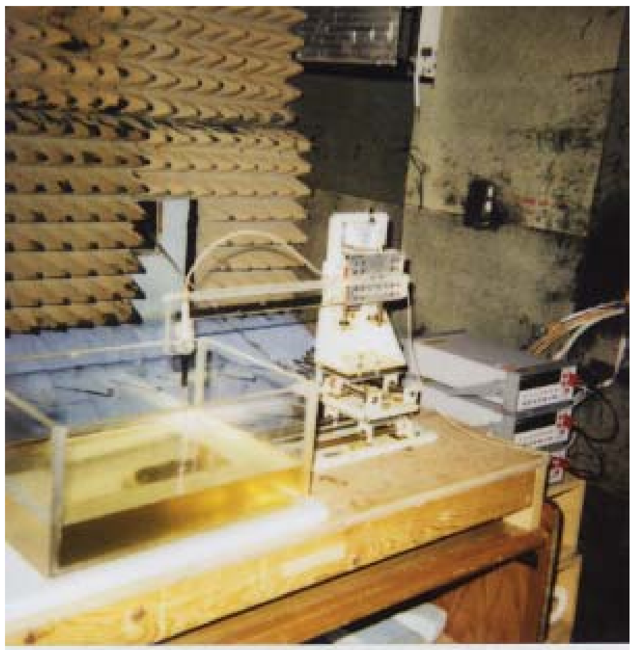


Fig. 3. Photograph of the three-dimensional stepper-motor-controlled SAR measurement system using a planar phantom (see Fig. 5 for a detailed examination of the placement of Askey Corporation 802.11 a/b Cardbus Card relative to this phantom).

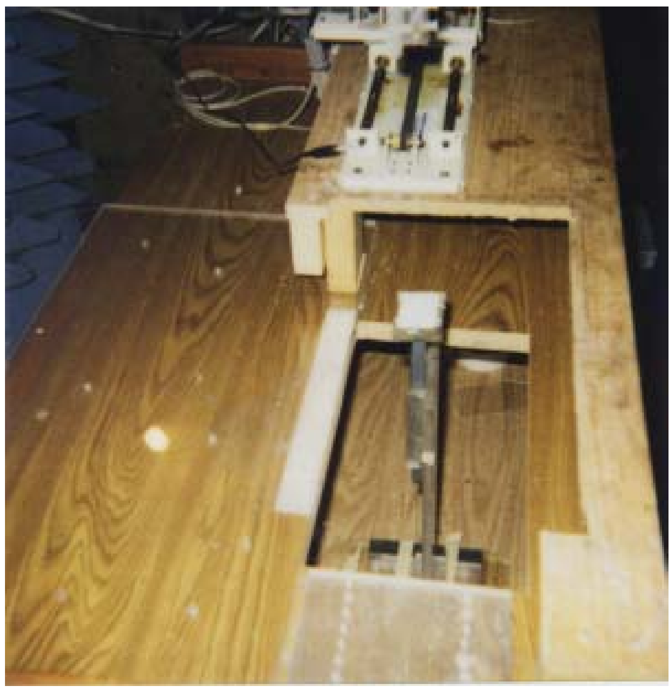


Fig. 4. The plastic holder used to support the portable computer with the Askey Corporation 802.11 a/b Cardbus Card (shown in Fig. 1).

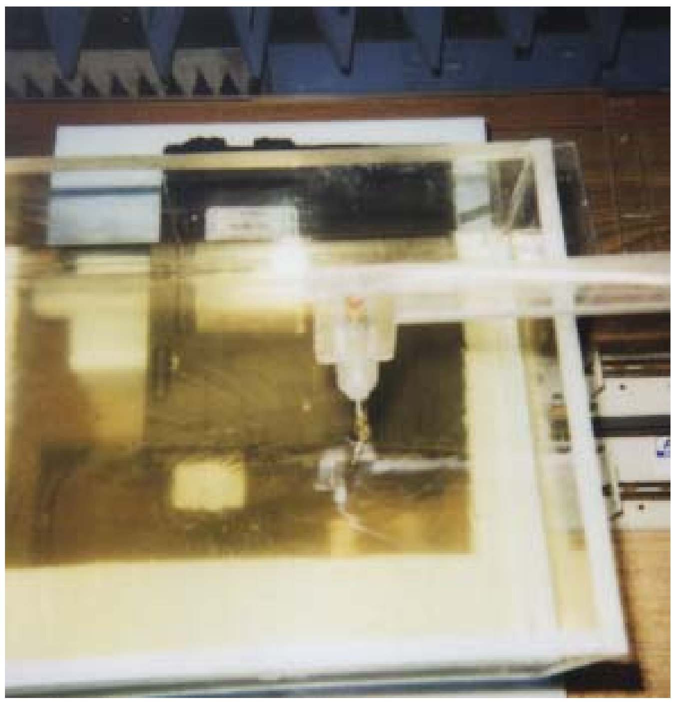


Fig. 5. Photograph of the Askey Corporation 802.11 a/b Cardbus Card inserted into a laptop computer with its bottom pressed against the bottom of the planar tissue-simulant phantom to simulate "above-lap" placement of the wireless PC. A Styrofoam block is used under the base to prevent bending of the 2 mm thin base of the phantom.

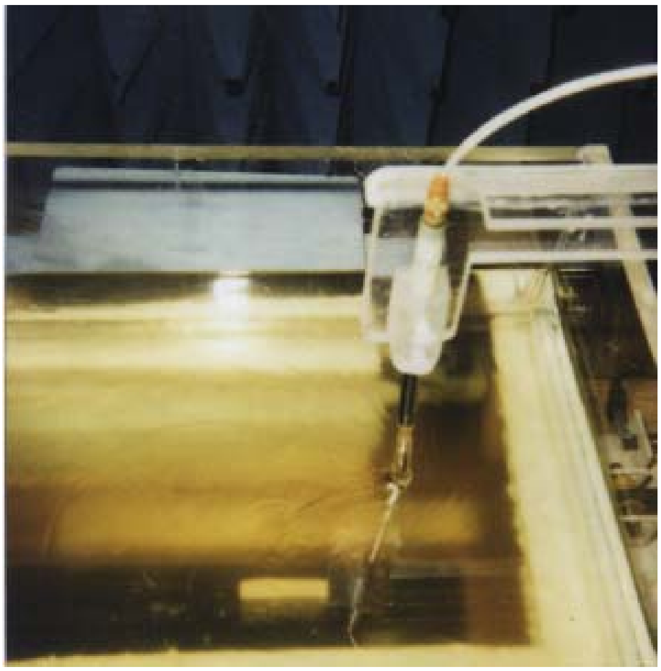
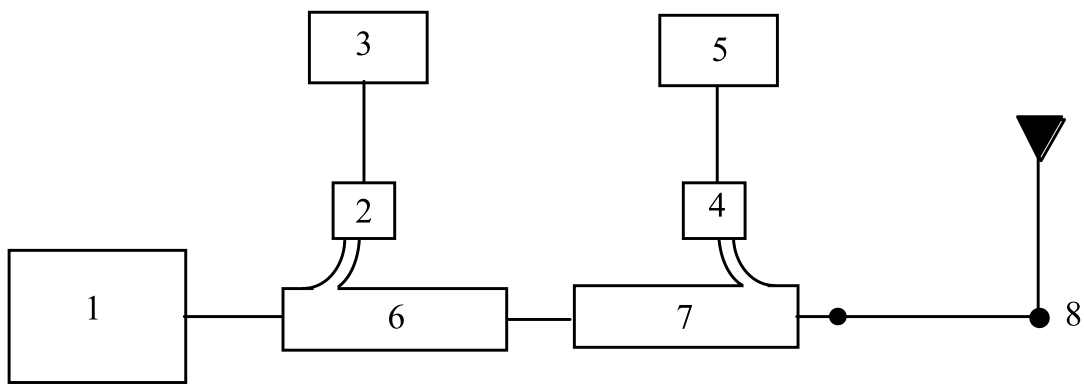


Fig. 6. Photograph of the Askey Corporation 802.11 a/b Cardbus Card inserted into a portable computer (as in Fig. 1) placed with the card edge at 90° and separated from the bottom of the phantom by 0 cm for "end-on" testing of SAR. As in Fig. 5, here too, a Styrofoam block is used under the base to prevent bending of the 2 mm thin base of the phantom.

Fig. 7. Photograph of the Narda Model 8021 Broadband Electric Field Probe used for SAR measurements.

Fig. 8. Photograph of the half-wave dipole at 1900 MHz used for system verification.



