SAR COMPLIANCE TESTING OF ASKEY COMPUTER CORPORATION 802.11 a/b CARDBUS CARD INSERTED INTO A TOSHIBA LAPTOP COMPUTER

FCC ID: H8NWLC221-D4

HOST COMPUTER: Toshiba Satellite Pro 6100 System

MODEL: PS610U-AAAA5

SERIAL #: 12062458J

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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 Toshiba Satellite Pro 6100 laptop computer (Model: PS610U-AAAA5, Serial # 12062458J manufactured by Toshiba Corporation, Japan). Photographs of the unit with the Cardbus Card inserted into the laptop computer are given in Figs. 1a and 1b for top and bottom sides of the PC, respectively. 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). The SAR test report for this 802.11 a/b Cardbus Card inserted into an IBM Model 2628-21T Laptop Computer was previously submitted on November 21, 2002. This SAR test report pertains to the use of the Askey Computer Corporation Model WLC 221-D4 Cardbus Card with the Toshiba Model PS610U-AAAA5 host computer. As compared to the previously used IBM Model 2628-21T host computer, a characteristic of the Toshiba host computer is that its keyboard is somewhat thinner. This results in a closer placement of the Cardbus Card of 1.08 cm for the laptop placement of the PC (this compares to an average separation on the order of 1.3 cm for the IBM host computer).

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. 1b) 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. 16 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. 8 -- 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 Toshiba 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 Toshiba 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 (see Figs. 7a, b). The triaxial (3 dipole) E-field probe shown in Fig. 8 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) and the fact that the bandwidth of 600 MHz for the entire set of measurements is on the order of ±5.5% of the midband frequencies.

The data for the calibration of the E-field probe closest to the SAR tests given here was January 23, 2003.

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. 9. 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. 10. 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 January 22, 23, 2003 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 35.575 and 36.262 W/kg which is a variability of less than 2%. Furthermore, both of the measured 1-g SARs are in excellent agreement with the FDTD-calculated 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. 11) 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 Im(ε^*), we can obtain the conductivity σ from the relationship

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

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. 12 and 13). 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. 14a-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. 15. Given in Tables 3-6 are the SAR distributions for the peak SAR region of volume 10 ×10 ×mm for which the coarse scans are given in Figs. 14a-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 Toshiba laptop computer with the bottom of the PC pressed against the bottom of the flat phantom (see Fig. 5). 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 $23.5 \pm 0.2^{\circ}C$.

The coarse scans measurements for the four measurements for the End-on position are shown in Fig. 16a-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. 17 and 18, respectively.

For the measurements in Tables 3-6, the separation between the Askey Cardbus Card and the bottom of the experimental phantom is about 1.08 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. 16a-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 0.12 to 0.77 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 802.11 a/b 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 Toshiba laptop computer for the normal mode at 5.26 GHz.

1-g SAR = 0.768 W/kg

a. At depth of 1 mm

1.455	1.530	1.548	1.506	1.406
1.513	1.585	1.596	1.521	1.445
1.535	1.637	1.591	1.584	1.476
1.509	1.558	1.575	1.511	1.405
1.412	1.483	1.481	1.432	1.359

b. At depth of 3 mm

0.999	1.059	1.063	1.037	0.968
1.039	1.089	1.092	1.048	0.999
1.053	1.115	1.091	1.089	1.015
1.043	1.078	1.079	1.042	0.971
0.979	1.022	1.018	1.001	0.950

c. At depth of 5 mm

0.640	0.685	0.682	0.668	0.622
0.665	0.697	0.695	0.674	0.647
0.673	0.706	0.697	0.699	0.651
0.675	0.699	0.689	0.673	0.629
0.638	0.659	0.655	0.661	0.628

d. At depth of 7 mm

0.377	0.409	0.403	0.397	0.368
0.393	0.409	0.406	0.400	0.388
0.396	0.410	0.409	0.414	0.386
0.407	0.422	0.407	0.403	0.379
0.389	0.393	0.392	0.412	0.392

e. At depth of 9 mm

0.211	0.232	0.228	0.225	0.208
0.222	0.225	0.224	0.226	0.223
0.222	0.225	0.228	0.234	0.219
0.237	0.245	0.231	0.233	0.222
0.233	0.226	0.228	0.255	0.243

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

1-g SAR = 0.695 W/kg

a. At depth of 1 mm

1.203	1.277	1.337	1.313	1.255
1.314	1.372	1.390	1.372	1.308
1.338	1.419	1.478	1.421	1.353
1.383	1.431	1.472	1.420	1.357
1.310	1.388	1.424	1.427	1.343

b. At depth of 3 mm

0.827	0.882	0.918	0.902	0.857
0.896	0.943	0.954	0.937	0.895
0.918	0.971	1.017	0.974	0.934
0.951	0.982	1.012	0.977	0.942
0.914	0.966	0.986	0.991	0.942

c. At depth of 5 mm

0.531	0.570	0.588	0.579	0.545
0.569	0.604	0.610	0.594	0.569
0.587	0.619	0.654	0.622	0.603
0.610	0.629	0.650	0.628	0.614
0.601	0.632	0.641	0.648	0.625

d. At depth of 7 mm

0.315	0.340	0.345	0.343	0.318
0.331	0.355	0.358	0.344	0.331
0.346	0.363	0.388	0.365	0.362
0.361	0.372	0.385	0.373	0.374
0.370	0.386	0.390	0.398	0.390

e. At depth of 9 mm

0.179	0.192	0.191	0.195	0.177
0.183	0.198	0.199	0.187	0.181
0.193	0.202	0.219	0.203	0.209
0.204	0.210	0.217	0.213	0.222
0.221	0.227	0.232	0.241	0.239

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

1-g SAR = 0.706 W/kg

a. At depth of 1 mm

1.244	1.265	1.315	1.279	1.293
1.327	1.338	1.362	1.297	1.325
1.359	1.350	1.382	1.358	1.367
1.353	1.363	1.384	1.359	1.251
1.250	1.328	1.323	1.301	1.251

b. At depth of 3 mm

0.870	0.885	0.923	0.913	0.909
0.927	0.943	0.956	0.927	0.947
0.948	0.945	0.976	0.971	0.952
0.938	0.953	0.961	0.955	0.886
0.887	0.931	0.932	0.925	0.902

c. At depth of 5 mm

0.575	0.587	0.615	0.622	0.607
0.611	0.631	0.636	0.632	0.646
0.627	0.627	0.654	0.662	0.624
0.613	0.633	0.632	0.637	0.599
0.600	0.621	0.625	0.630	0.629

d. At depth of 7 mm

0.360	0.369	0.391	0.406	0.385
0.379	0.401	0.402	0.412	0.422
0.395	0.396	0.415	0.431	0.384
0.377	0.405	0.396	0.405	0.391
0.389	0.398	0.405	0.417	0.431

e. At depth of 9 mm

0.225	0.233	0.250	0.266	0.245
0.230	0.254	0.252	0.268	0.275
0.252	0.252	0.261	0.279	0.233
0.230	0.267	0.255	0.257	0.260
0.256	0.262	0.269	0.285	0.308

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

1-g SAR = 0.560 W/kg

a. At depth of 1 mm

0.955	0.944	0.961	0.998	0.967
1.068	1.045	1.050	1.014	1.031
1.082	1.117	1.102	1.106	1.061
1.163	1.154	1.167	1.137	1.066
1.088	1.109	1.067	1.048	0.967

b. At depth of 3 mm

0.667	0.672	0.675	0.698	0.685
0.741	0.727	0.733	0.710	0.726
0.757	0.775	0.770	0.774	0.743
0.813	0.810	0.816	0.798	0.748
0.770	0.775	0.747	0.733	0.683

c. At depth of 5 mm

0.442	0.456	0.451	0.463	0.462
0.484	0.476	0.483	0.471	0.485
0.501	0.506	0.509	0.513	0.492
0.536	0.539	0.540	0.529	0.498
0.518	0.512	0.495	0.485	0.459

d. At depth of 7 mm

0.279	0.294	0.288	0.291	0.296
0.296	0.292	0.299	0.298	0.308
0.314	0.312	0.319	0.322	0.308
0.333	0.339	0.337	0.332	0.316
0.331	0.319	0.311	0.304	0.296

e. At depth of 9 mm

0.178	0.188	0.186	0.182	0.189
0.178	0.176	0.183	0.191	0.194
0.196	0.192	0.200	0.202	0.192
0.203	0.211	0.209	0.205	0.201
0.211	0.196	0.193	0.189	0.194

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

1-g SAR = 0.305 W/kg

a. At depth of 1 mm

0.510	0.512	0.537	0.524	0.508
0.552	0.584	0.572	0.575	0.552
0.563	0.595	0.608	0.615	0.589
0.571	0.611	0.638	0.634	0.604
0.562	0.598	0.626	0.617	0.601

b. At depth of 3 mm

0.358	0.361	0.373	0.365	0.358
0.389	0.410	0.402	0.401	0.387
0.398	0.416	0.426	0.425	0.408
0.400	0.426	0.447	0.441	0.419
0.398	0.420	0.440	0.437	0.426

c. At depth of 5 mm

0.237	0.242	0.243	0.240	0.238
0.259	0.273	0.267	0.264	0.256
0.267	0.275	0.280	0.276	0.264
0.265	0.281	0.295	0.288	0.273
0.267	0.279	0.294	0.293	0.287

d. At depth of 7 mm

0.148	0.154	0.149	0.148	0.150
0.164	0.170	0.168	0.164	0.160
0.168	0.172	0.173	0.168	0.159
0.165	0.175	0.182	0.176	0.167
0.169	0.175	0.186	0.187	0.186

e. At depth of 9 mm

0.090	0.096	0.090	0.089	0.093
0.102	0.104	0.104	0.101	0.098
0.104	0.107	0.102	0.099	0.092
0.100	0.108	0.107	0.105	0.100
0.105	0.109	0.118	0.118	0.122

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

1-g SAR = 0.217 W/kg

a. At depth of 1 mm

0.326	0.373	0.397	0.391	0.374
0.369	0.406	0.433	0.447	0.437
0.381	0.415	0.435	0.450	0.431
0.400	0.393	0.431	0.449	0.412
0.359	0.384	0.413	0.401	0.374

b. At depth of 3 mm

0.241	0.264	0.279	0.274	0.262
0.265	0.292	0.305	0.313	0.304
0.272	0.292	0.306	0.312	0.300
0.279	0.281	0.302	0.313	0.282
0.256	0.273	0.294	0.286	0.272

c. At depth of 5 mm

0.172	0.179	0.185	0.182	0.174
0.184	0.201	0.204	0.207	0.199
0.186	0.196	0.205	0.204	0.197
0.185	0.191	0.201	0.206	0.182
0.174	0.186	0.201	0.196	0.193

d. At depth of 7 mm

0.121	0.118	0.116	0.114	0.111
0.124	0.133	0.130	0.129	0.124
0.121	0.125	0.130	0.125	0.122
0.117	0.125	0.128	0.129	0.110
0.114	0.122	0.134	0.130	0.136

e. At depth of 9 mm

0.086	0.079	0.072	0.070	0.073
0.087	0.089	0.083	0.080	0.078
0.079	0.080	0.082	0.077	0.075
0.074	0.082	0.082	0.082	0.068
0.076	0.083	0.092	0.090	0.101

