SAR COMPLIANCE TESTING OF PROXIM CORPORATION MODEL 8460 (FCC ID# HZB-8460) CARDBUS CARD 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 Proxim Corporation Model 8460 Cardbus Card inserted into a 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 Model 8460 Cardbus Card placed on the laptop is given in Fig. 2. The Proxim Model 8460 Cardbus Card operates with a nominal conducted RF power output of 20 dBm (100 mW) for the frequency band 5.18-5.825 GHz.

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 cards 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 2.5 cm (see Fig. 6).

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 x 21.6 cm allows placement of a plastic holder (shown in Fig. 4) on which the laptop computer with Proxim Model 8460 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 Proxim Model 8460 Cardbus Card is mounted sideways on the plastic holder and moved up so that the spacing between the end of the cardbus card to the base of the flat phantom is 2.5 cm as determined by a Styrofoam spacer of thickness 1" (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" x 16.5" (30.5 x 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 August 8, 2002.

IV. SAR System Verification

Since we do not have a dipole at 2450 MHz, 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 three measured SAR distributions for the peak 1-g SAR region using this system verification dipole for each day of SAR measurements August 7-9, 2002 are given in Appendix B. Also given in Appendix B are the dipole SAR plots for each date of device testing. The peak 1-g SAR varies from 35.485 to 36.256 which is a variability of less than ± 1.1%. 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. 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]

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

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

The highest SAR region for each of the measurement frequencies (5.18, 5.32, 5.745, and 5.825 GHz) 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 x 9.6 cm. Three typical coarse scans taken at 20-minute intervals for the Proxim Model 8460 Cardbus Card -- PC combination radiating at 5.32 GHz pressed against the bottom of the flat phantom (see Fig. 5) are given in Figs. 11a,b,c, respectively. In these figures, the two axes marked are 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. 12. 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 RF power conducted by the Proxim Model 8460 Cardbus Card was measured using the Hewlett Packard (HP) Model 8481 Power Sensor with HP Model 436A Power Meter as illustrated in Fig. 13. After the first 15 minutes of warm-up time, the power was stable at 20 ± 0.2 dBm for up to 60 minutes of observation time. We have also validated the stability of output power by repeated coarse as well as finer 1-g SAR measurements. Given in Table 2a,b,c are the SAR distributions for the peak SAR region of volume 10 x 10 x 10 mm for three repeated runs each lasting a period of 20 minutes, for which the coarse SAR scans are given in Figs. 11a,b,c. The SARs are given for xy planes at heights z of 1, 3, 5, 7, and 9 mm for each of the three repeated measurements for the Model 8460 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 x 5 x 5 or 125 points are averaged to obtain peak 1-g SAR values (for a volume of 1 cm^3). The peak 1-g SAR values are obtained as 0.797, 0.801, and 0.804 W/kg. This is a variation of less than ± 1.5% in SAR drift for the hot spot. The temperature variation of the tissue-simulant fluid measured with a Bailey Instruments Model BAT 8 Temperature Probe over this 60-minute period was 23.7 ± 0.2°C.

The detailed SAR distributions measured with a stepper-motor-controlled step size of 2 mm for transmit frequencies of 5.18, 5.32, 5.745, and 5.845 GHz are given in Tables 3-6 for the "above-lap" position and in Tables 7-10 for the "end-on" position, respectively. The z-axis scan plots taken at the highest SAR locations for each set of tests are given in Fig. 14 and 15, respectively.

For the measurements in Tables 3-6, the separation between the Proxim Model 8460 Cardbus Card and the bottom of the experimental phantom is on the order of 1 cm. For the "end-on" position, the separation between the card edge at 90° to the bottom of the flat phantom is 2.5 cm and the SAR distributions at the various frequencies are given in Tables 7-10. The peak 1-g SARs for various configurations of the Cardbus card are summarized in Table 11. In Table 11, it is interesting to note that the peak 1-g SARs are not too different for 5.18 and 5.32 GHz, but are considerably smaller at the higher frequencies of 5.745 and 5.825 GHz. This may be due to the Cardbus antenna not being as well match to the circuit at the higher frequencies as it is at the lower frequencies of 5.18 and 5.32 GHz. In any case, from Table 11, it may be noted that all of the measured 1-g SARs are less than the FCC96-326 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 maximum radiated power condition of 20 dBm (100 mW), the Proxim Model 8460 Cardbus Card has been measured to give peak 1-g SARs of 0.22 to 0.80 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 2a. Repeated measurements of the peak 1-g SAR each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. **Measurement 1 (first 20 minutes).**