1. RF generator, MCL Model 15222 with Model 6051 plug-in (1000-2000 MHz).
2. HP Model 8481A power sensor.
3. HP Model 436A power meter.
4. HP Model 8482A power sensor.
5. HP Model 436A power meter.
6. Narda Model 3042B-30, 30 dB coaxial directional coupler.
7. Narda Model 3042-10, 10 dB coaxial directional coupler.
8. Reference dipole antenna.

Fig. 9. The microwave circuit arrangement used for SAR system verification.

Fig. 10. Photograph of the Hewlett Packard Model 85070B Dielectric Probe. This is an open-circuited coaxial line probe.

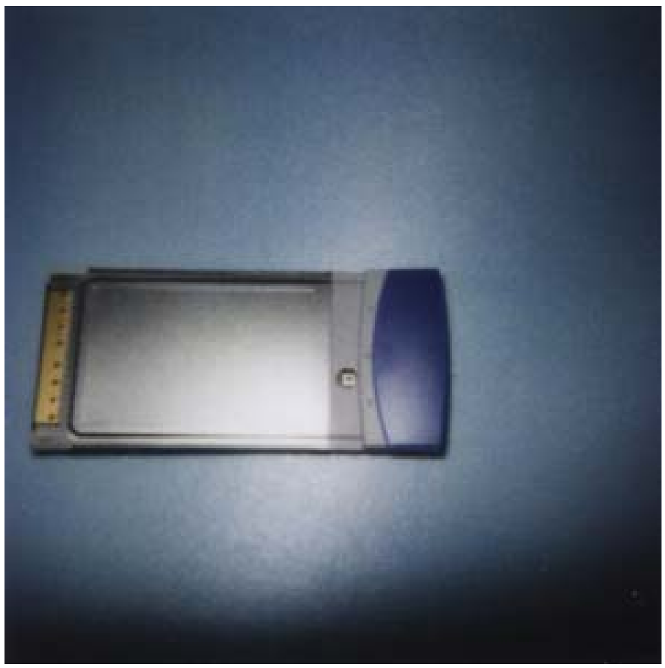
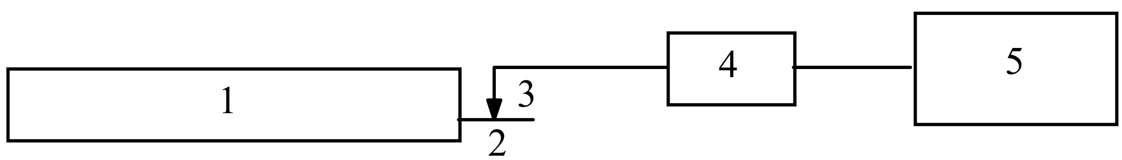
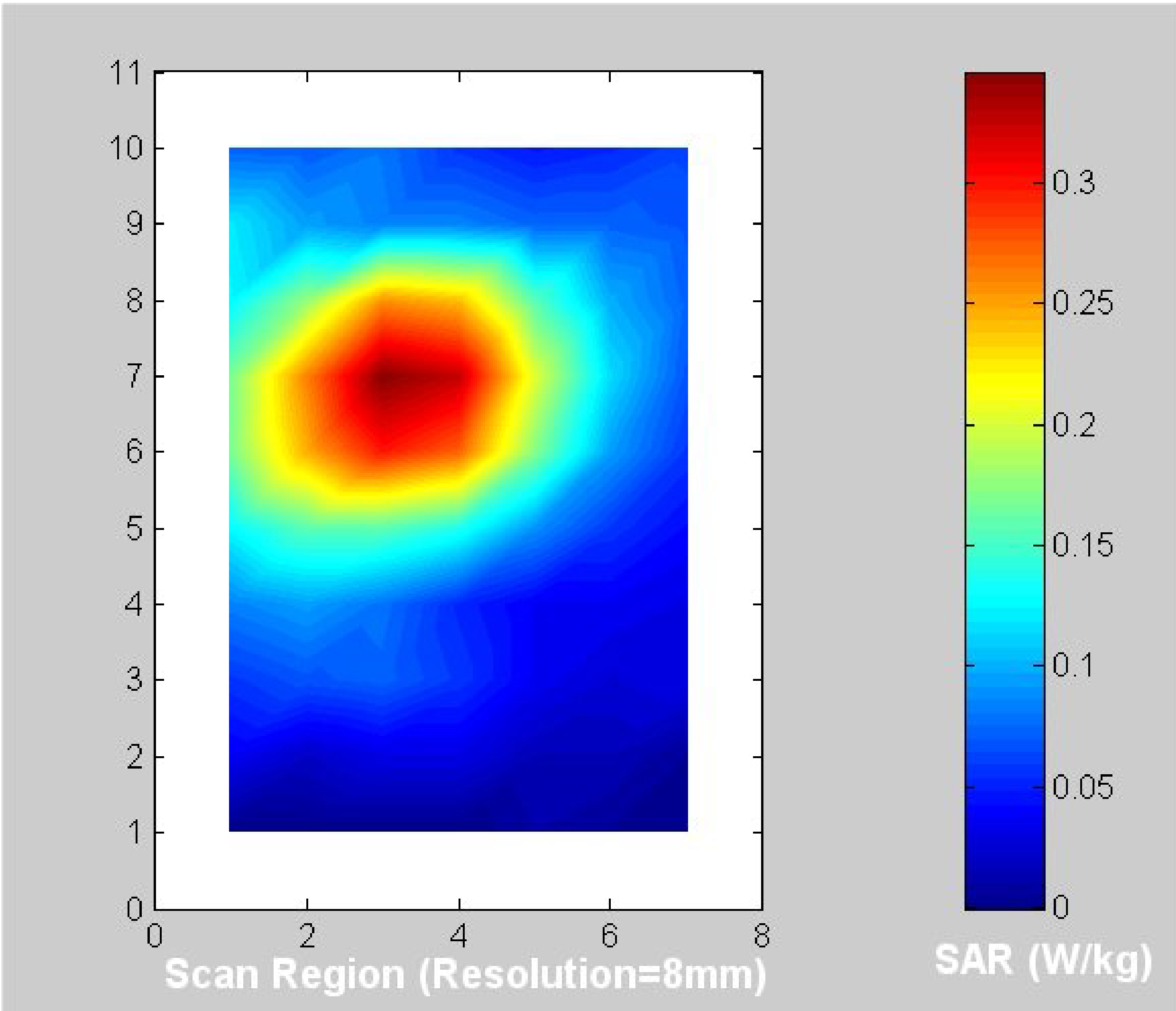


Fig. 11. Photograph of the Askey Corporation 802.11 a/b Cardbus Card with coaxial output for conducted power measurements.



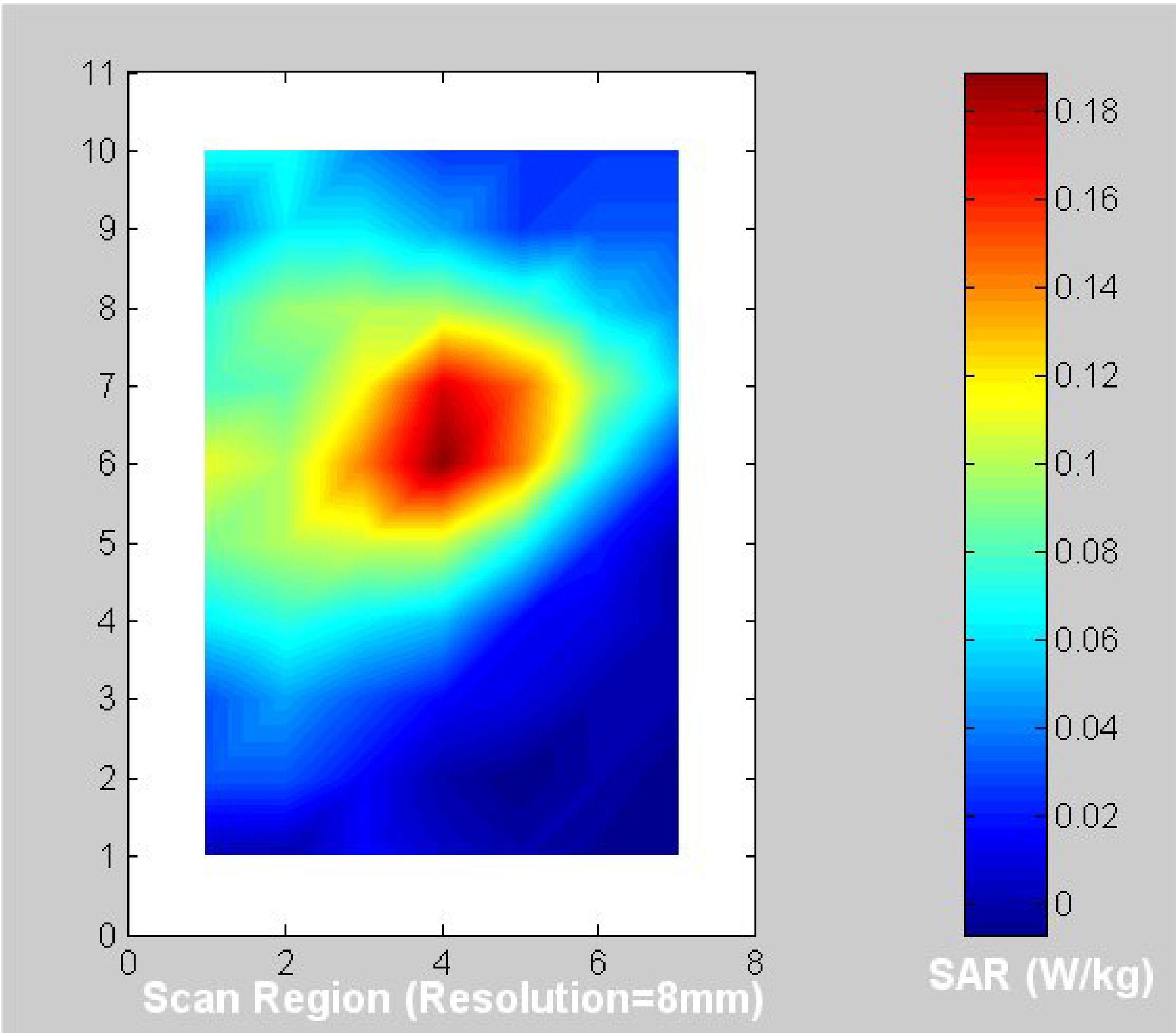
1. Laptop computer
2. Askey Cardbus Card.
3. Coaxial output for conducted power measurements.
4. HP Model 8481A Power Sensor.
5. HP Model 436A Power Meter.