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

1-g SAR = 0.270 W/kg

a. At depth of 1 mm

0.449	0.458	0.490	0.474	0.463
0.478	0.512	0.522	0.512	0.525
0.512	0.541	0.563	0.577	0.555
0.536	0.529	0.544	0.530	0.519
0.467	0.478	0.511	0.508	0.527

b. At depth of 3 mm

0.314	0.323	0.343	0.337	0.325
0.335	0.357	0.364	0.359	0.371
0.356	0.381	0.394	0.399	0.387
0.372	0.369	0.375	0.371	0.363
0.328	0.335	0.355	0.359	0.375

c. At depth of 5 mm

0.207	0.218	0.227	0.228	0.216
0.222	0.235	0.239	0.238	0.248
0.234	0.254	0.260	0.259	0.255
0.242	0.243	0.243	0.245	0.240
0.218	0.223	0.233	0.241	0.255

d. At depth of 7 mm

0.129	0.140	0.142	0.146	0.135
0.140	0.145	0.147	0.148	0.157
0.145	0.160	0.161	0.157	0.159
0.148	0.151	0.148	0.153	0.150
0.138	0.141	0.144	0.156	0.167

e. At depth of 9 mm

0.079	0.091	0.089	0.092	0.083
0.088	0.086	0.088	0.091	0.098
0.088	0.098	0.097	0.093	0.098
0.090	0.092	0.090	0.093	0.093
0.086	0.089	0.088	0.103	0.112

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

1-g SAR = 0.118 W/kg

a. At depth of 1 mm

0.196	0.214	0.220	0.229	0.217
0.211	0.233	0.251	0.247	0.231
0.233	0.245	0.258	0.243	0.227
0.219	0.233	0.247	0.237	0.219
0.215	0.224	0.228	0.209	0.171

b. At depth of 3 mm

0.139	0.150	0.154	0.158	0.148
0.150	0.165	0.174	0.172	0.158
0.162	0.170	0.179	0.168	0.155
0.154	0.164	0.170	0.163	0.149
0.150	0.155	0.157	0.145	0.124

c. At depth of 5 mm

0.093	0.099	0.101	0.103	0.094
0.101	0.110	0.112	0.112	0.101
0.106	0.111	0.116	0.109	0.099
0.102	0.109	0.110	0.105	0.095
0.099	0.101	0.101	0.094	0.087

d. At depth of 7 mm

0.060	0.062	0.063	0.062	0.056
0.065	0.070	0.067	0.068	0.060
0.065	0.067	0.070	0.066	0.058
0.064	0.069	0.067	0.063	0.057
0.061	0.061	0.061	0.058	0.060

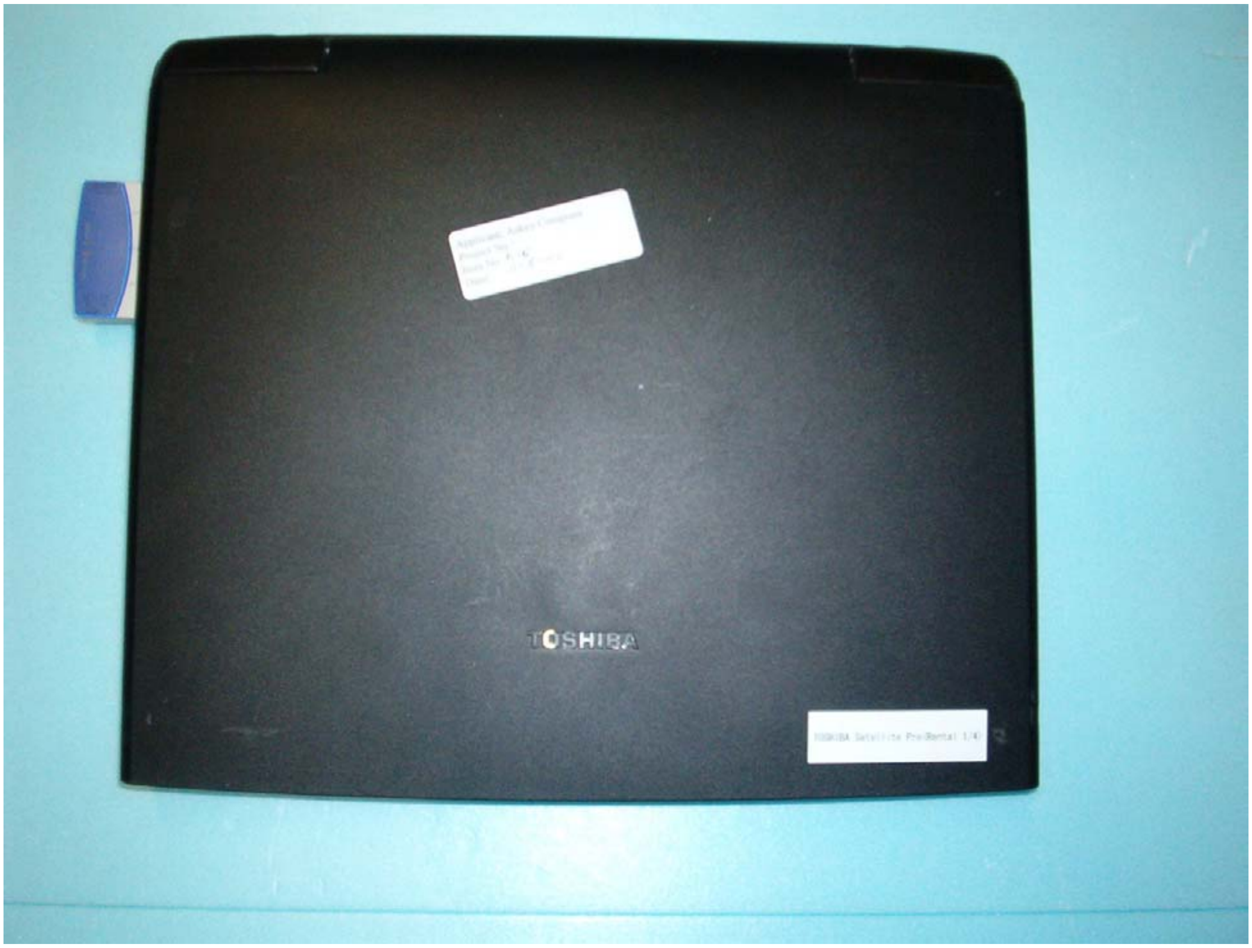
e. At depth of 9 mm

0.039	0.037	0.039	0.036	0.032
0.041	0.043	0.039	0.040	0.034
0.039	0.040	0.041	0.039	0.032
0.039	0.042	0.039	0.037	0.033
0.037	0.037	0.036	0.036	0.043

Table 11. The peak 1-g SARs measured for the Askey Corporation 802.11 a/b Cardbus Card inserted into a Toshiba Satellite Pro 6100 laptop computer.

1-g SAR in W/kg

Toshiba 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 Toshiba PC pressed against bottom of the flat phantom	1.08 cm	0.768	0.695	0.706	0.560
"End-on": card edge at 90° pressed against the bottom of the flat phantom	0 cm	0.305	0.217	0.270	0.118



a. Top side of the laptop computer.

Fig. 1a. Photograph of the Askey Corporation Model WLC221-D4 Cardbus Card inserted into a Toshiba Satellite Pro 6100 laptop computer.

b. Bottom side of the laptop computer.

Fig. 1a. Photograph of the Askey Corporation Model WLC221-D4 Cardbus Card inserted into a Toshiba Satellite Pro 6100 laptop computer.

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

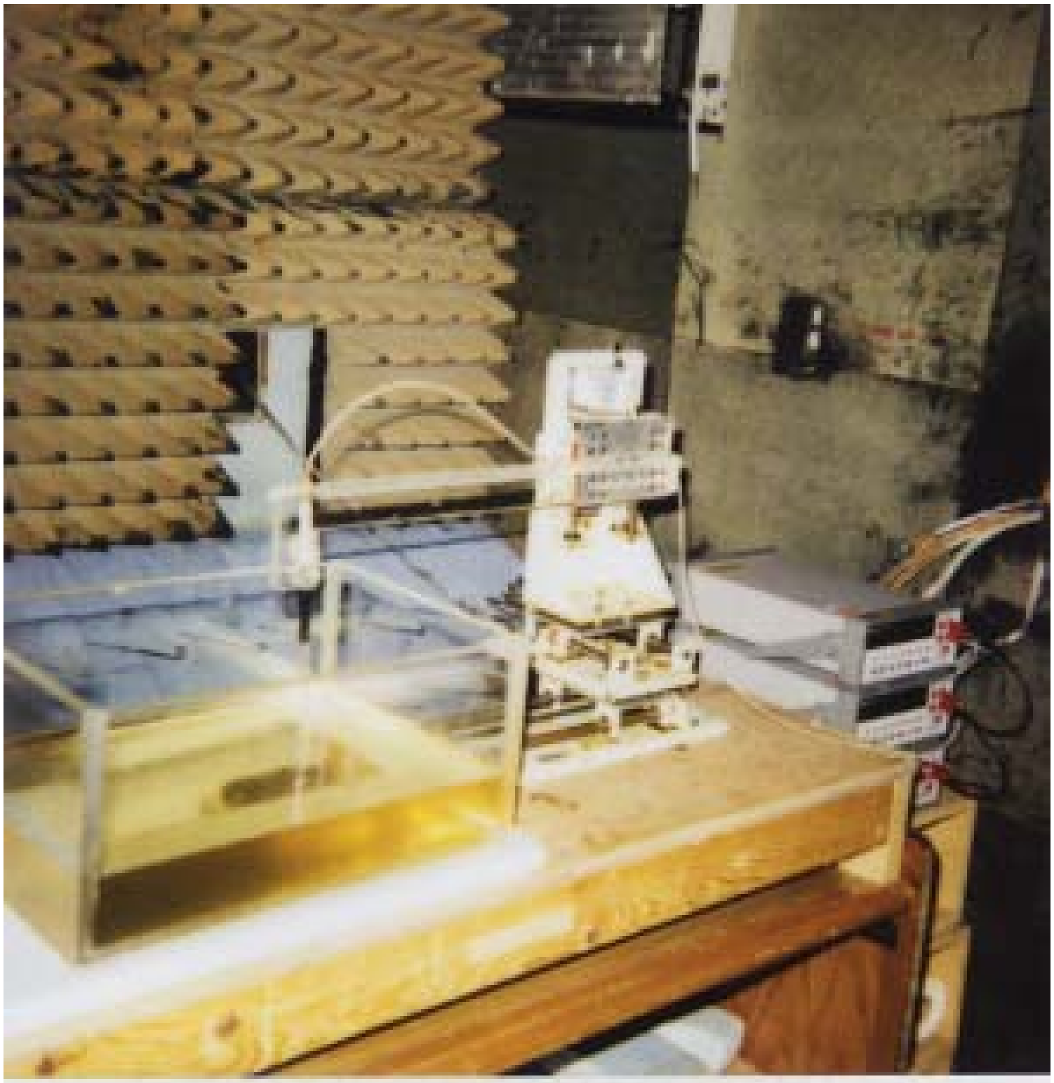


Fig. 3. Photograph of the three-dimensional stepper-motor-controlled SAR measurement system using a planar phantom (see Figs. 5, 6 for a detailed examination of the placement of Askey Corporation 802.11 a/b Cardbus Card relative to this phantom).