1-g SAR = 0.797 W/kg

a. At depth of 1 mm

1.382	1.491	1.551	1.549	1.489
1.443	1.506	1.575	1.615	1.547
1.498	1.582	1.596	1.592	1.575
1.498	1.614	1.644	1.635	1.586
1.518	1.566	1.659	1.677	1.656

b. At depth of 3 mm

0.970	1.024	1.059	1.064	1.031
0.999	1.047	1.085	1.101	1.059
1.039	1.088	1.097	1.095	1.079
1.045	1.114	1.128	1.121	1.084
1.046	1.083	1.138	1.160	1.154

c. At depth of 5 mm

0.643	0.658	0.673	0.683	0.670
0.649	0.684	0.699	0.699	0.677
0.676	0.699	0.703	0.705	0.690
0.687	0.720	0.721	0.715	0.689
0.673	0.7000	0.729	0.755	0.760

d. At depth of 7 mm

0.401	0.393	0.394	0.407	0.405
0.393	0.416	0.417	0.409	0.399
0.409	0.415	0.414	0.420	0.408
0.424	0.432	0.422	0.418	0.399
0.399	0.418	0.433	0.460	0.474

e. At depth of 9 mm

0.245	0.229	0.220	0.236	0.236
0.231	0.243	0.238	0.231	0.227
0.239	0.235	0.229	0.241	0.234
0.256	0.250	0.231	0.229	0.215
0.224	0.238	0.248	0.277	0.297

Table 2b. Repeated measurements of the peak 1-g SAR each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. **Measurement 2 (second 20 minutes).**

1-g SAR = 0.801 W/kg

a. At depth of 1 mm

1.514	1.618	1.651	1.621	1.575
1.512	1.679	1.683	1.656	1.621
1.553	1.640	1.702	1.700	1.577
1.511	1.605	1.678	1.701	1.650
1.510	1.627	1.674	1.702	1.645

b. At depth of 3 mm

1.029	1.097	1.106	1.091	1.059
1.041	1.123	1.130	1.125	1.084
1.053	1.118	1.147	1.143	1.067
1.024	1.090	1.137	1.148	1.114
1.042	1.106	1.141	1.175	1.152

c. At depth of 5 mm

0.646	0.687	0.679	0.674	0.655
0.666	0.686	0.695	0.704	0.664
0.660	0.705	0.711	0.704	0.664
0.640	0.682	0.709	0.713	0.691
0.670	0.697	0.723	0.760	0.762

d. At depth of 7 mm

0.366	0.389	0.368	0.371	0.363
0.390	0.370	0.379	0.394	0.360
0.373	0.399	0.393	0.384	0.368
0.356	0.380	0.395	0.397	0.383
0.393	0.398	0.419	0.457	0.475

e. At depth of 9 mm

0.189	0.200	0.176	0.180	0.183
0.211	0.173	0.181	0.195	0.172
0.193	0.202	0.193	0.183	0.179
0.175	0.186	0.193	0.200	0.187
0.213	0.210	0.230	0.266	0.290

Table 2c. Repeated measurements of the peak 1-g SAR each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. **Measurement 3 (third 20 minutes).**

1-g SAR = 0.804 W/kg

a. At depth of 1 mm

1.354	1.424	1.482	1.462	1.428
1.435	1.505	1.569	1.586	1.503
1.452	1.532	1.592	1.574	1.507
1.438	1.538	1.593	1.571	1.501
1.412	1.476	1.543	1.539	1.474

b. At depth of 3 mm

0.972	1.020	1.052	1.033	1.011
1.023	1.073	1.111	1.111	1.057
1.029	1.080	1.119	1.106	1.063
1.020	1.079	1.113	1.096	1.058
0.998	1.041	1.087	1.087	1.044

c. At depth of 5 mm

0.670	0.700	0.712	0.696	0.683
0.698	0.730	0.747	0.736	0.705
0.694	0.723	0.745	0.736	0.712
0.688	0.717	0.736	0.723	0.707
0.670	0.697	0.727	0.730	0.705

d. At depth of 7 mm

0.448	0.465	0.462	0.451	0.445
0.459	0.477	0.480	0.461	0.446
0.448	0.459	0.471	0.465	0.455
0.442	0.453	0.460	0.450	0.449
0.429	0.443	0.462	0.466	0.458

e. At depth of 9 mm

0.307	0.314	0.303	0.299	0.297
0.307	0.313	0.307	0.287	0.281
0.290	0.290	0.296	0.292	0.291
0.283	0.286	0.287	0.279	0.282
0.274	0.280	0.292	0.297	0.302