Fig. 12. The microwave circuit arrangement used for conducted power measurements for the Askey Corporation 802.11 a/b Cardbus Card.



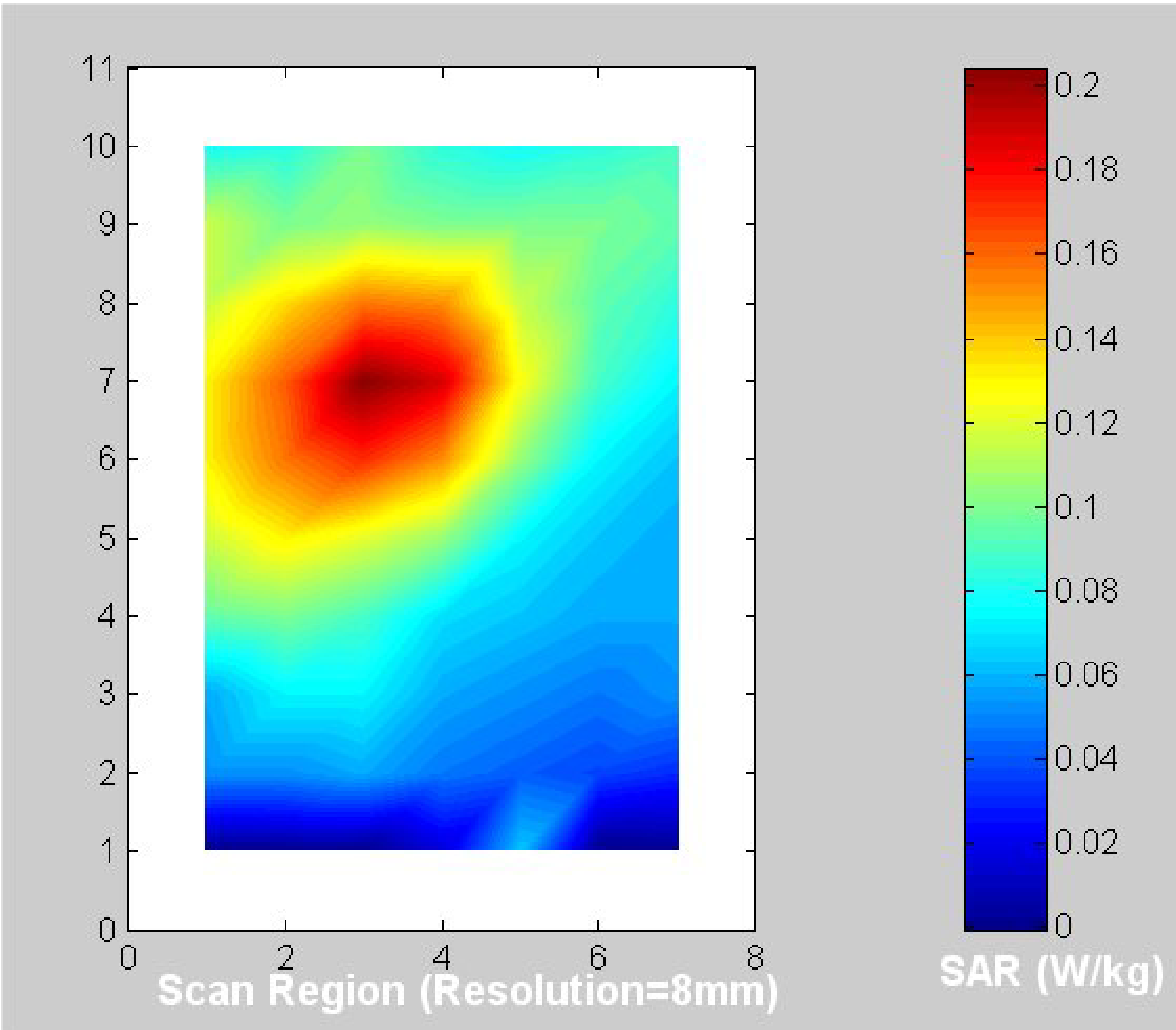
(a) 5.26 GHz normal mode (see Table 3 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a laptop computer.



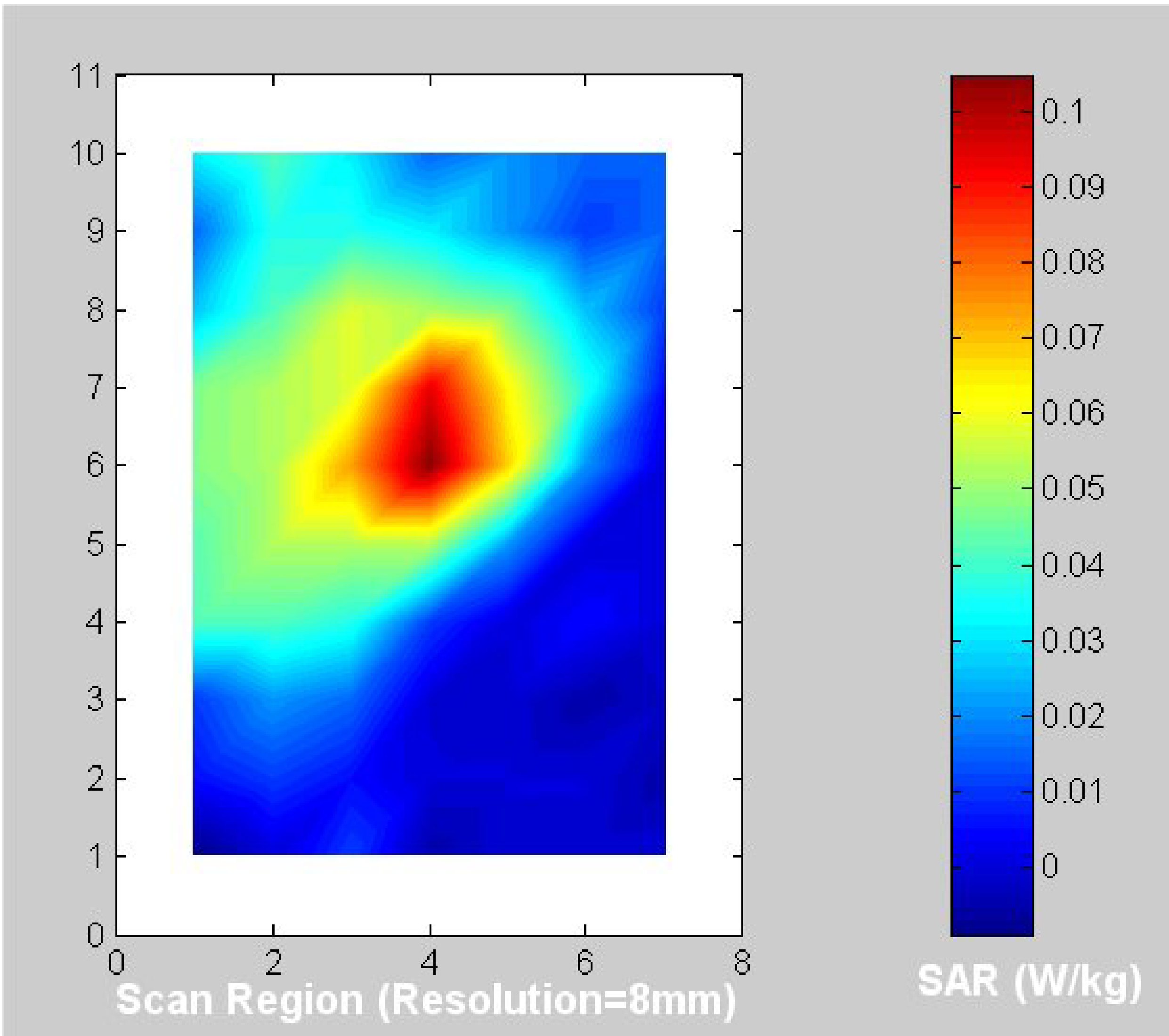
(b) 5.785 GHz normal mode (see Table 4 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a laptop computer.