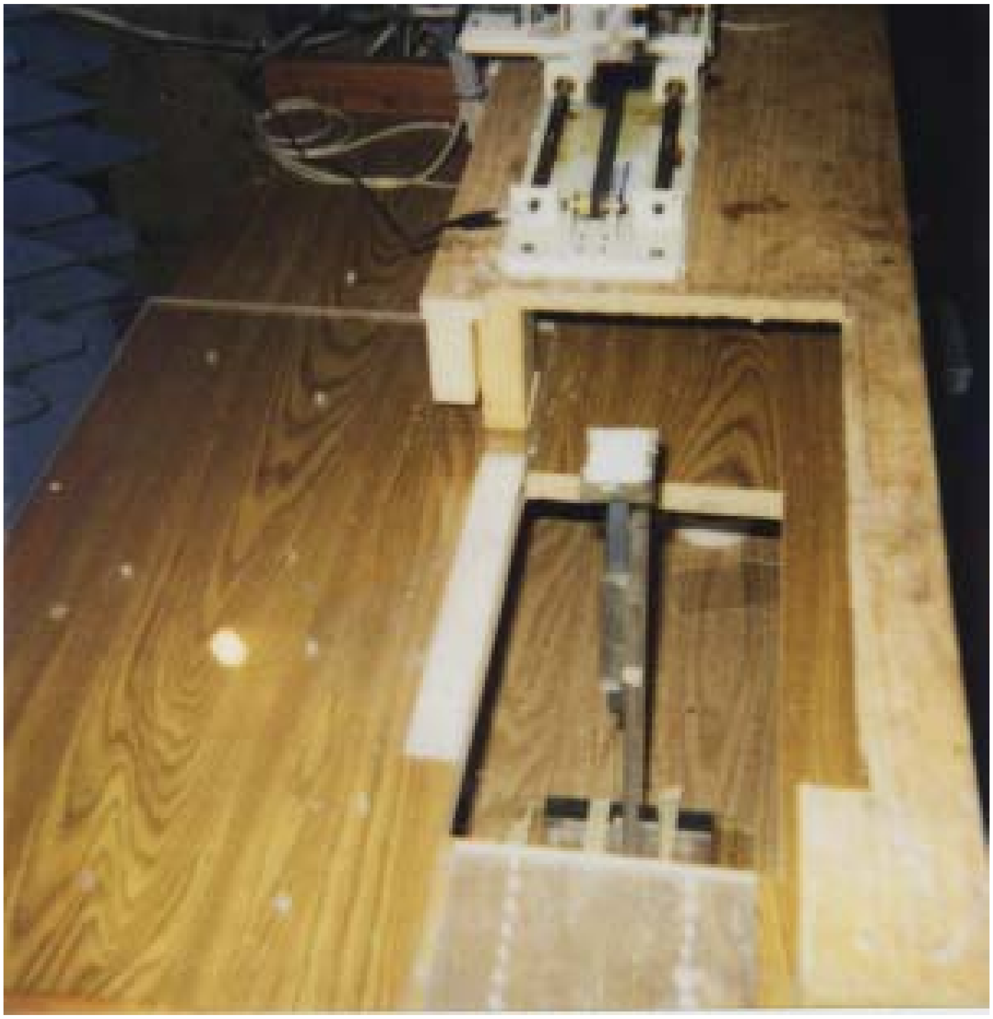


Fig. 4. The plastic holder used to support the portable computer with the Askey Corporation 802.11 a/b Cardbus Card (shown in Fig. 1).

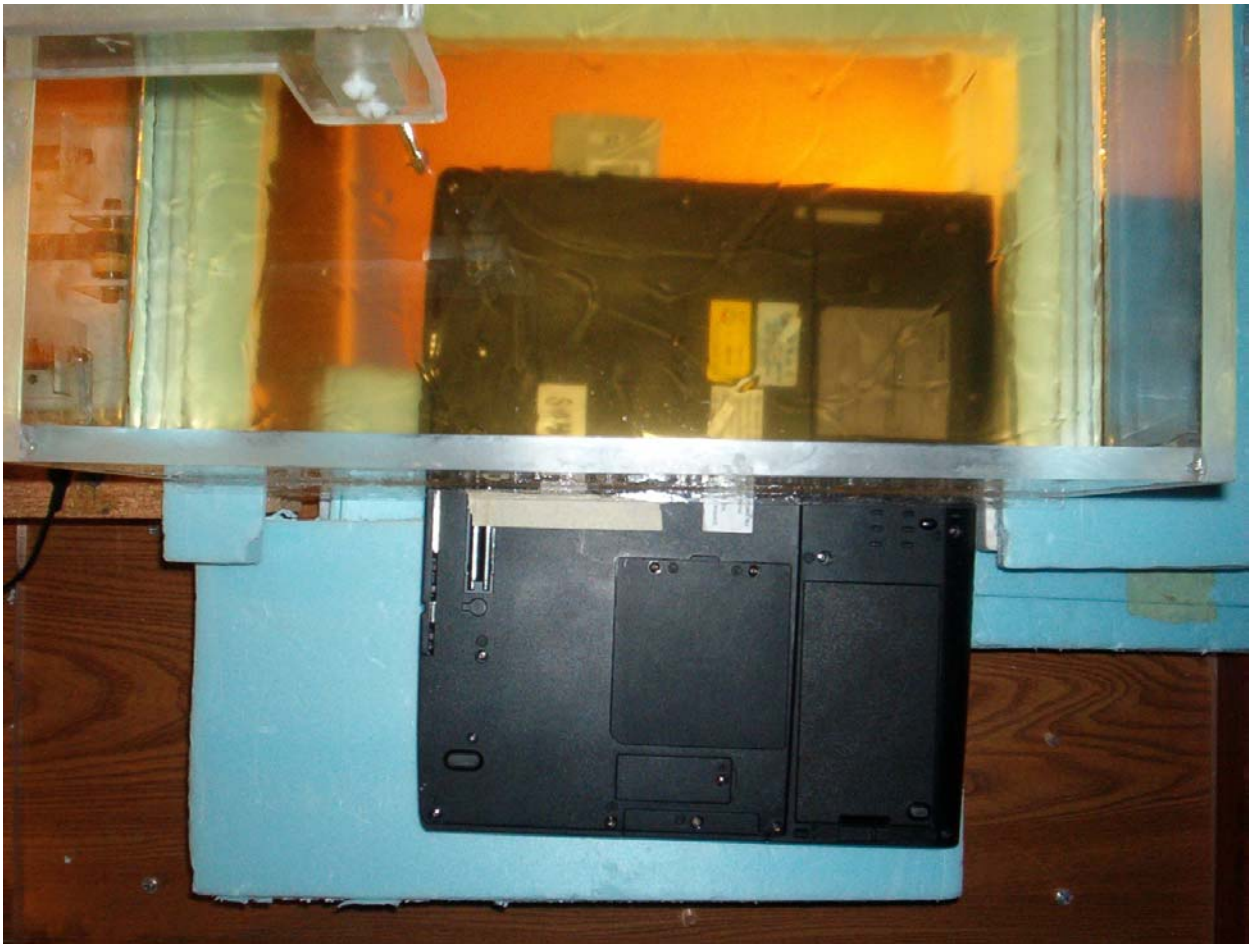


Fig. 5. Photograph of the Askey Corporation 802.11 a/b Cardbus Card inserted into a Toshiba laptop computer with its bottom pressed against the bottom of the planar tissue-simulant phantom to simulate "above-lap" placement of the wireless PC. A Styrofoam block is used under the base to prevent bending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

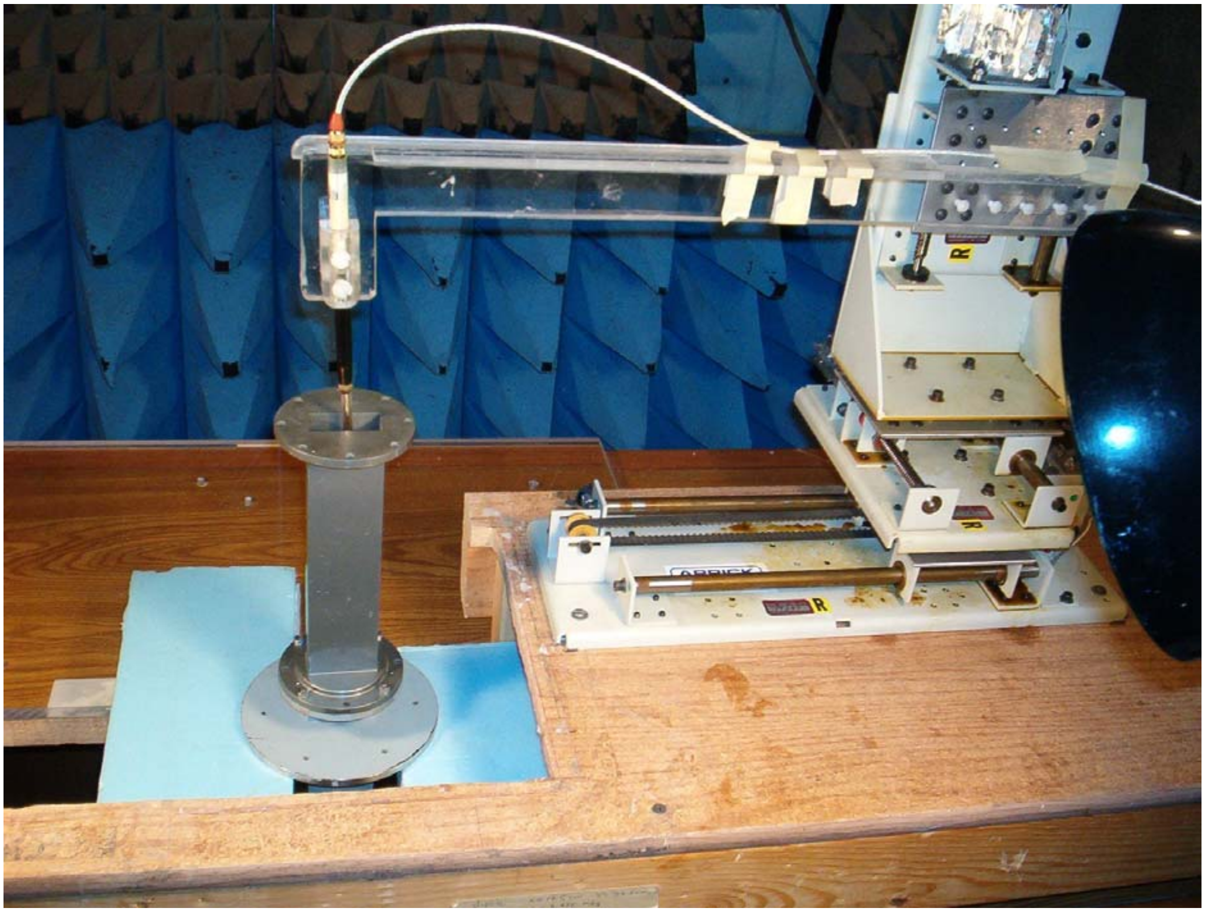


Fig. 7a. A photograph of the waveguide setup used for calibration of the Narda Model 8021 E-field probe in the frequency band 5.2-5.8 GHz.