Table 3. **Above-lap position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.18 GHz

1-g SAR = 0.667 W/kg

a. At depth of 1 mm

1.345	1.507	1.532	1.558	1.373
1.407	1.464	1.598	1.574	1.387
1.400	1.451	1.505	1.489	1.346
1.342	1.420	1.440	1.354	1.203
1.244	1.379	1.406	1.332	1.181

b. At depth of 3 mm

0.905	1.001	1.024	1.033	0.911
0.940	0.981	1.070	1.037	0.909
0.933	0.969	0.994	0.981	0.886
0.890	0.955	0.948	0.893	0.800
0.824	0.921	0.938	0.900	0.848

c. At depth of 5 mm

0.554	0.601	0.622	0.619	0.544
0.571	0.597	0.651	0.614	0.533
0.564	0.585	0.592	0.582	0.524
0.532	0.583	0.560	0.528	0.480
0.494	0.561	0.571	0.564	0.586

d. At depth of 7 mm

0.292	0.308	0.326	0.317	0.271
0.299	0.313	0.342	0.306	0.258
0.292	0.299	0.300	0.290	0.260
0.269	0.303	0.276	0.259	0.241
0.256	0.299	0.306	0.324	0.397

e. At depth of 9 mm

0.119	0.121	0.136	0.126	0.092
0.125	0.128	0.143	0.113	0.084
0.118	0.111	0.118	0.107	0.093
0.099	0.116	0.098	0.086	0.085
0.108	0.135	0.141	0.180	0.279

Table 4. **Above-lap position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.32 GHz

1-g SAR = 0.804 W/kg

a. At depth of 1 mm

1.354	1.424	1.482	1.462	1.428
1.435	1.505	1.569	1.586	1.503
1.452	1.532	1.592	1.574	1.507
1.438	1.538	1.593	1.571	1.501
1.412	1.476	1.543	1.539	1.474

b. At depth of 3 mm

0.972	1.020	1.052	1.033	1.011
1.023	1.073	1.111	1.111	1.057
1.029	1.080	1.119	1.106	1.063
1.020	1.079	1.113	1.096	1.058
0.998	1.041	1.087	1.087	1.044

c. At depth of 5 mm

0.670	0.700	0.712	0.696	0.683
0.698	0.730	0.747	0.736	0.705
0.694	0.723	0.745	0.736	0.712
0.688	0.717	0.736	0.723	0.707
0.670	0.697	0.727	0.730	0.705

d. At depth of 7 mm

0.448	0.465	0.462	0.451	0.445
0.459	0.477	0.480	0.461	0.446
0.448	0.459	0.471	0.465	0.455
0.442	0.453	0.460	0.450	0.449
0.429	0.443	0.462	0.466	0.458

e. At depth of 9 mm

0.307	0.314	0.303	0.299	0.297
0.307	0.313	0.307	0.287	0.281
0.290	0.290	0.296	0.292	0.291
0.283	0.286	0.287	0.279	0.282
0.274	0.280	0.292	0.297	0.302

Table 5. **Above-lap position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.745 GHz

1-g SAR = 0.761 W/kg

a. At depth of 1 mm

1.380	1.492	1.541	1.568	1.497
1.516	1.633	1.706	1.711	1.644
1.555	1.709	1.791	1.766	1.688
1.518	1.686	1.762	1.776	1.690
1.428	1.581	1.675	1.699	1.637

b. At depth of 3 mm

0.910	0.982	1.024	1.029	0.989
0.997	1.077	1.124	1.134	1.086
1.031	1.123	1.180	1.168	1.115
1.001	1.108	1.157	1.172	1.111
0.943	1.043	1.106	1.124	1.091

c. At depth of 5 mm

0.541	0.583	0.617	0.607	0.590
0.591	0.642	0.668	0.682	0.649
0.620	0.667	0.701	0.699	0.666
0.597	0.659	0.686	0.699	0.657
0.564	0.622	0.661	0.675	0.665

d. At depth of 7 mm

0.275	0.296	0.321	0.303	0.300
0.300	0.328	0.339	0.354	0.332
0.322	0.336	0.356	0.359	0.340
0.305	0.336	0.346	0.357	0.330
0.291	0.319	0.341	0.353	0.359

e. At depth of 9 mm

0.111	0.120	0.136	0.117	0.120
0.123	0.136	0.137	0.150	0.136
0.138	0.135	0.144	0.147	0.138
0.125	0.141	0.139	0.147	0.128
0.124	0.135	0.145	0.158	0.174

Table 6. **Above-lap position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.825 GHz