(c) 5.25 GHz turbo mode (see Table 5 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a laptop computer.



(d) 5.80 GHz turbo mode (see Table 6 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a laptop computer.

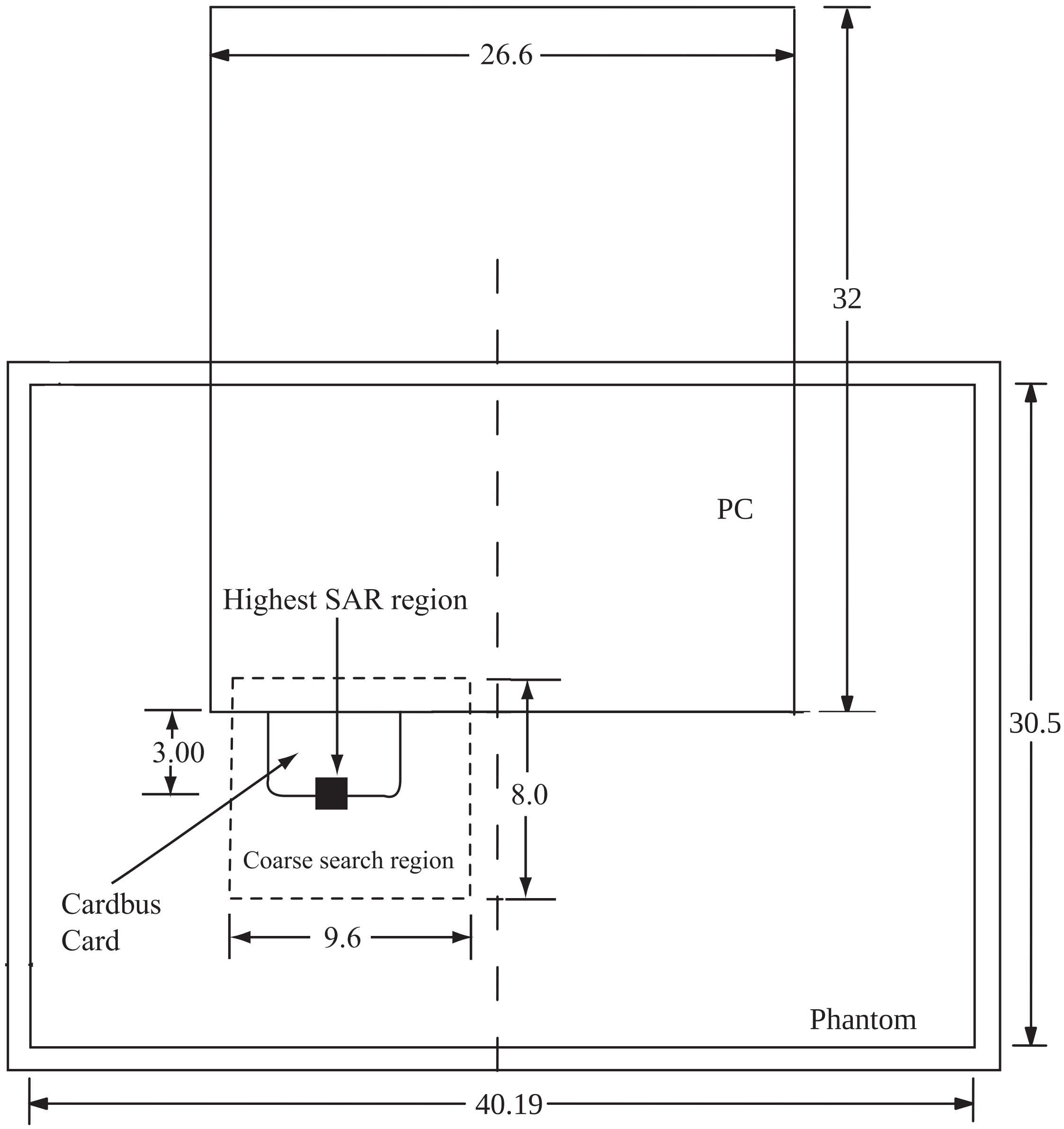
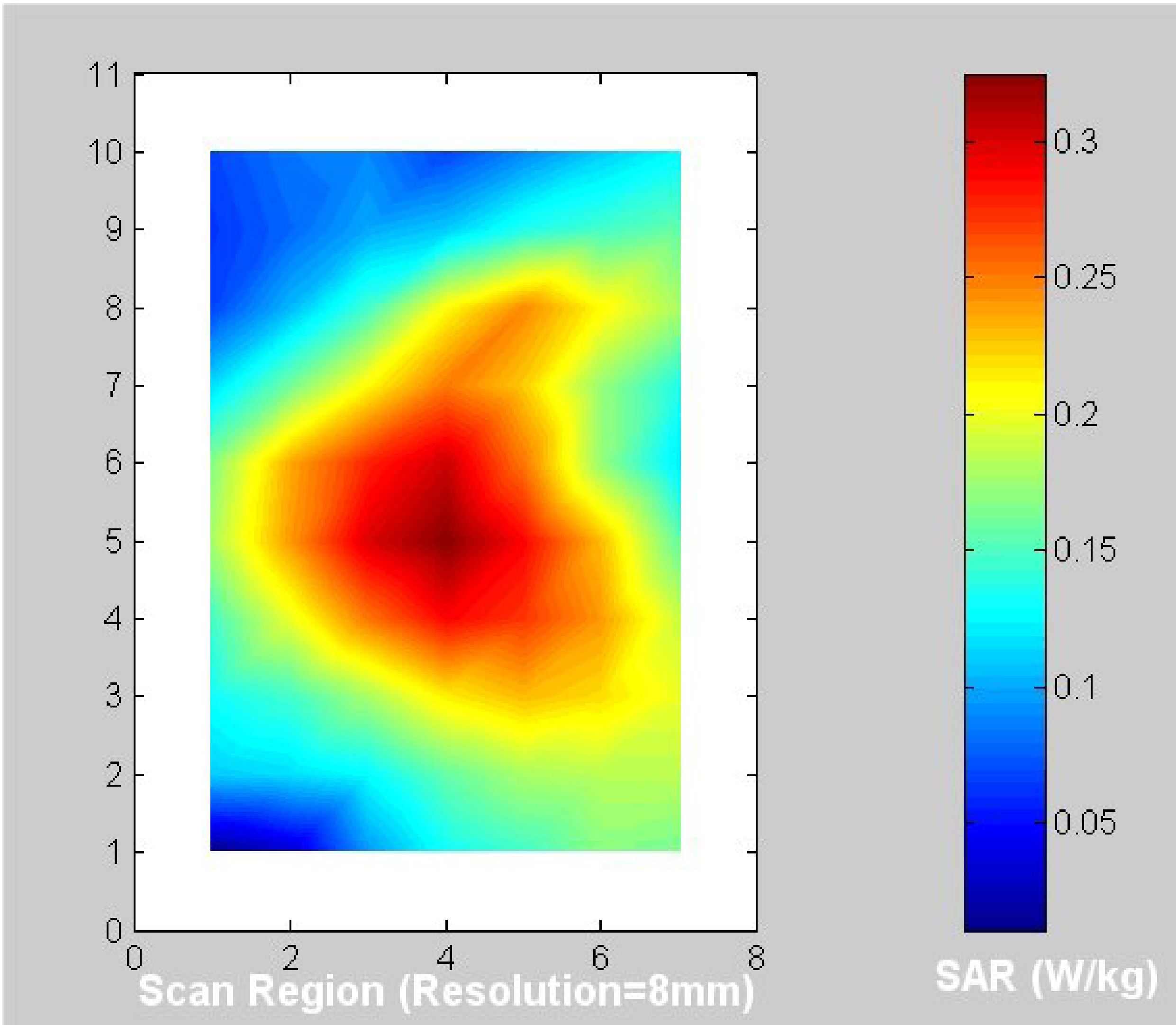
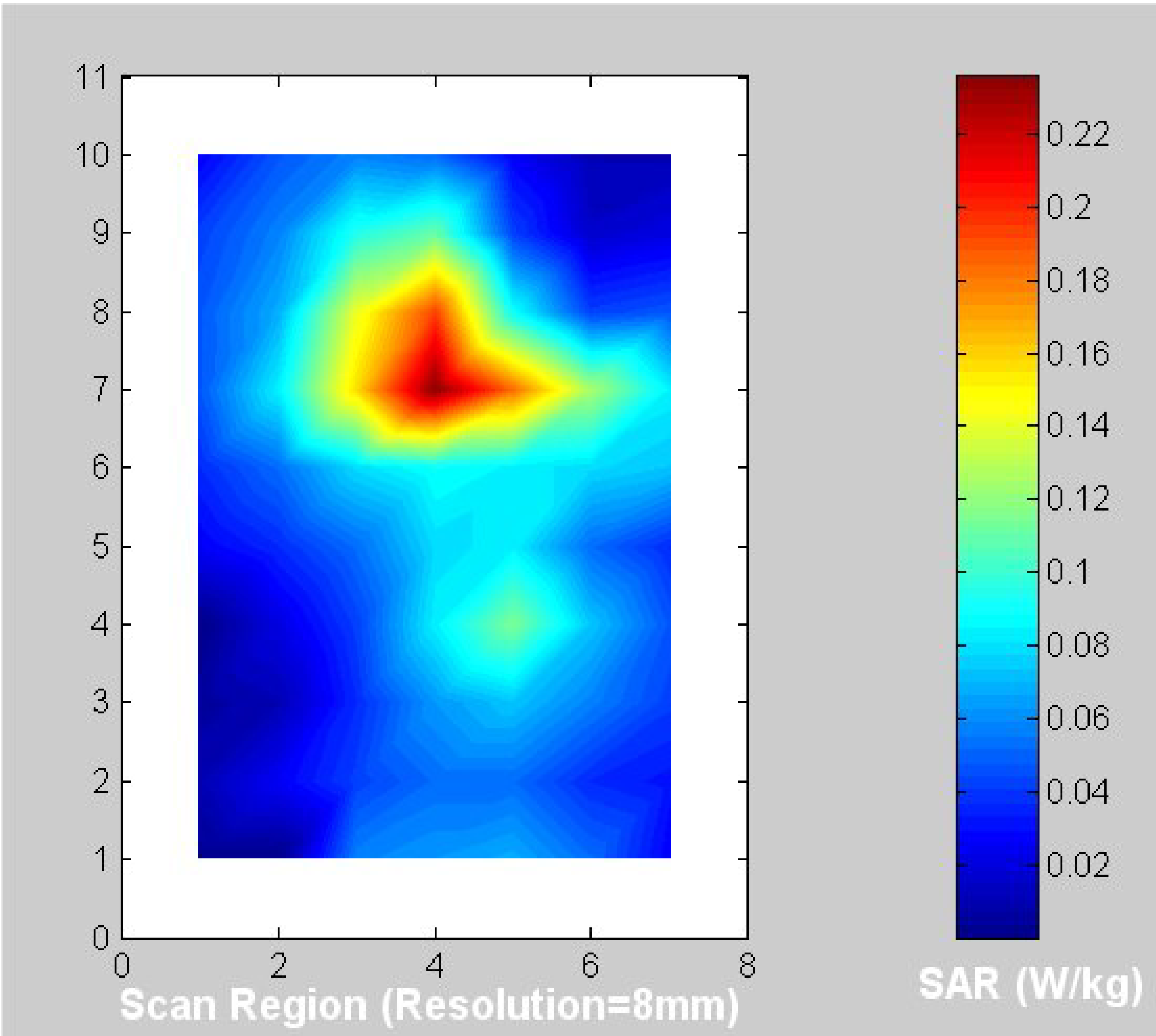