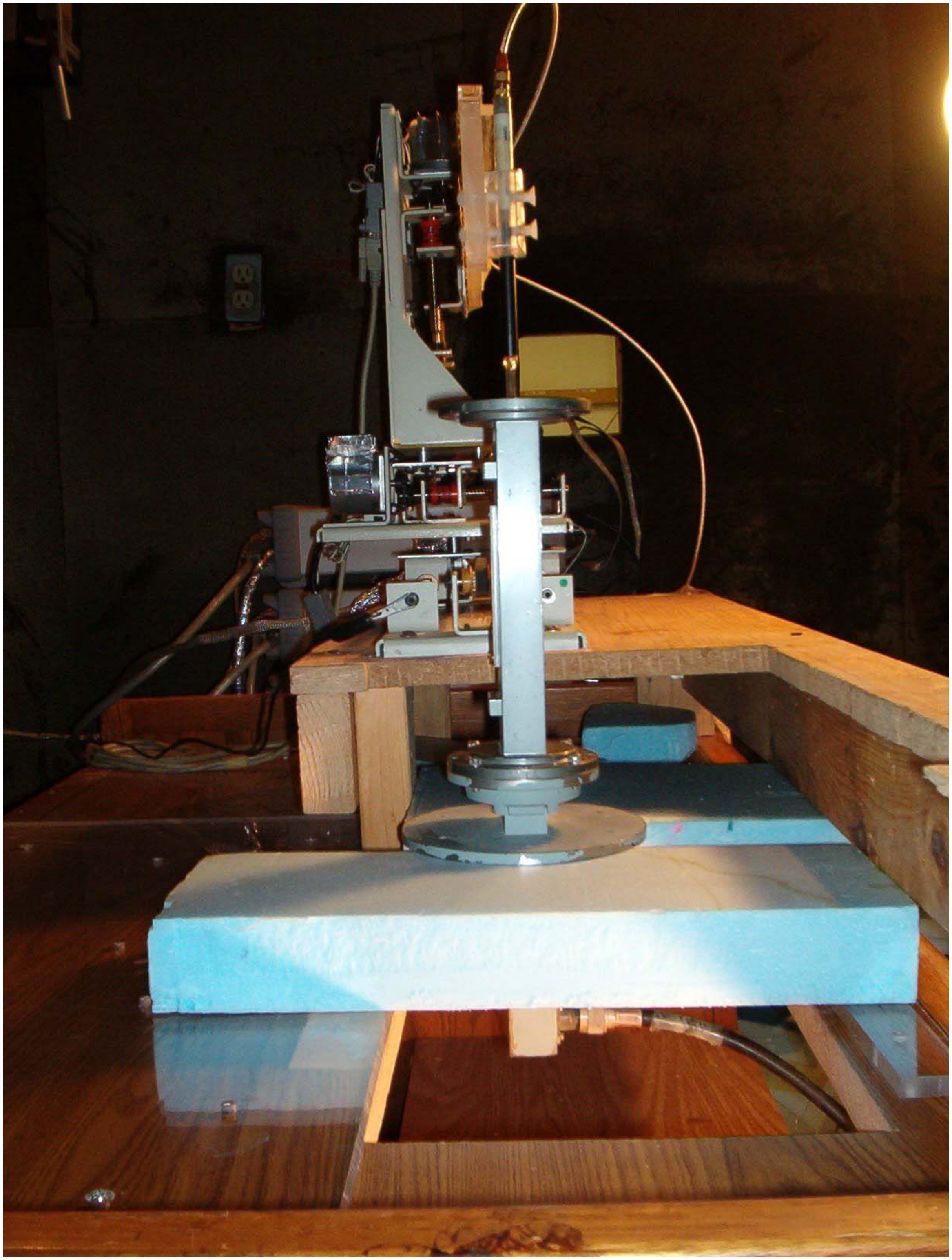
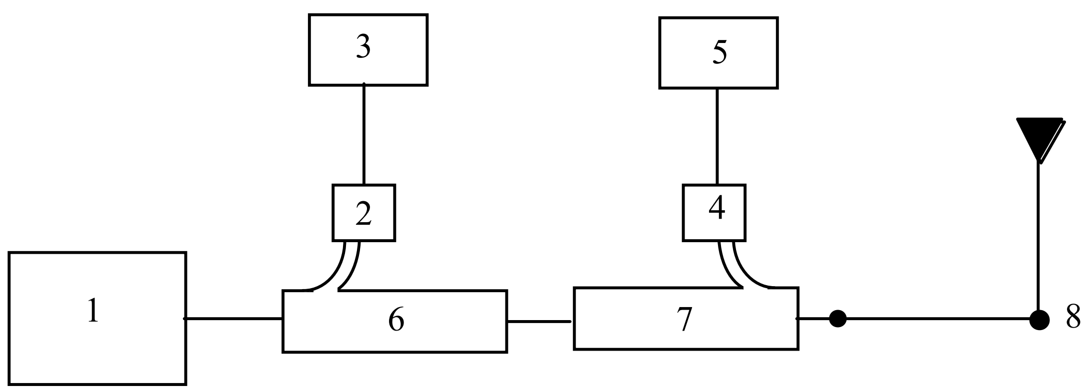


Fig. 7b. Photograph of the waveguide setup showing also the coax to waveguide coupler at the bottom used to feed power to the vertical waveguide containing the tissue-simulant fluid.

Fig. 8. Photograph of the Narda Model 8021 Broadband Electric Field Probe used for SAR measurements.

Fig. 9. Photograph of the half-wave dipole at 1900 MHz used for system verification.

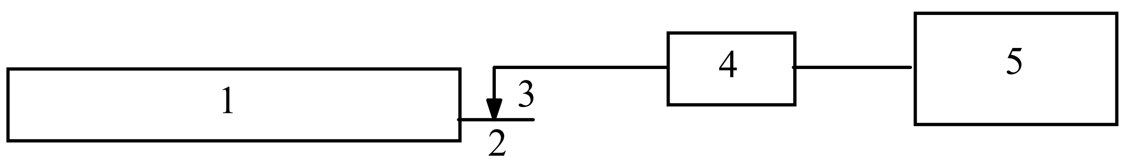


1. RF generator, MCL Model 15222 with Model 6051 plug-in (1000-2000 MHz).
2. HP Model 8481A power sensor.
3. HP Model 436A power meter.
4. HP Model 8482A power sensor.
5. HP Model 436A power meter.
6. Narda Model 3042B-30, 30 dB coaxial directional coupler.
7. Narda Model 3042-10, 10 dB coaxial directional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

Fig. 10. The microwave circuit arrangement used for SAR system verification.

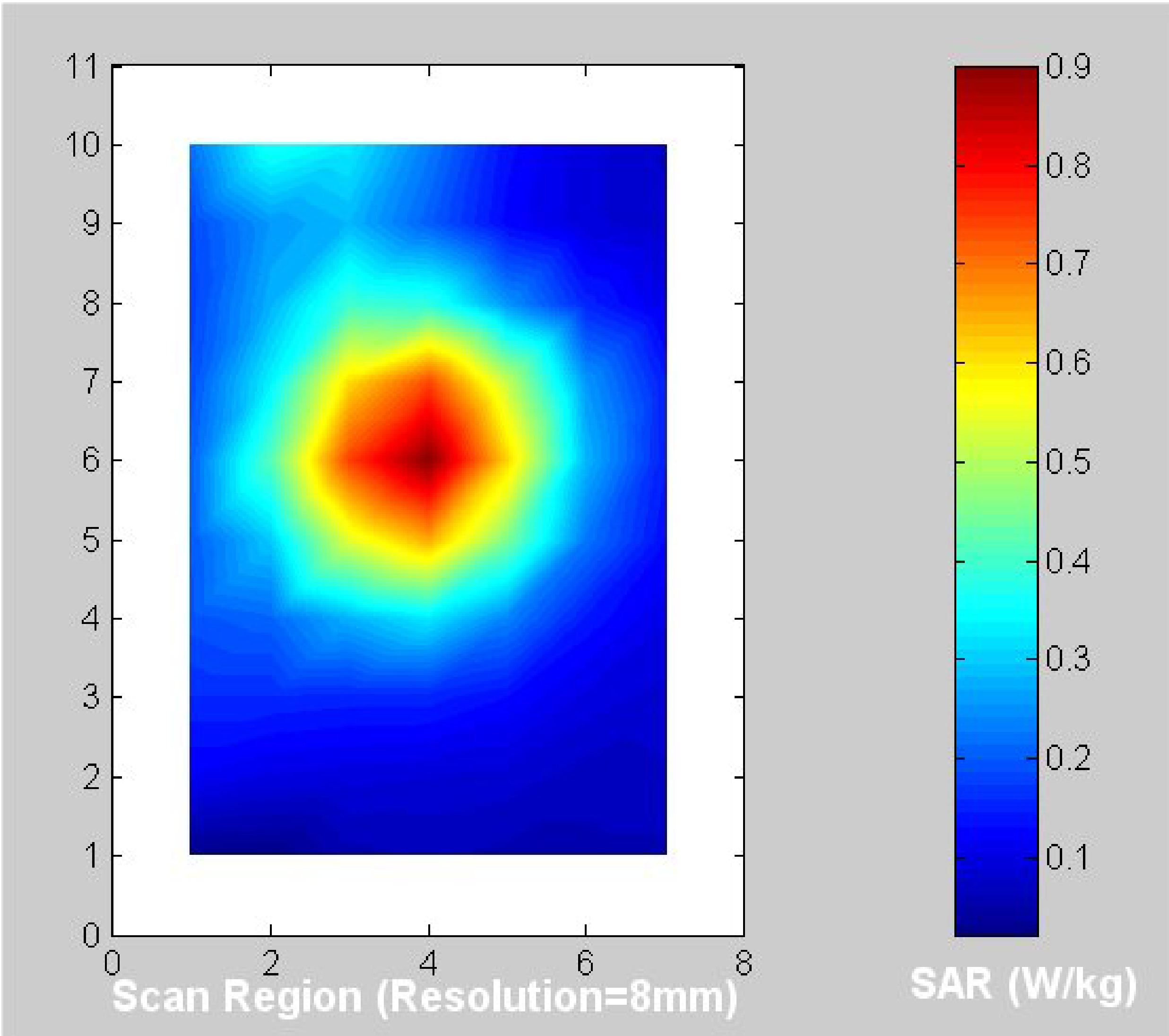
Fig. 11. Photograph of the Hewlett Packard Model 85070B Dielectric Probe. This is an open-circuited coaxial line probe.

Fig. 12. Photograph of the Askey Corporation 802.11 a/b Cardbus Card with coaxial output for conducted power measurements.



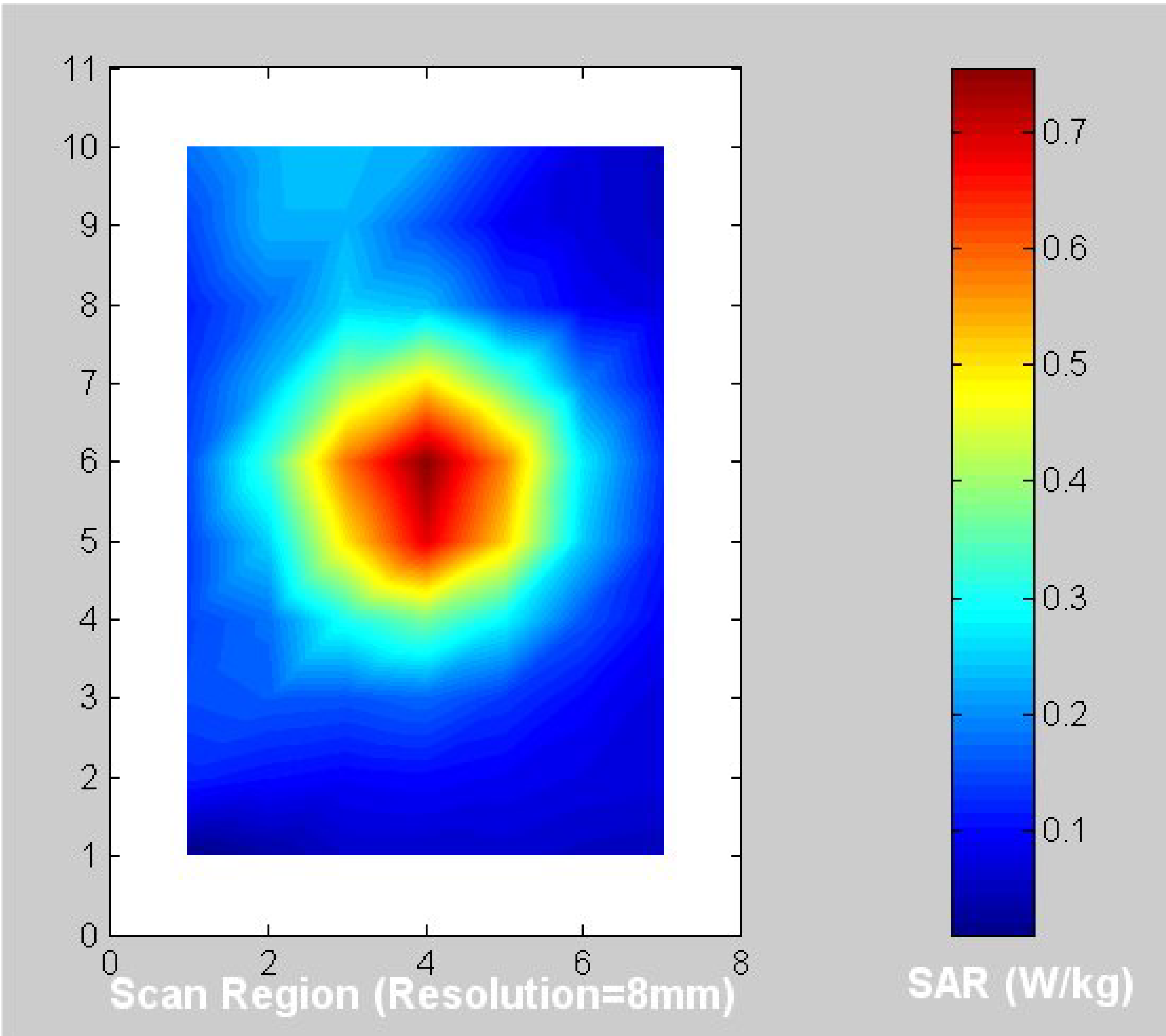
1. Toshiba laptop computer.
2. Askey Cardbus Card.
3. Coaxial output for conducted power measurements.
4. HP Model 8481A Power Sensor.
5. HP Model 436A Power Meter.