1-g SAR = 0.653 W/kg

a. At depth of 1 mm

1.292	1.363	1.434	1.397	1.309
1.391	1.496	1.506	1.535	1.416
1.377	1.500	1.540	1.537	1.474
1.347	1.487	1.534	1.518	1.420
1.282	1.401	1.471	1.476	1.432

b. At depth of 3 mm

0.839	0.885	0.937	0.901	0.835
0.905	0.980	0.982	0.992	0.914
0.905	0.980	0.997	0.995	0.952
0.881	0.962	0.993	0.993	0.923
0.837	0.916	0.966	0.982	0.960

c. At depth of 5 mm

0.484	0.511	0.546	0.513	0.465
0.524	0.574	0.570	0.568	0.522
0.533	0.571	0.572	0.571	0.543
0.515	0.552	0.571	0.580	0.534
0.489	0.536	0.571	0.596	0.592

d. At depth of 7 mm

0.227	0.241	0.261	0.234	0.199
0.248	0.278	0.272	0.264	0.240
0.261	0.273	0.265	0.267	0.249
0.249	0.258	0.268	0.279	0.251
0.238	0.262	0.287	0.316	0.326

e. At depth of 9 mm

0.068	0.075	0.082	0.064	0.037
0.077	0.092	0.087	0.079	0.068
0.090	0.087	0.077	0.082	0.069
0.083	0.078	0.084	0.090	0.076
0.084	0.095	0.112	0.144	0.164

Table 7. **End-on position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.18 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.218 W/kg

a. At depth of 1 mm

0.419	0.436	0.419	0.464	0.510
0.483	0.454	0.525	0.500	0.393
0.496	0.454	0.485	0.456	0.517
0.392	0.423	0.487	0.468	0.456
0.471	0.497	0.496	0.535	0.595

b. At depth of 3 mm

0.277	0.283	0.277	0.301	0.343
0.325	0.314	0.350	0.321	0.269
0.308	0.299	0.317	0.307	0.326
0.250	0.289	0.306	0.312	0.286
0.299	0.323	0.329	0.372	0.424

c. At depth of 5 mm

0.164	0.162	0.164	0.175	0.211
0.198	0.201	0.210	0.181	0.170
0.164	0.175	0.183	0.185	0.175
0.137	0.178	0.163	0.185	0.152
0.165	0.186	0.197	0.243	0.250

d. At depth of 7 mm

0.081	0.073	0.081	0.087	0.115
0.103	0.115	0.105	0.081	0.094
0.063	0.083	0.082	0.092	0.067
0.053	0.091	0.061	0.088	0.053
0.069	0.087	0.101	0.148	0.121

e. At depth of 9 mm

0.027	0.015	0.027	0.036	0.054
0.040	0.057	0.037	0.021	0.041
0.005	0.022	0.014	0.026	0.001
0.000	0.028	0.003	0.020	0.010
0.009	0.025	0.041	0.086	0.049

Table 8. **End-on position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.32 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.317 W/kg

a. At depth of 1 mm

0.642	0.651	0.635	0.616	0.599
0.684	0.629	0.616	0.644	0.601
0.655	0.640	0.664	0.636	0.635
0.630	0.636	0.663	0.649	0.657
0.656	0.647	0.661	0.679	0.657

b. At depth of 3 mm

0.435	0.441	0.434	0.422	0.416
0.461	0.424	0.415	0.432	0.407
0.444	0.437	0.446	0.433	0.430
0.428	0.429	0.446	0.446	0.440
0.444	0.438	0.450	0.459	0.448

c. At depth of 5 mm

0.272	0.277	0.275	0.270	0.269
0.285	0.262	0.257	0.265	0.254
0.278	0.276	0.275	0.273	0.268
0.267	0.266	0.277	0.284	0.271
0.277	0.274	0.285	0.287	0.286

d. At depth of 7 mm

0.153	0.159	0.156	0.159	0.159
0.157	0.144	0.142	0.145	0.141
0.156	0.158	0.151	0.154	0.150
0.147	0.147	0.153	0.164	0.147
0.157	0.155	0.166	0.163	0.173

e. At depth of 9 mm

0.078	0.086	0.079	0.089	0.086
0.076	0.068	0.070	0.069	0.068
0.079	0.081	0.075	0.078	0.076
0.069	0.072	0.076	0.084	0.070
0.081	0.083	0.092	0.087	0.108