Fig. 14. Illustration of the peak SAR location with respect to the phantom and the Askey Corporation 802.11 a/b Cardbus Card for the **Above-lap position**. All dimensions are in cm.



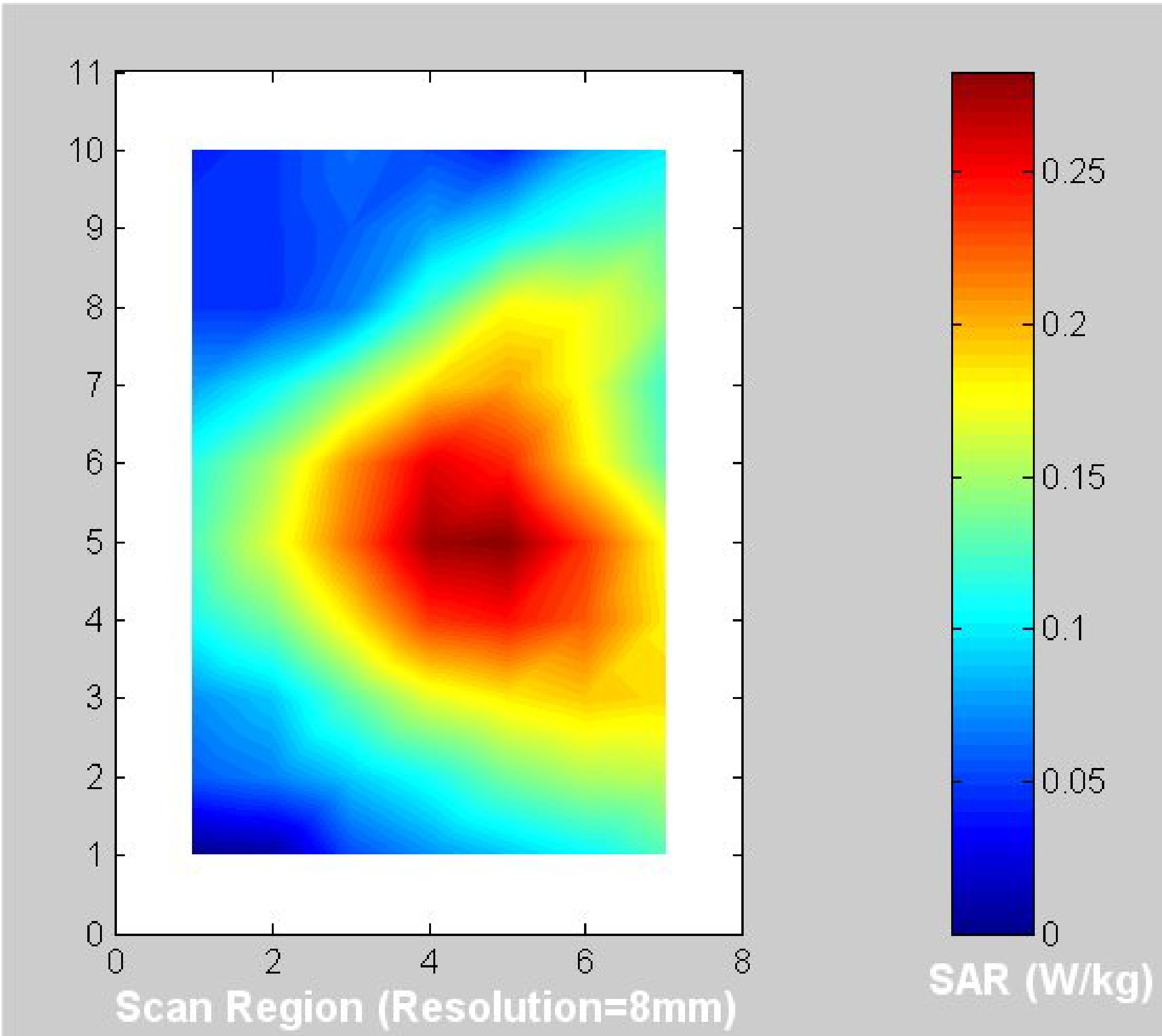
(a) 5.26 GHz normal mode (see Table 7 for the peak 1-g SAR).