Fig. 13. The microwave circuit arrangement used for conducted power measurements for the Askey Corporation 802.11 a/b Cardbus Card.



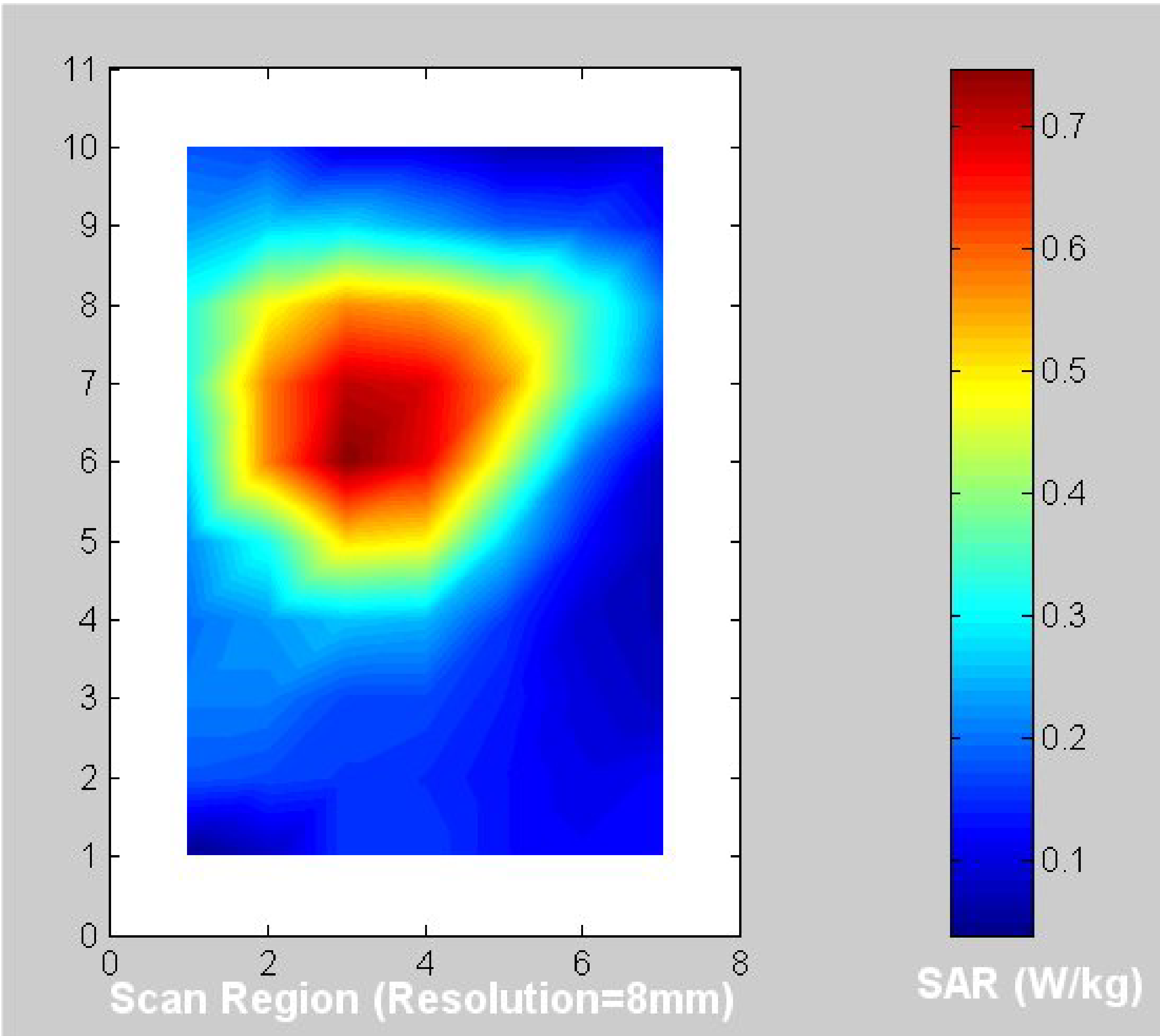
(a) 5.26 GHz normal mode (see Table 3 for the peak 1-g SAR).

Fig. 14. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a Toshiba laptop computer.



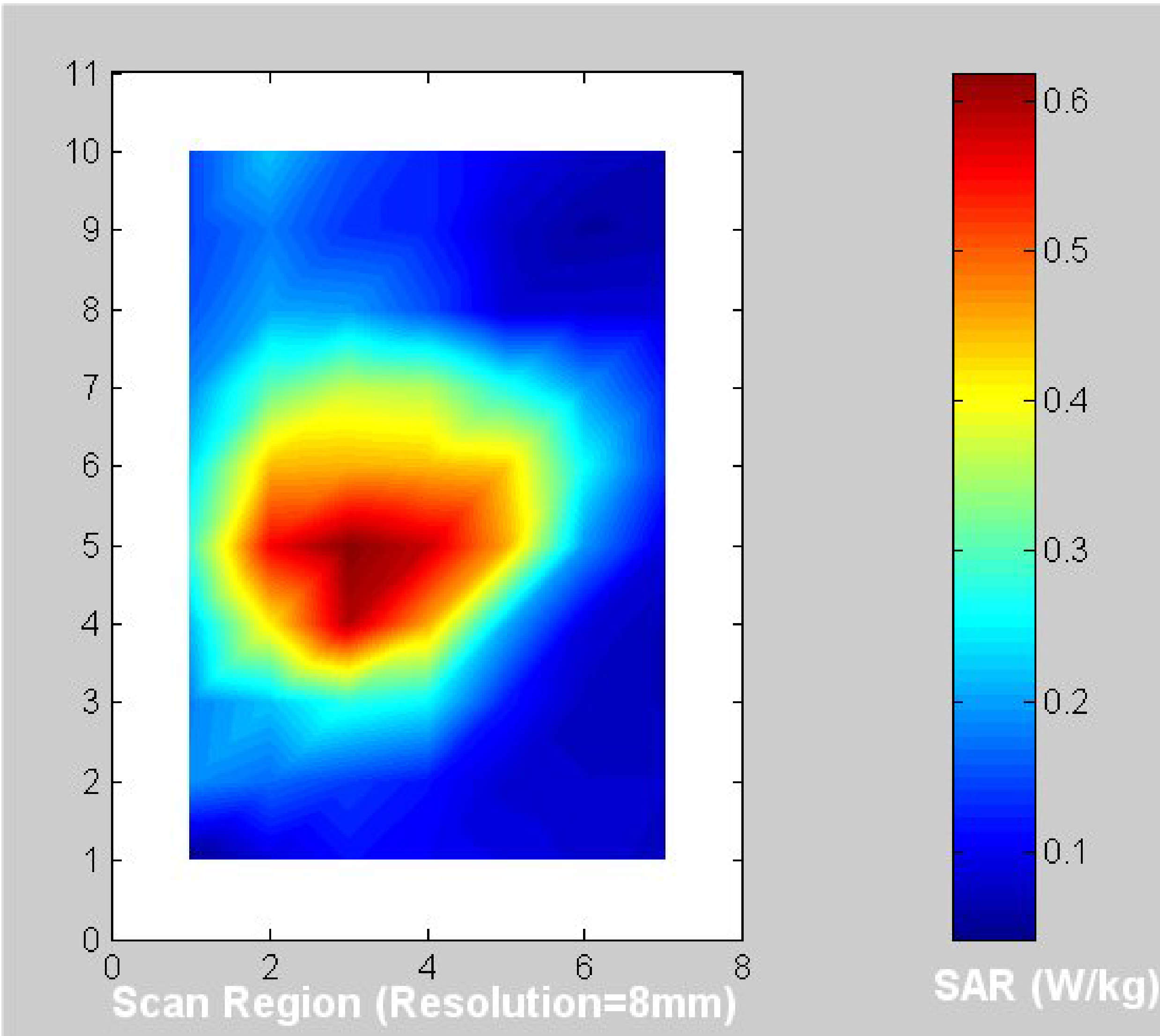
(b) 5.785 GHz normal mode (see Table 4 for the peak 1-g SAR).

Fig. 14. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a Toshiba laptop computer.



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

Fig. 14. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a Toshiba laptop computer.



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

Fig. 14. Coarse scans for the SAR measurements for the **Above-lap position** of the Askey Corporation 802.11 a/b Cardbus Card inserted in a Toshiba laptop computer.