Table 9. **End-on position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.745 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.274 W/kg

a. At depth of 1 mm

0.472	0.470	0.502	0.482	0.511
0.550	0.531	0.471	0.552	0.530
0.512	0.501	0.567	0.496	0.524
0.478	0.522	0.573	0.597	0.542
0.556	0.562	0.575	0.564	0.585

b. At depth of 3 mm

0.334	0.340	0.345	0.328	0.350
0.366	0.363	0.337	0.380	0.364
0.346	0.344	0.376	0.352	0.363
0.333	0.368	0.394	0.416	0.379
0.386	0.389	0.393	0.404	0.424

c. At depth of 5 mm

0.225	0.234	0.221	0.208	0.223
0.225	0.232	0.232	0.245	0.234
0.216	0.220	0.230	0.234	0.234
0.219	0.245	0.255	0.274	0.250
0.254	0.253	0.252	0.276	0.299

d. At depth of 7 mm

0.144	0.152	0.131	0.122	0.132
0.128	0.138	0.155	0.148	0.140
0.121	0.129	0.127	0.141	0.137
0.136	0.153	0.154	0.170	0.155
0.158	0.154	0.152	0.181	0.210

e. At depth of 9 mm

0.093	0.092	0.073	0.070	0.076
0.074	0.080	0.107	0.089	0.082
0.062	0.072	0.068	0.075	0.070
0.083	0.091	0.091	0.105	0.095
0.100	0.092	0.092	0.118	0.158

Table 10. **End-on position.** The SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) inserted into a laptop computer at 5.825 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.310 W/kg

a. At depth of 1 mm

0.532	0.599	0.578	0.578	0.577
0.592	0.497	0.639	0.605	0.667
0.601	0.638	0.618	0.616	0.625
0.616	0.652	0.599	0.632	0.605
0.579	0.585	0.609	0.640	0.630

b. At depth of 3 mm

0.376	0.410	0.395	0.395	0.394
0.402	0.375	0.448	0.425	0.456
0.416	0.433	0.428	0.437	0.424
0.419	0.445	0.423	0.433	0.412
0.401	0.398	0.420	0.434	0.436

c. At depth of 5 mm

0.251	0.261	0.251	0.251	0.251
0.254	0.268	0.297	0.284	0.291
0.271	0.274	0.279	0.293	0.267
0.266	0.285	0.282	0.276	0.261
0.260	0.252	0.271	0.273	0.284

d. At depth of 7 mm

0.160	0.153	0.145	0.14	0.148
0.147	0.174	0.184	0.179	0.171
0.168	0.160	0.172	0.185	0.155
0.158	0.169	0.177	0.161	0.151
0.157	0.148	0.163	0.158	0.177

e. At depth of 9 mm

0.100	0.085	0.077	0.077	0.083
0.081	0.095	0.112	0.112	0.097
0.107	0.091	0.106	0.112	0.087
0.095	0.099	0.107	0.086	0.082
0.091	0.085	0.095	0.088	0.112

Table 11. The peak 1-g SARs measured for the Proxim Model 8460 Cardbus Card (nominal conducted power of 20 dBm) 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	5.18 GHz	5.32 GHz	5.745 GHz	5.825 GHz
"Above-lap": bottom of PC pressed against bottom of the flat phantom	1 cm	0.667	0.804	0.761	0.653
"End-on": card edge at 90° relative to the bottom of the flat phantom	2.5 cm	0.218	0.317	0.274	0.310

Fig. 1. Photograph of the Proxim Model 8460 Cardbus Card inserted into a laptop computer.

Fig. 2. A picture of the Proxim Model 8460 Cardbus Card placed on the laptop computer.

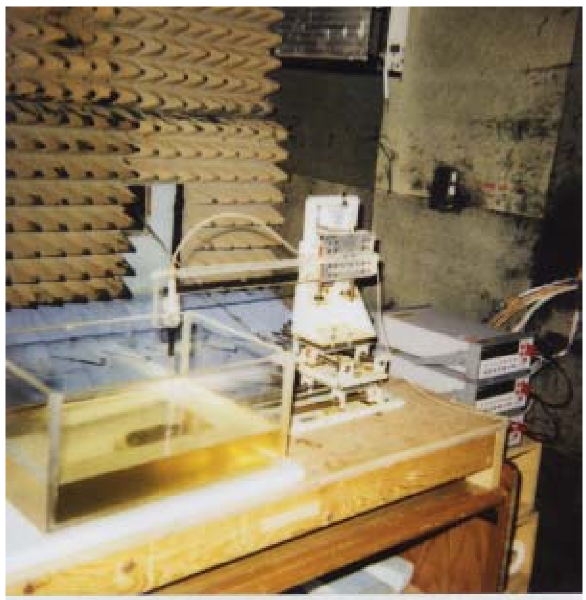


Fig. 3. Photograph of the three-dimensional stepper-motor-controlled SAR measurement system using a planar phantom (see Fig. 5 for a detailed examination of the placement of Proxim Model 8460 Cardbus Card relative to this phantom).