Fig. 15. Coarse scans for the SAR measurements for the **End-on position** of the Askey Corporation 802.11 a/b Cardbus Card touching the base of the flat phantom.



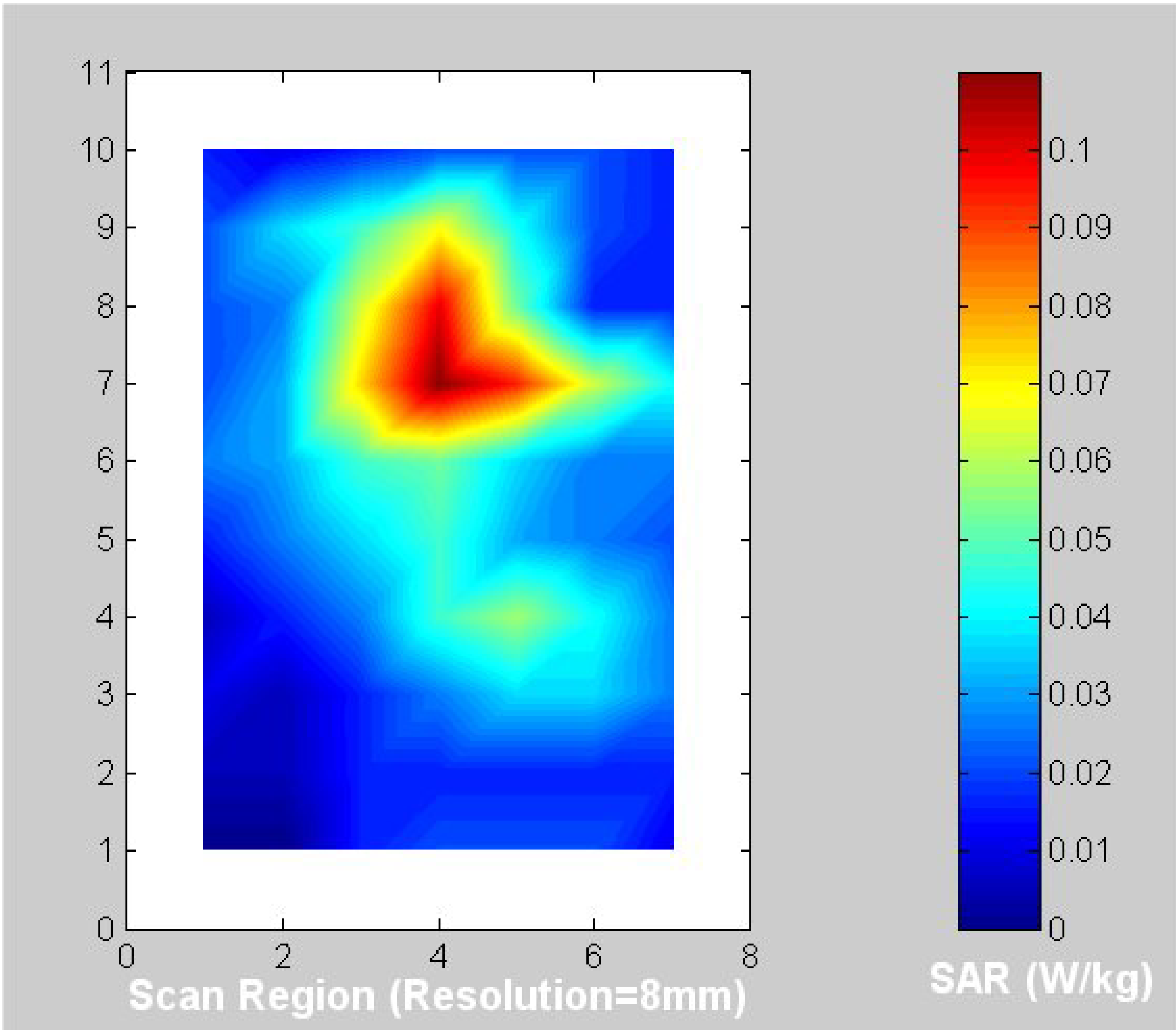
(b) 5.785 GHz normal mode (see Table 8 for the peak 1-g SAR).

Fig. 15. Coarse scans for the SAR measurements for the **End-on position** of the Askey Corporation 802.11 a/b Cardbus Card touching the base of the flat phantom



(c) 5.25 GHz turbo mode (see Table 9 for the peak 1-g SAR).

Fig. 15. Coarse scans for the SAR measurements for the **End-on position** of the Askey Corporation 802.11 a/b Cardbus Card touching the base of the flat phantom



(d) 5.80 GHz turbo mode (see Table 10 for the peak 1-g SAR).

Fig. 15. Coarse scans for the SAR measurements for the **End-on position** of the Askey Corporation 802.11 a/b Cardbus Card touching the base of the flat phantom

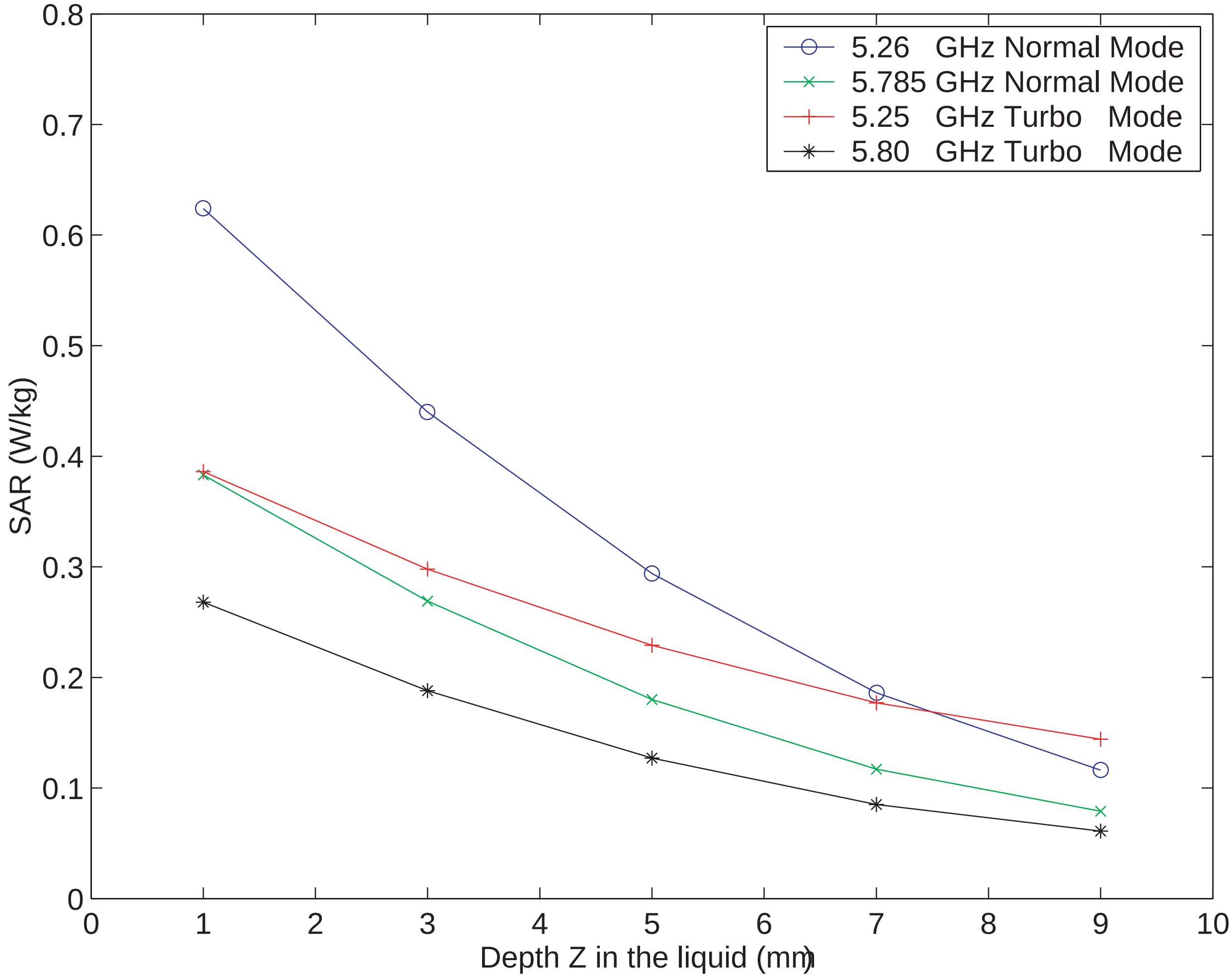


Fig. 16. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 3-6 -- Above-lap position) for Askey 802.11 a/b Cardbus Card.