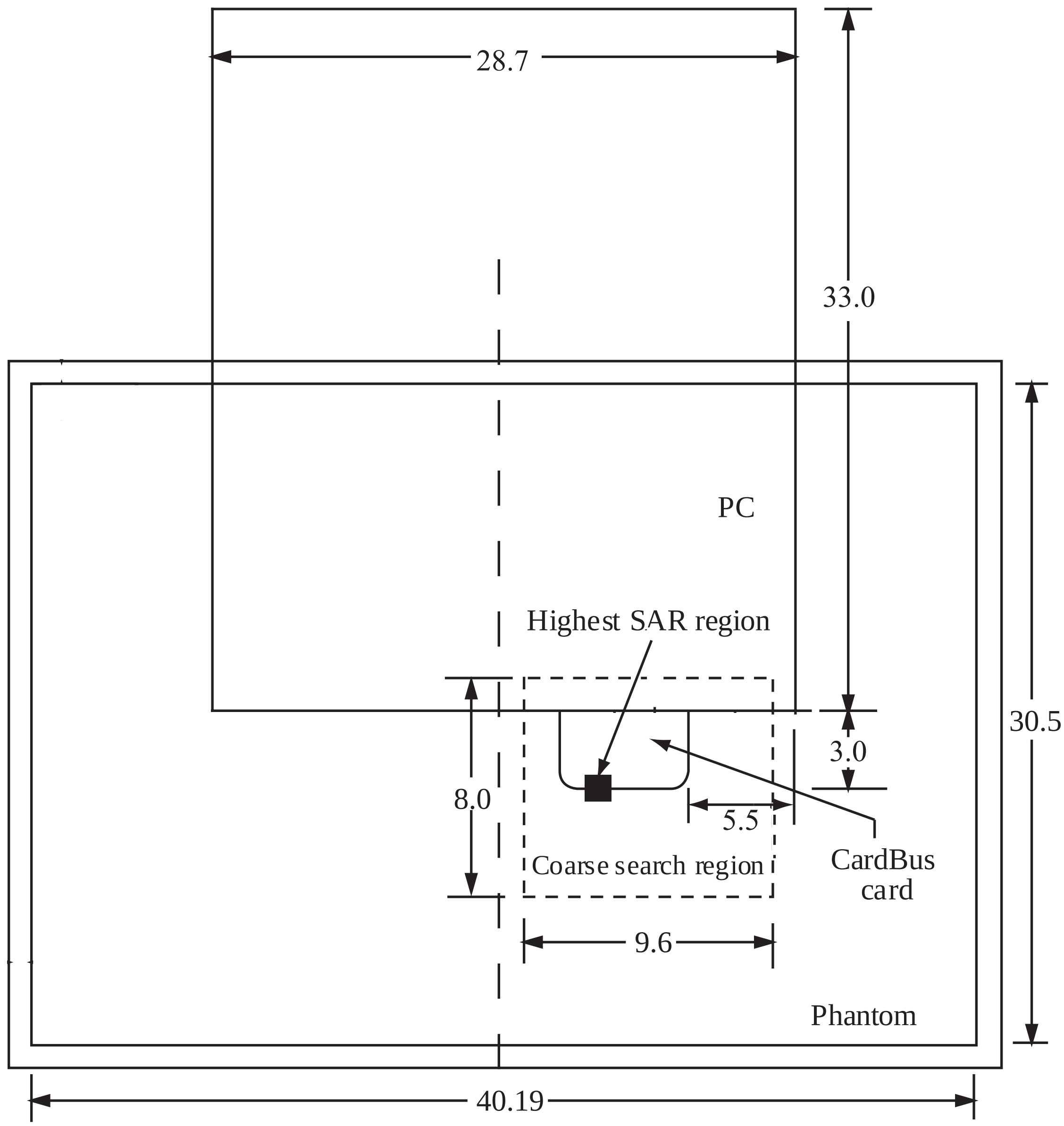
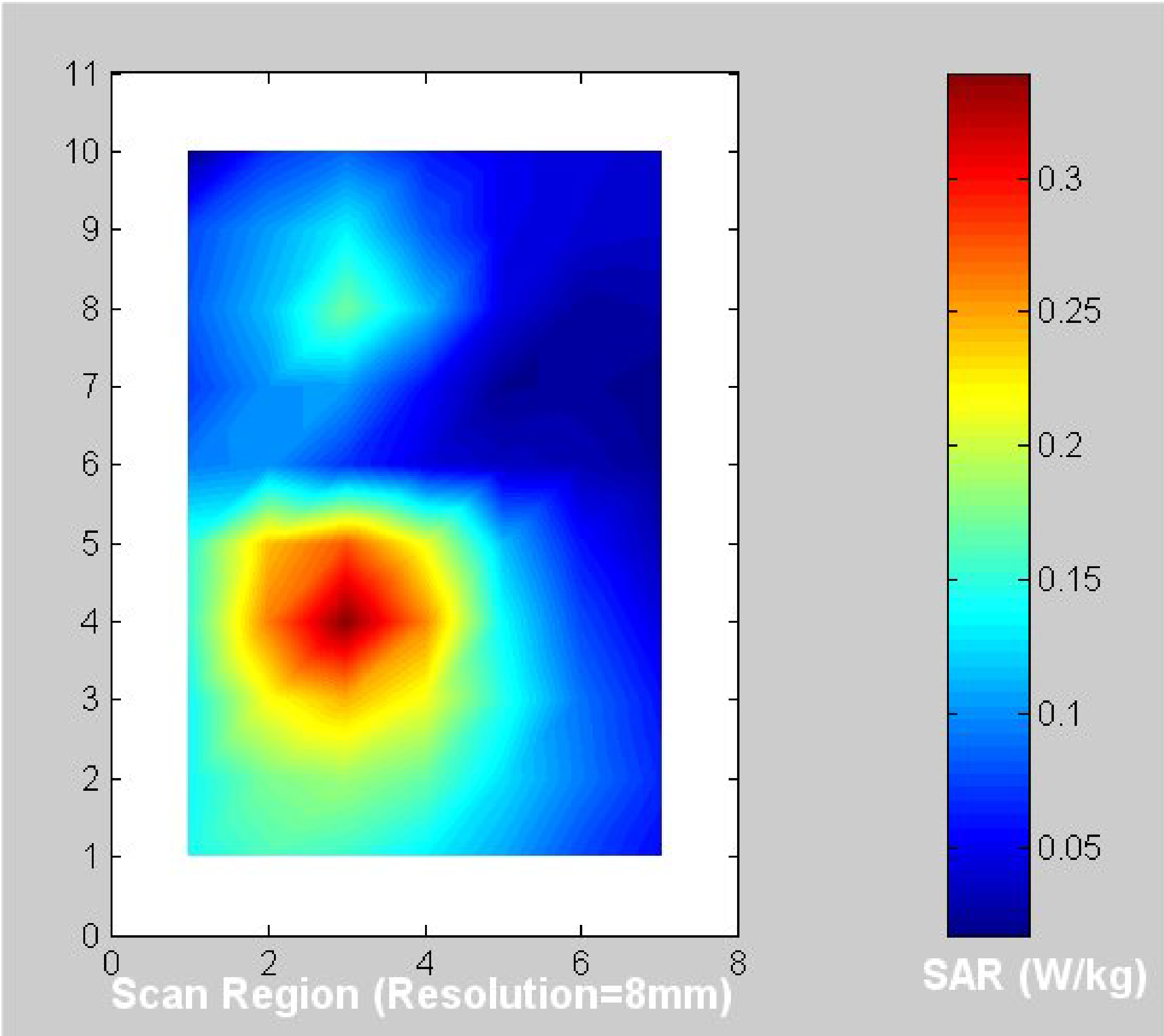
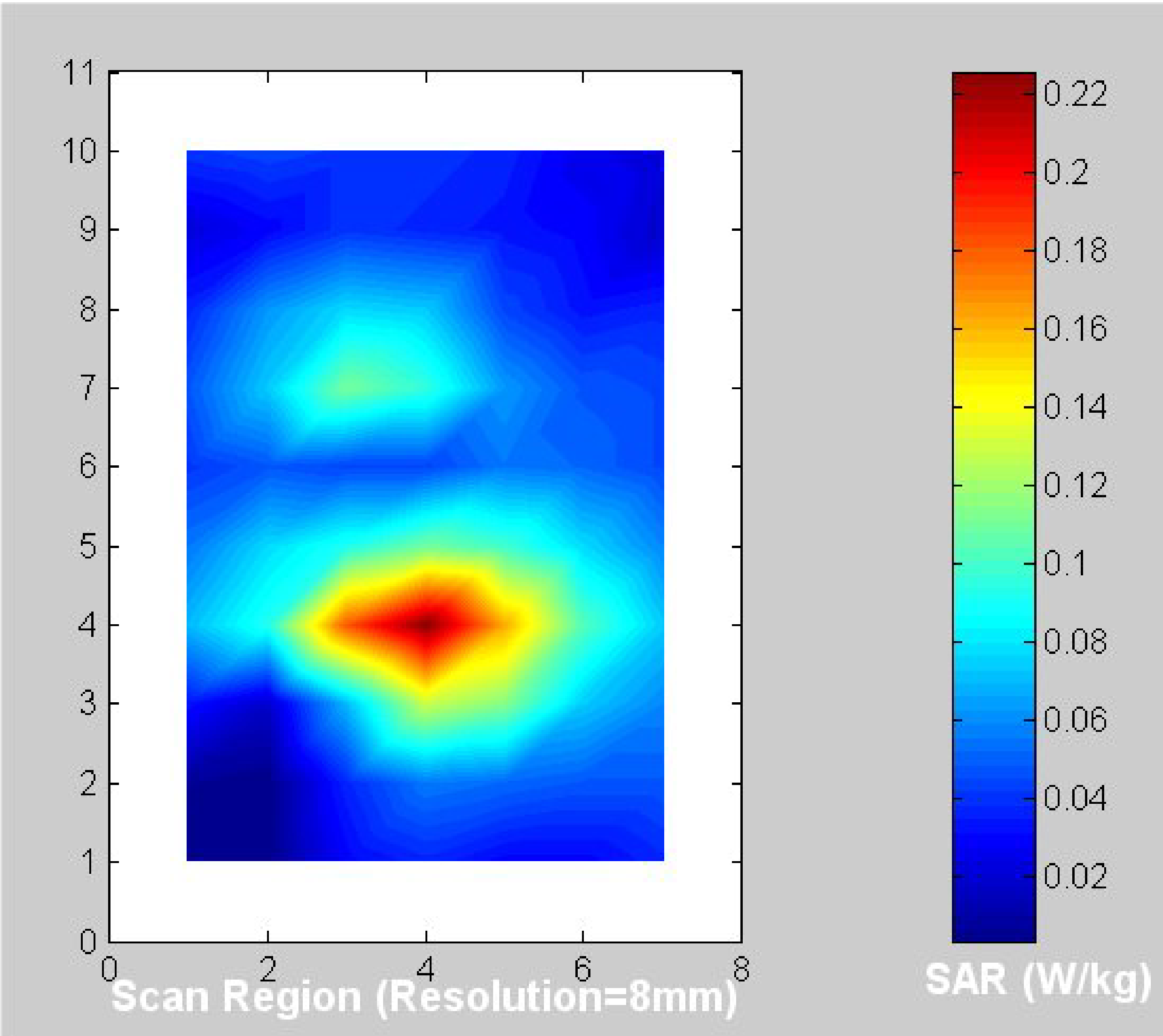


Fig. 14. Illustration of the peak SAR location with respect to the phantom and the Askey Model WLC 221-D4 Cardbus Card for the **Above-lap position**. All dimensions are in cm.



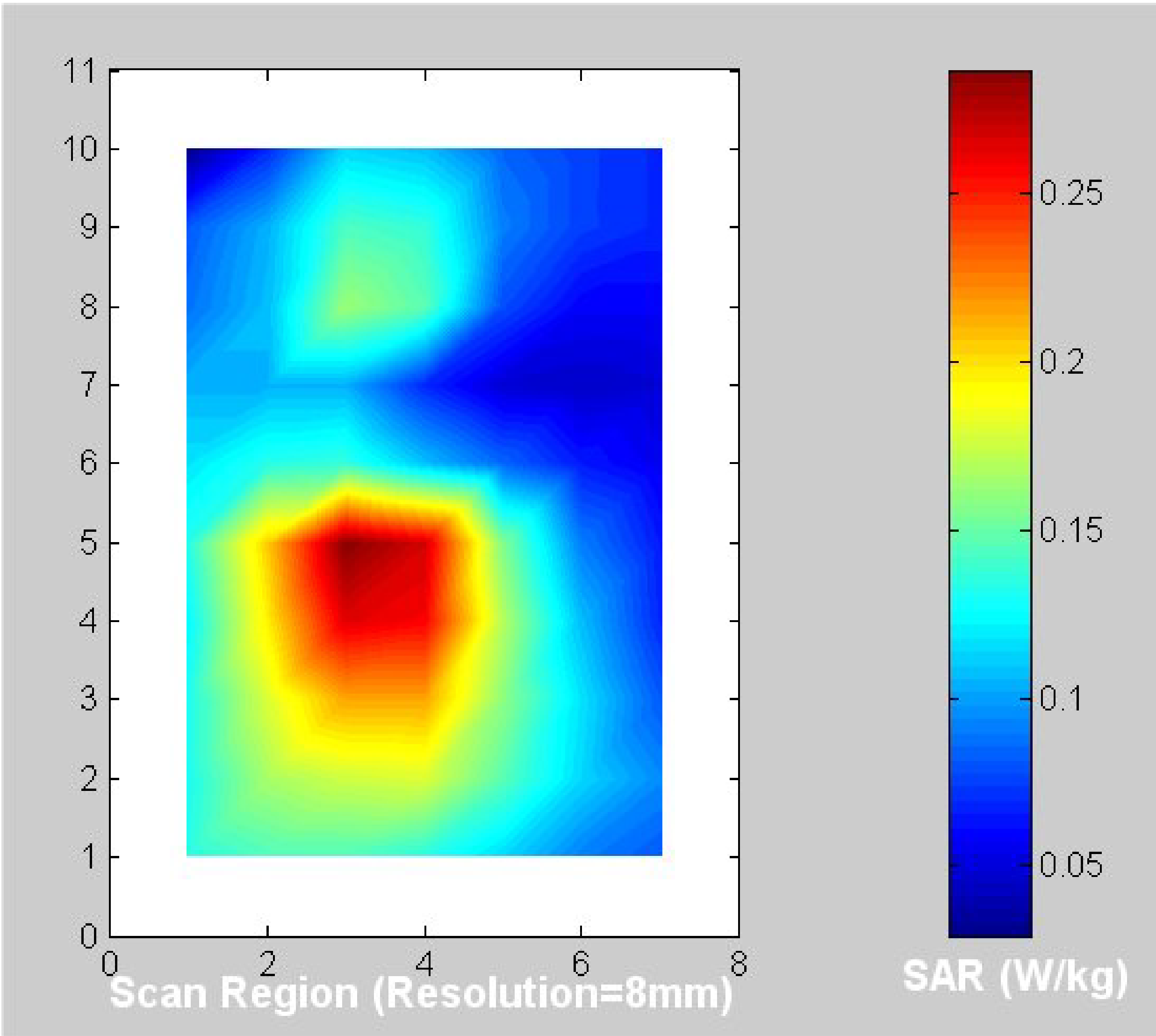
(a) 5.26 GHz normal mode (see Table 7 for the peak 1-g SAR).