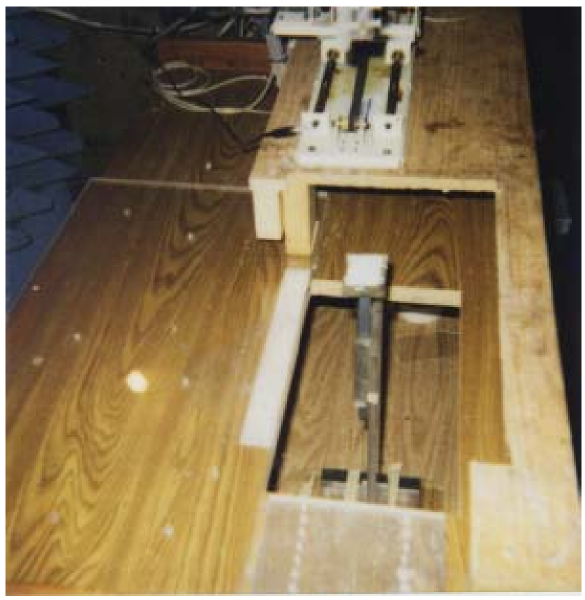


Fig. 4. The plastic holder used to support the portable computer with the Proxim Model 8460 Cardbus Card (shown in Fig. 1).

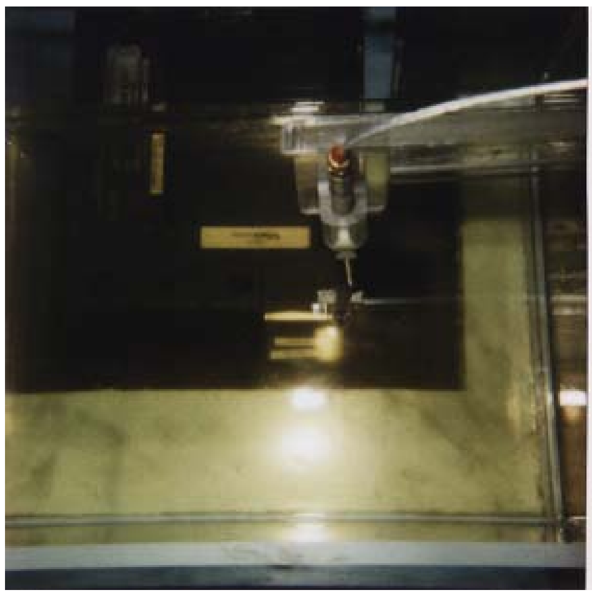


Fig. 5. Photograph of the Proxim Model 8460 Cardbus Card inserted into a laptop computer with its bottom pressed against the bottom of the planar tissue-simulant phantom to simulate "above-lap" placement of the wireless PC. A Styrofoam block is used under the base to prevent bending of the 2 mm thin base of the phantom.

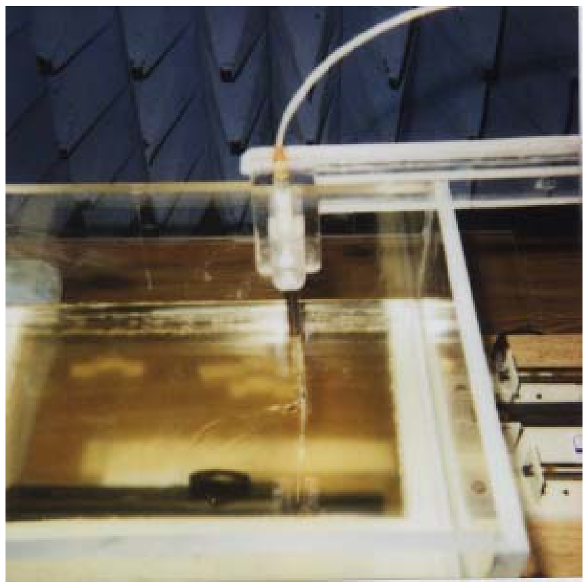
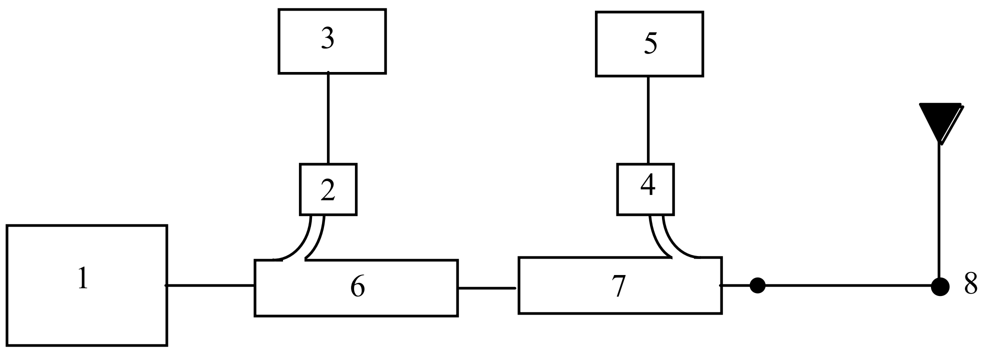