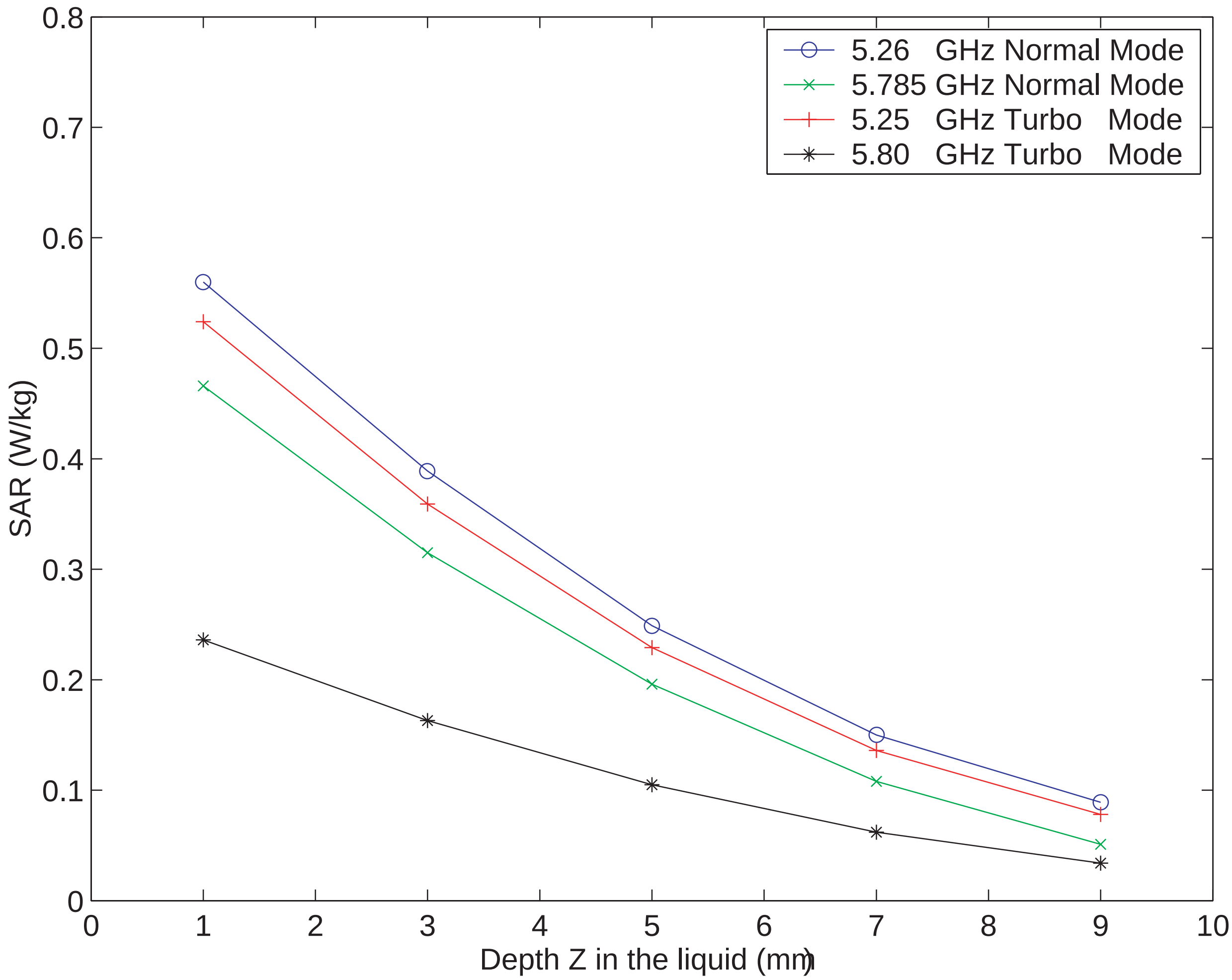


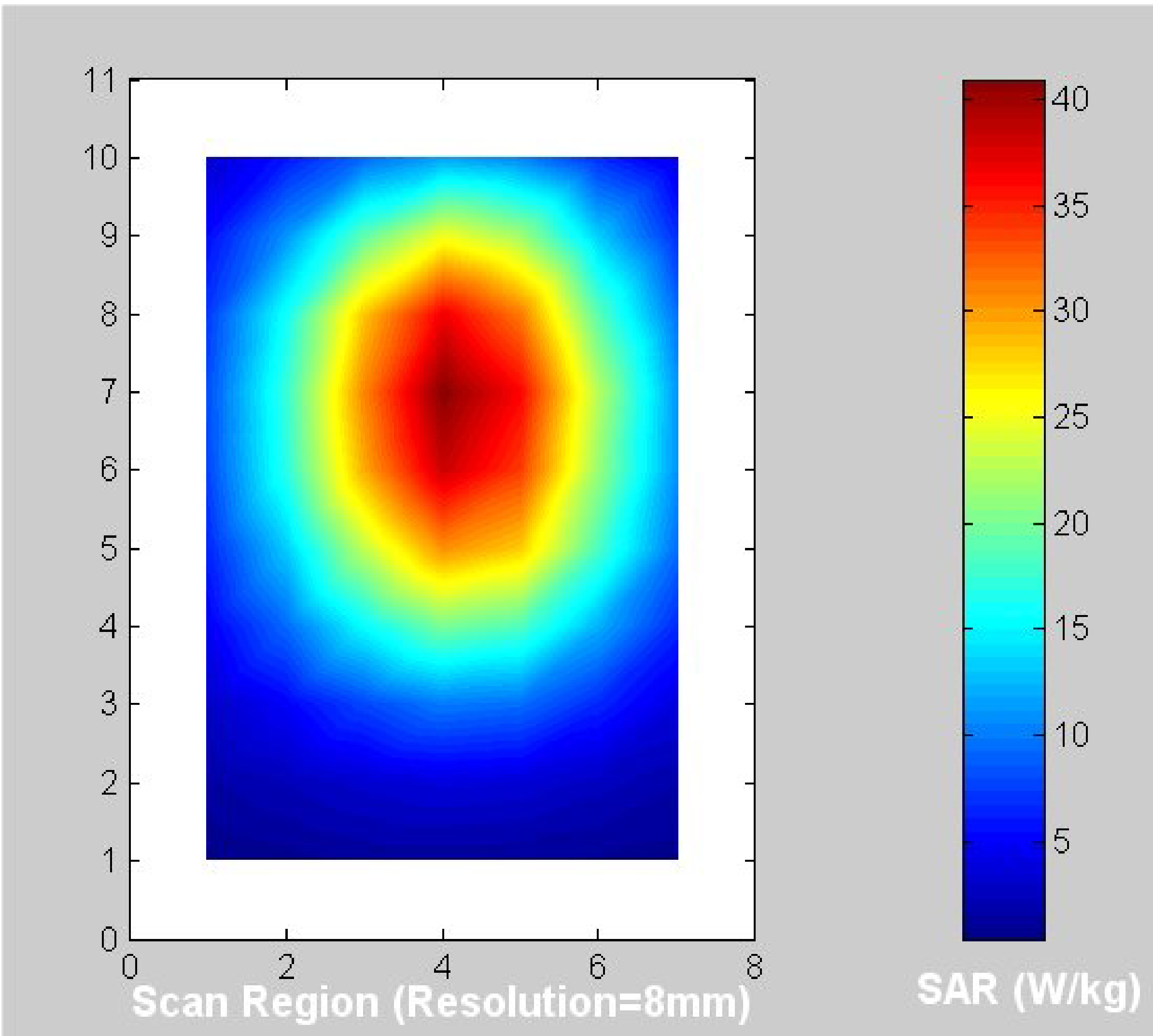
Fig. 17. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 7-10 -- End-on position) for the Askey Corporation 802.11 a/b Cardbus Card.