Fig. 16. 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.



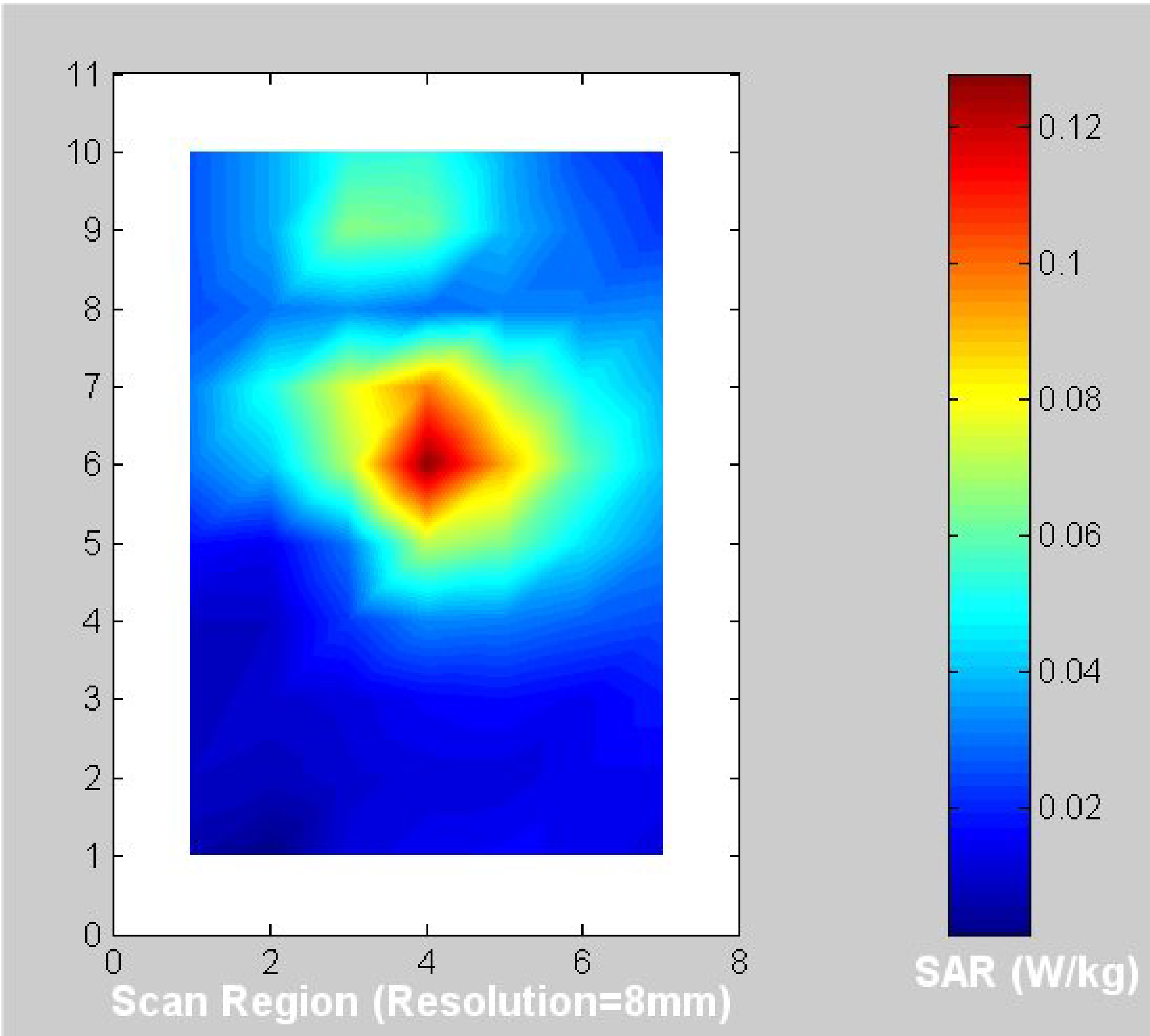
(b) 5.785 GHz normal mode (see Table 8 for the peak 1-g SAR).

Fig. 16. 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. 16. 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. 16. 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

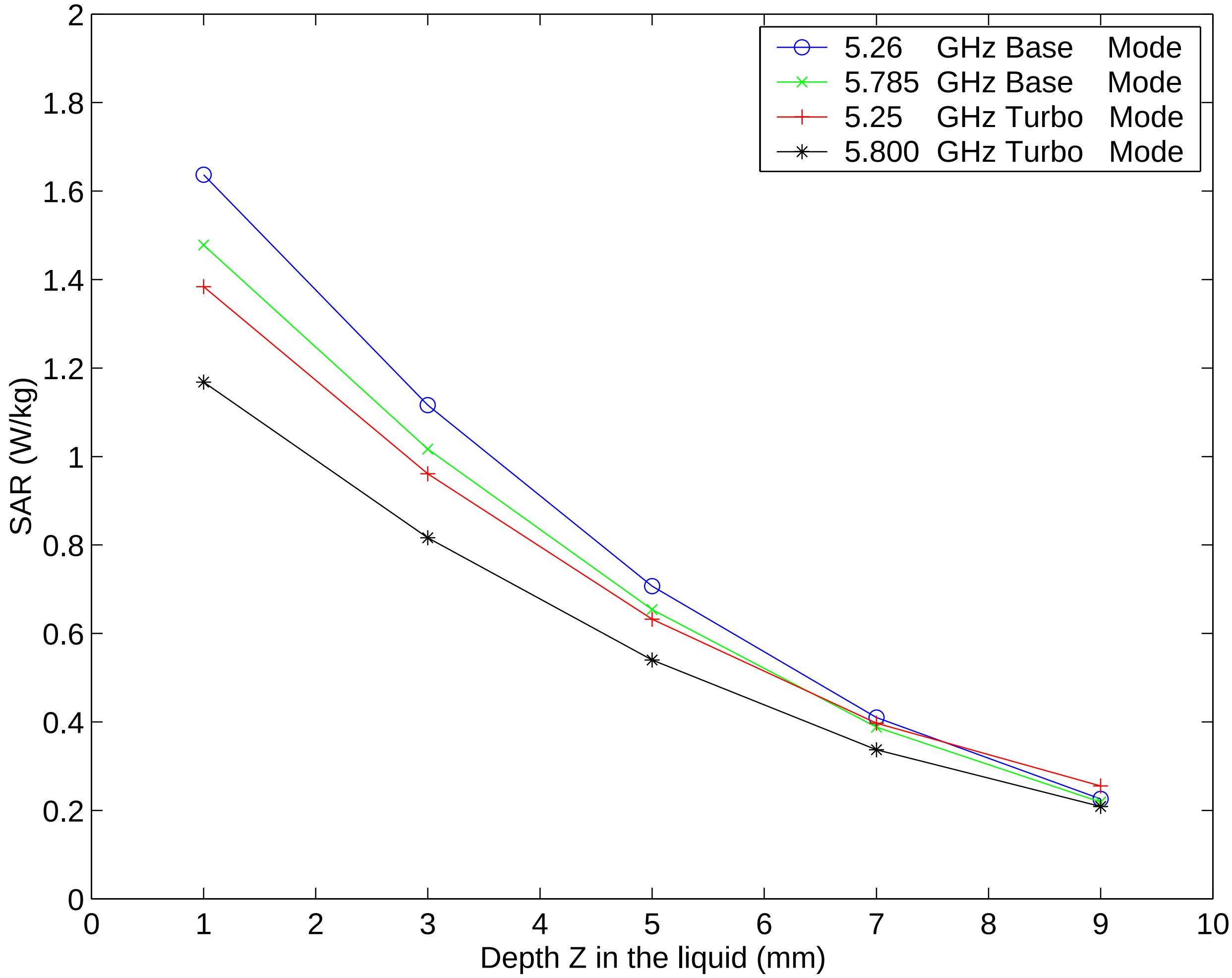


Fig. 17. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 3-6 -- Above-lap position) for Askey 802.11 a/b Cardbus Card inserted into a Toshiba laptop computer.