Fig. 6. Photograph of the Proxim Model 8460 Cardbus Card inserted into a portable computer (as in Fig. 1) placed with the card edge at 90° and separated from the bottom of the phantom by 2.5 cm for "end-on" testing of SAR. As in Fig. 5, here too, a Styrofoam block is used under the base to prevent bending 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.

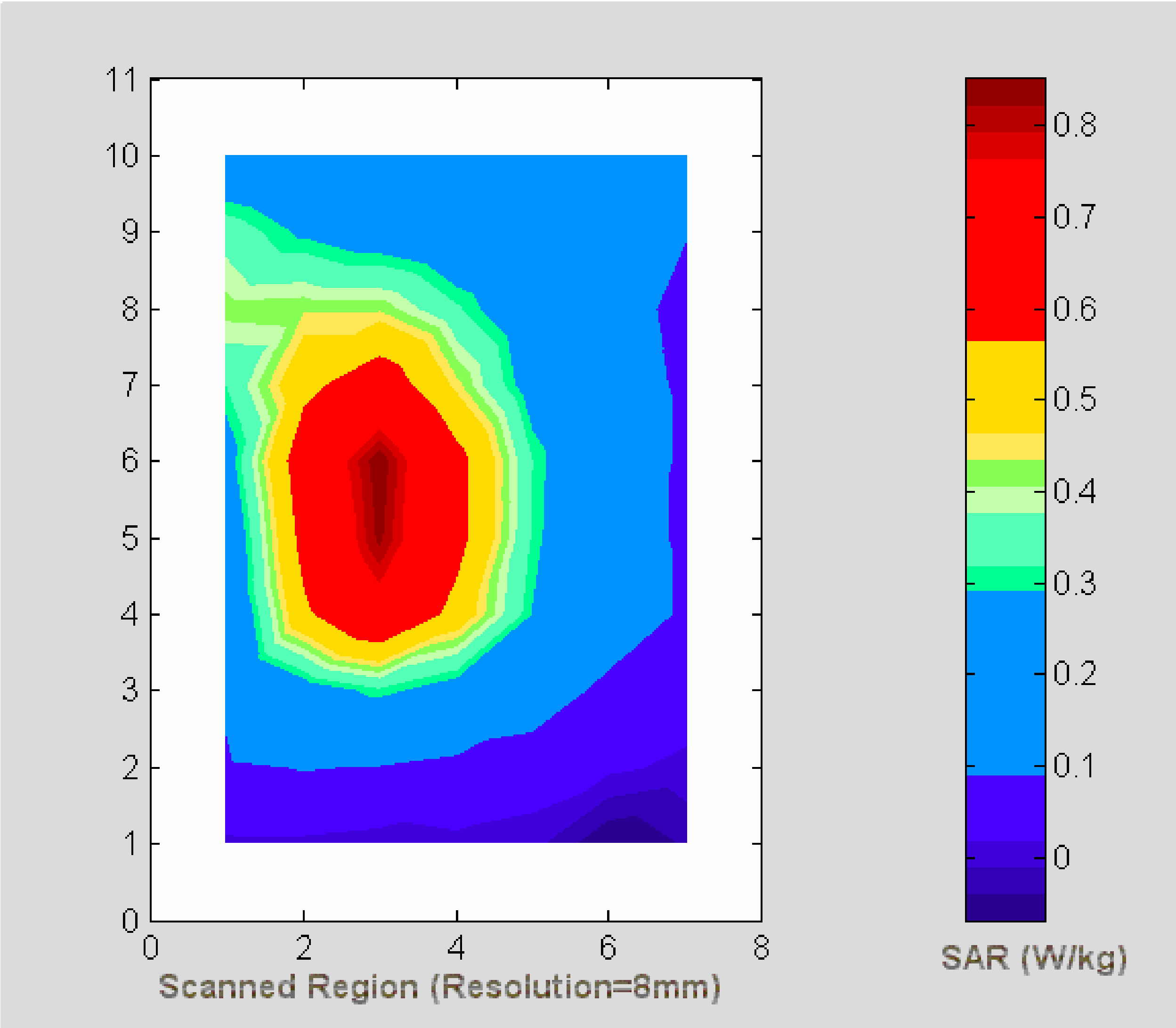


Fig. 11a. Repeated measurements for the three coarse scans each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. Measurement 1 (see Table 2a for the peak 1-g SAR).