APPENDIX B

SAR System Verification for November 19, 20, 2002

The measured SAR distribution for the peak 1-g SAR region using a dipole at 1900 MHz

For November 19, 2002 - The dipole SAR Plot



1-g SAR = 36.189 W/kg

a. At depth of 1 mm

53.389	56.274	57.900	57.848	55.949
54.519	57.225	58.814	58.611	56.749
54.765	57.554	59.093	58.923	56.924
54.450	57.142	58.589	58.375	56.413
53.725	56.404	57.649	57.399	55.103

b. At depth of 3 mm

42.063	44.166	45.300	45.263	43.864
42.898	44.883	46.061	45.914	44.524
43.160	45.147	46.297	46.161	44.697
42.924	44.888	45.910	45.787	44.354
42.379	44.291	45.211	45.038	43.377

c. At depth of 5 mm

32.486	33.946	34.690	34.660	33.666
33.083	34.481	35.313	35.213	34.211
33.344	34.690	35.510	35.404	34.379
33.177	34.545	35.232	35.170	34.168
32.781	34.071	34.728	34.614	33.463

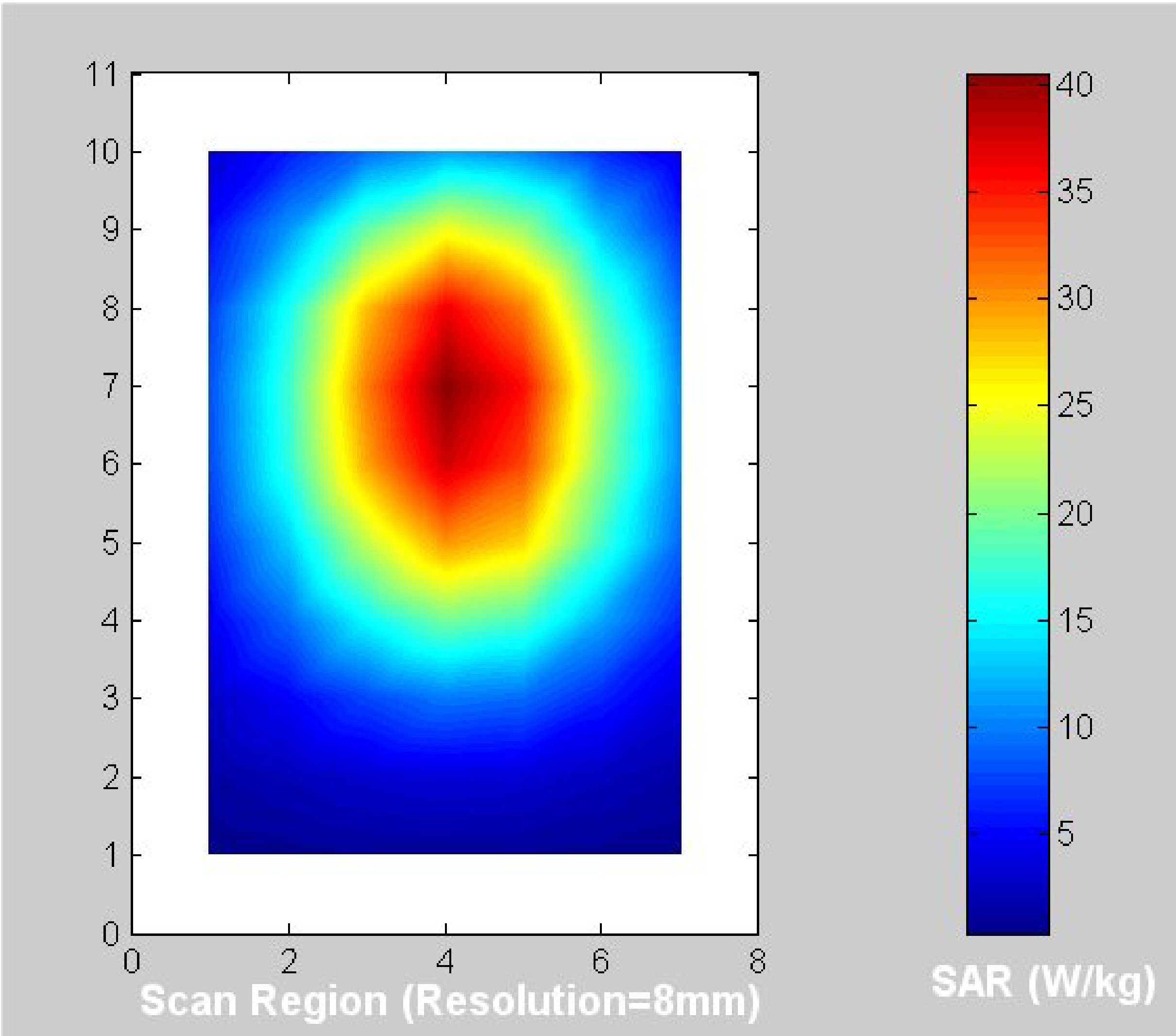
d. At depth of 7 mm

24.661	25.614	26.070	26.042	25.355
25.075	26.019	26.571	26.508	25.810
25.316	26.182	26.732	26.653	25.970
25.208	26.110	26.552	26.526	25.853
24.930	25.746	26.201	26.128	25.362

e. At depth of 9 mm

18.586	19.169	19.440	19.408	18.932
18.874	19.498	19.834	19.800	19.321
19.075	19.624	19.963	19.908	19.471
19.017	19.584	19.872	19.852	19.410
18.827	19.314	19.629	19.578	19.073

For November 20, 2002 - The Dipole SAR Plot



1-g SAR = 36.626 W/kg

a. At depth of 1 mm

53.803	56.646	58.308	58.243	56.332
54.270	56.962	58.543	58.370	56.614
53.845	56.636	58.086	57.916	56.073
52.971	55.672	56.953	56.826	54.973
51.749	54.189	55.480	55.247	53.043

b. At depth of 3 mm

42.368	44.434	45.630	45.598	44.191
42.732	44.719	45.835	45.712	44.396
42.435	44.458	45.534	45.384	44.022
41.756	43.691	44.664	44.549	43.202
40.787	42.538	43.518	43.359	41.765

c. At depth of 5 mm

32.704	34.137	34.955	34.942	33.944
32.984	34.383	35.129	35.044	34.091
32.788	34.187	34.949	34.816	33.847
32.269	33.589	34.299	34.198	33.255
31.516	32.711	33.429	33.329	32.228

d. At depth of 7 mm

24.811	25.757	26.281	26.277	25.592
25.026	25.954	26.426	26.365	25.698
24.902	25.822	26.333	26.214	25.547
24.510	25.367	25.860	25.772	25.131
23.937	24.708	25.213	25.156	24.431

e. At depth of 9 mm

18.690	19.293	19.610	19.601	19.134
18.857	19.431	19.724	19.677	19.219
18.779	19.364	19.686	19.577	19.124
18.479	19.023	19.346	19.271	18.830
18.048	18.528	18.869	18.841	18.374

APPENDIX C

Uncertainty Analysis

The uncertainty analysis of the University of Utah SAR Measurement System is given in Table A.1. Several of the numbers on tolerances are obtained by following procedures similar to those detailed in [8], while others have been obtained using methods suggested in [4].

Table B.1. Uncertainty analysis of the University of Utah SAR Measurement System.

Uncertainty Component	Tolerance ± %	Prob. Dist.	Div.	C_i 1-g	1-g u_i ± %
Measurement System					
Probe calibration	2.0	N	1	1	2.0
Axial istropy	4.0	R	$\sqrt{3}$	$(1\text{-cp})^{1/2}$	1.6
Hemispherical isotropy	5.5	R	$\sqrt{3}$	$\sqrt{c_p}$	0.0
Boundary effect	0.8	R	$\sqrt{3}$	1	0.5
Linearity	3.0	R	$\sqrt{3}$	1	1.7
System detection limits	1.0	R	$\sqrt{3}$	1	0.6
Readout electronics	1.0	N	1	1	1.0
Response time	0.0	R	$\sqrt{3}$	1	0.0
Integration time	0.5	R	$\sqrt{3}$	1	0.3
RF ambient conditions	0	R	$\sqrt{3}$	1	0
Probe positioner mechanical tolerance	0.5	R	$\sqrt{3}$	1	0.3
Probe positioning with respect to phantom shell	2.0	R	$\sqrt{3}$	1	1.2
Extrapolation, interpolation, and integration algorithms for max. SAR evaluation	5.0	R	$\sqrt{3}$	1	2.9
Test Sample Related					
Test sample positioning	3	R	$\sqrt{3}$	1	1.7
Device holder uncertainty	3	R	$\sqrt{3}$	1	1.7
Output power variation - SAR drift measurement	5	R	$\sqrt{3}$	1	2.9
Phantom and Tissue Parameters					
Phantom uncertainty - shell thickness tolerance	10.0	R	$\sqrt{3}$	1	5.8
Liquid conductivity - deviation from target values	0.4	R	$\sqrt{3}$	0.7	0.2
Liquid conductivity - measurement uncertainty	1.5	R	$\sqrt{3}$	0.7	0.6
Liquid permitivity - deviation from target values	0.8	R	$\sqrt{3}$	0.6	0.3
Liquid permittivity - measurement uncertainty	3.5	R	$\sqrt{3}$	0.6	1.2
Combined Standard Uncertainty		RSS			8.3
Expanded Uncertainty (95% Confidence Level)					16.6