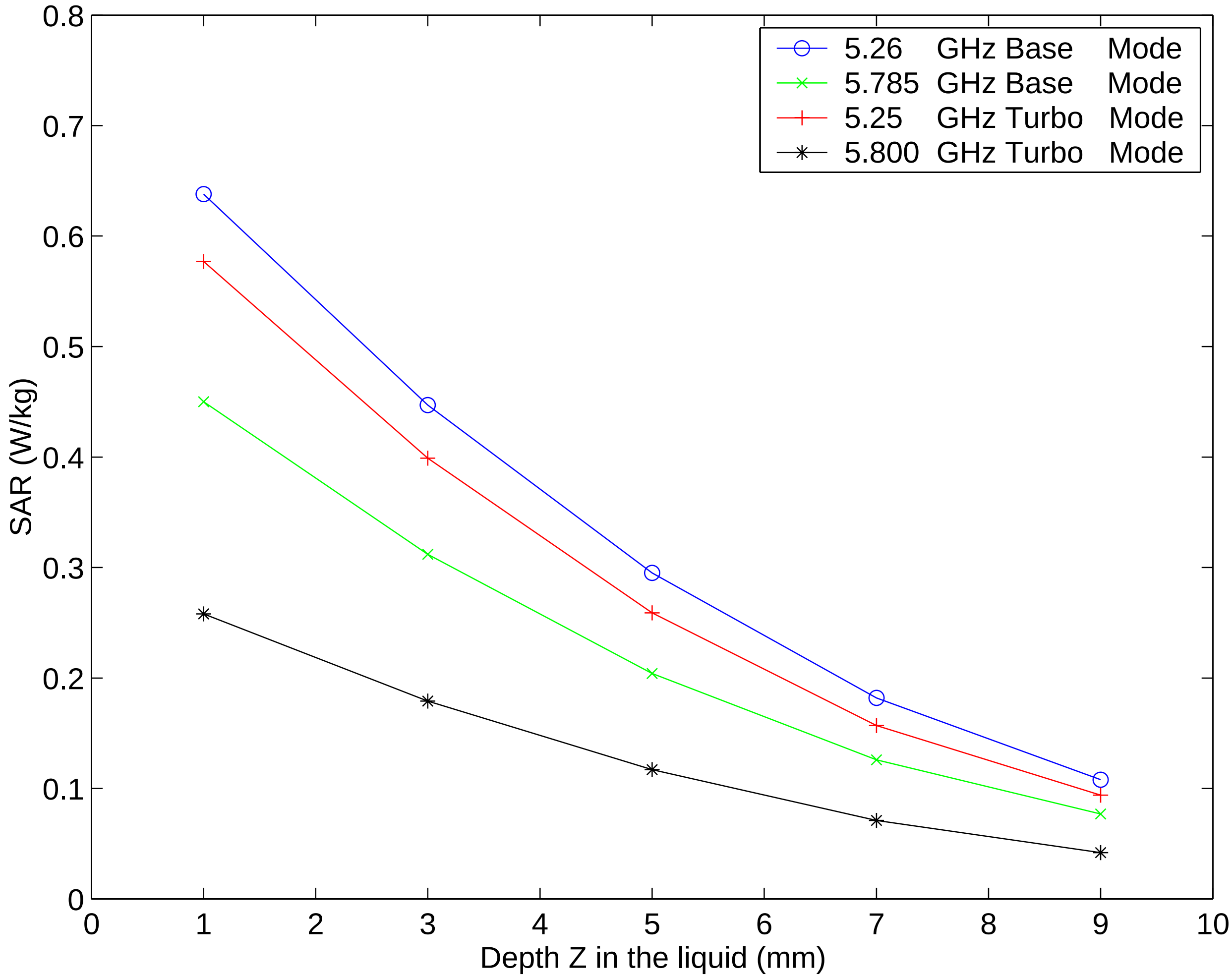


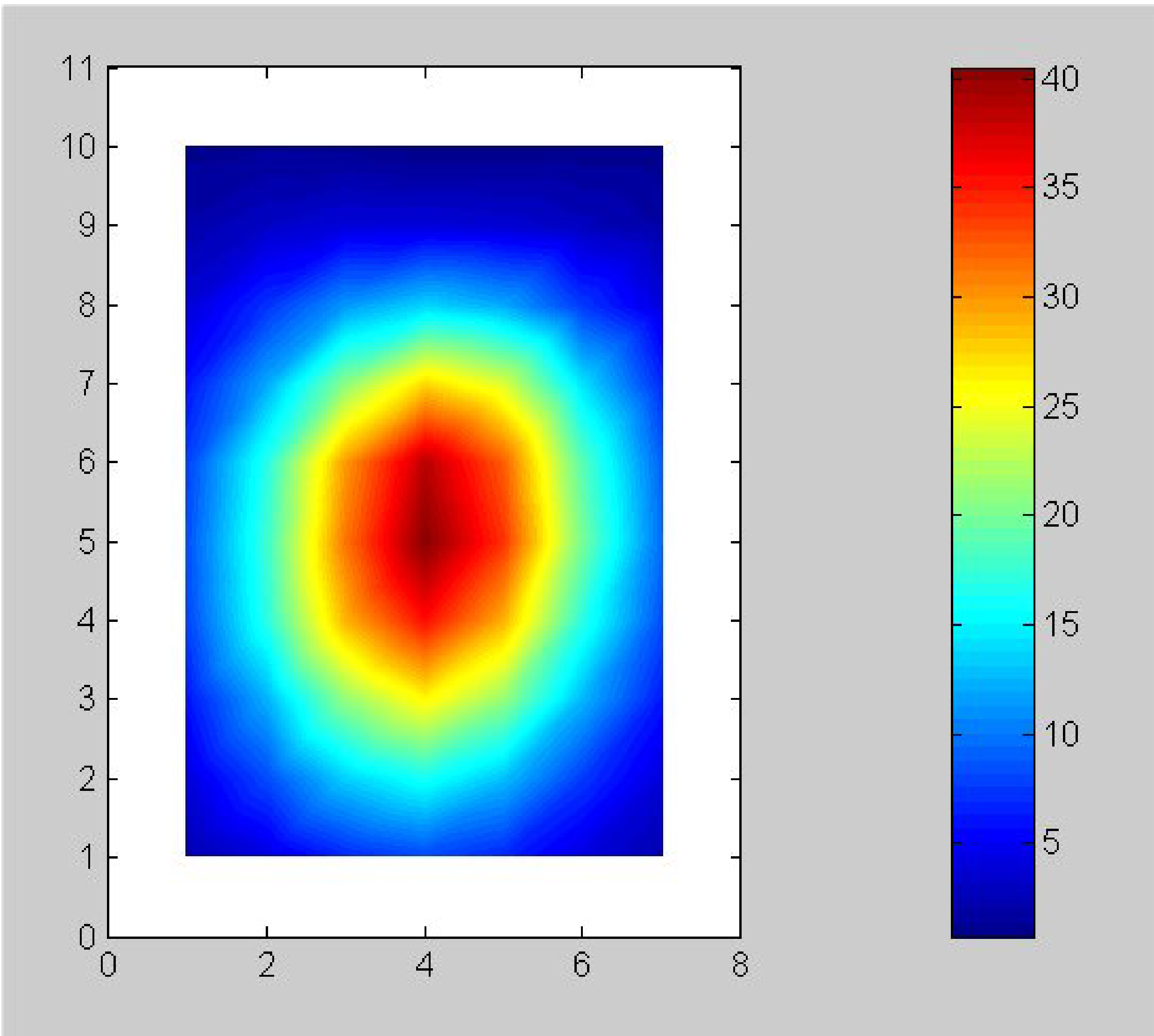
Fig. 18. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 7-10 -- End-on position) for the Askey Corporation 802.11 a/b Cardbus Card.

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 January 22, 2003 - The dipole SAR Plot



1-g SAR = 35.575 W/kg

a. At depth of 1 mm

54.819	56.674	56.847	55.237	52.280
55.546	57.530	57.835	56.300	53.296
55.589	57.698	58.175	56.590	53.712
54.987	57.204	57.679	56.189	53.413
53.838	56.116	56.701	55.474	52.798

b. At depth of 3 mm

43.044	44.389	44.533	43.353	41.219
43.682	45.142	45.374	44.238	42.034
43.774	45.324	45.659	44.498	42.360
43.340	44.953	45.317	44.208	42.170
42.480	44.145	44.579	43.674	41.716

c. At depth of 5 mm

33.092	34.022	34.141	33.309	31.836
33.647	34.674	34.840	34.030	32.481
33.773	34.862	35.082	34.262	32.735
33.479	34.596	34.862	34.064	32.629
32.859	34.020	34.327	33.686	32.318

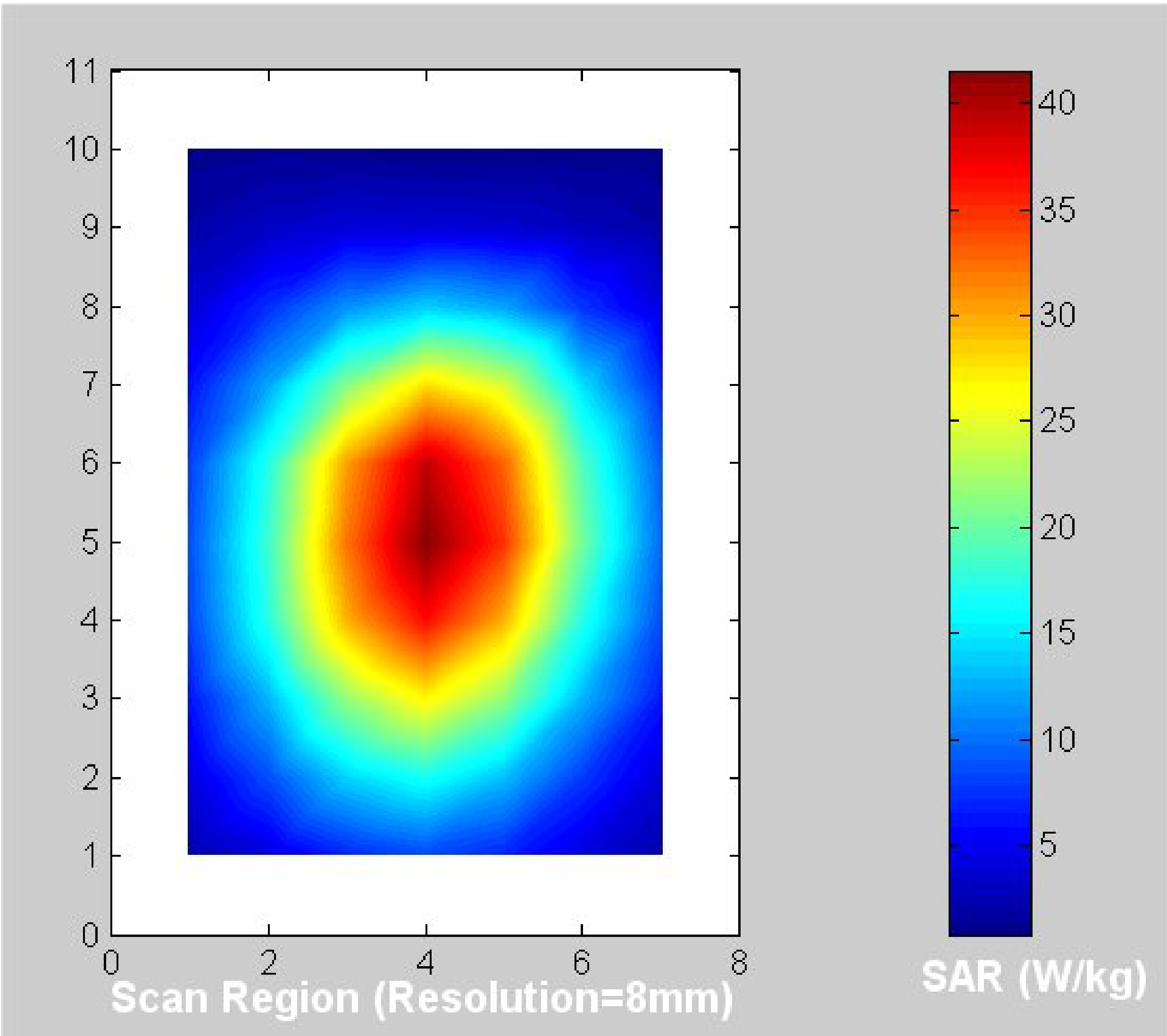
d. At depth of 7 mm

24.965	25.573	25.670	25.105	24.131
25.442	26.123	26.233	25.676	24.637
25.587	26.313	26.446	25.883	24.837
25.403	26.134	26.314	25.759	24.789
24.974	25.741	25.944	25.508	24.604

e. At depth of 9 mm

18.661	19.042	19.122	18.741	18.104
19.065	19.490	19.553	19.178	18.502
19.215	19.677	19.750	19.360	18.667
19.113	19.567	19.674	19.292	18.652
18.825	19.307	19.430	19.142	18.574

For January 23, 2003 - The Dipole SAR Plot



1-g SAR = 36.262 W/kg

a. At depth of 1 mm

55.721	57.815	57.951	56.132	53.048
56.658	58.834	59.139	57.269	54.202
56.775	59.016	59.474	57.733	54.635
55.892	58.107	58.698	57.276	54.422
54.532	56.850	57.616	56.305	53.657

b. At depth of 3 mm

43.818	45.353	45.478	44.159	41.878
44.576	46.151	46.389	45.064	42.812
44.686	46.320	46.654	45.433	43.141
44.045	45.681	46.125	45.074	42.985
43.022	44.742	45.297	44.383	42.427

c. At depth of 5 mm

33.750	34.827	34.936	34.021	32.400
34.353	35.443	35.623	34.729	33.144
34.461	35.599	35.830	35.020	33.391
34.020	35.176	35.497	34.747	33.280
33.277	34.502	34.884	34.280	32.891

d. At depth of 7 mm

25.517	26.235	26.324	25.719	24.617
25.990	26.710	26.841	26.265	25.200
26.101	26.853	27.001	26.494	25.384
25.814	26.593	26.812	26.296	25.307
25.295	26.130	26.375	25.996	25.048

e. At depth of 9 mm

19.119	19.577	19.643	19.252	18.527
19.485	19.952	20.043	19.670	18.979
19.606	20.082	20.167	19.854	19.120
19.430	19.931	20.070	19.721	19.067
19.076	19.627	19.771	19.530	18.899

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