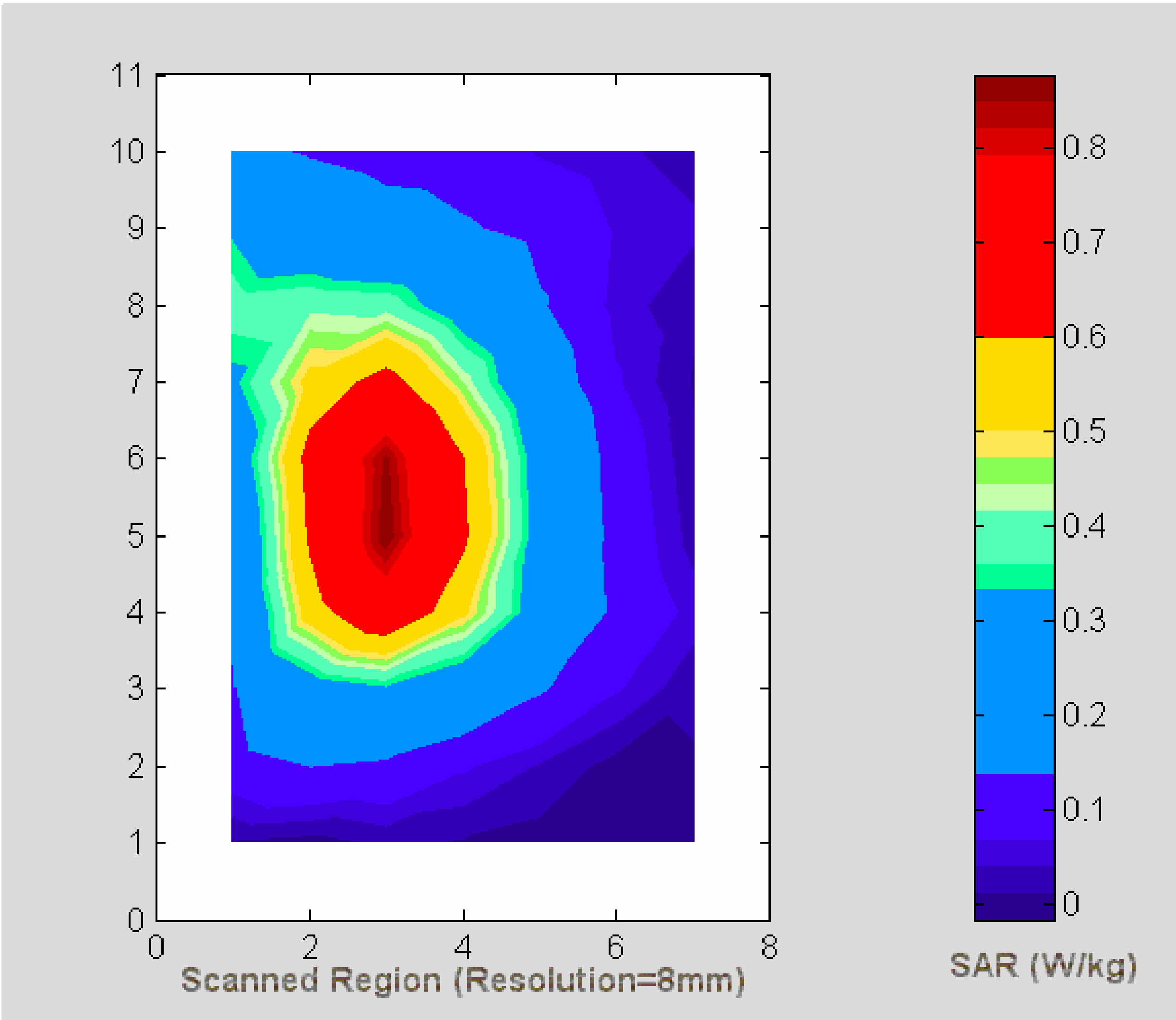


Fig. 11b. Repeated measurements for the three coarse scans each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. Measurement 2 (see Table 2b for the peak 1-g SAR).

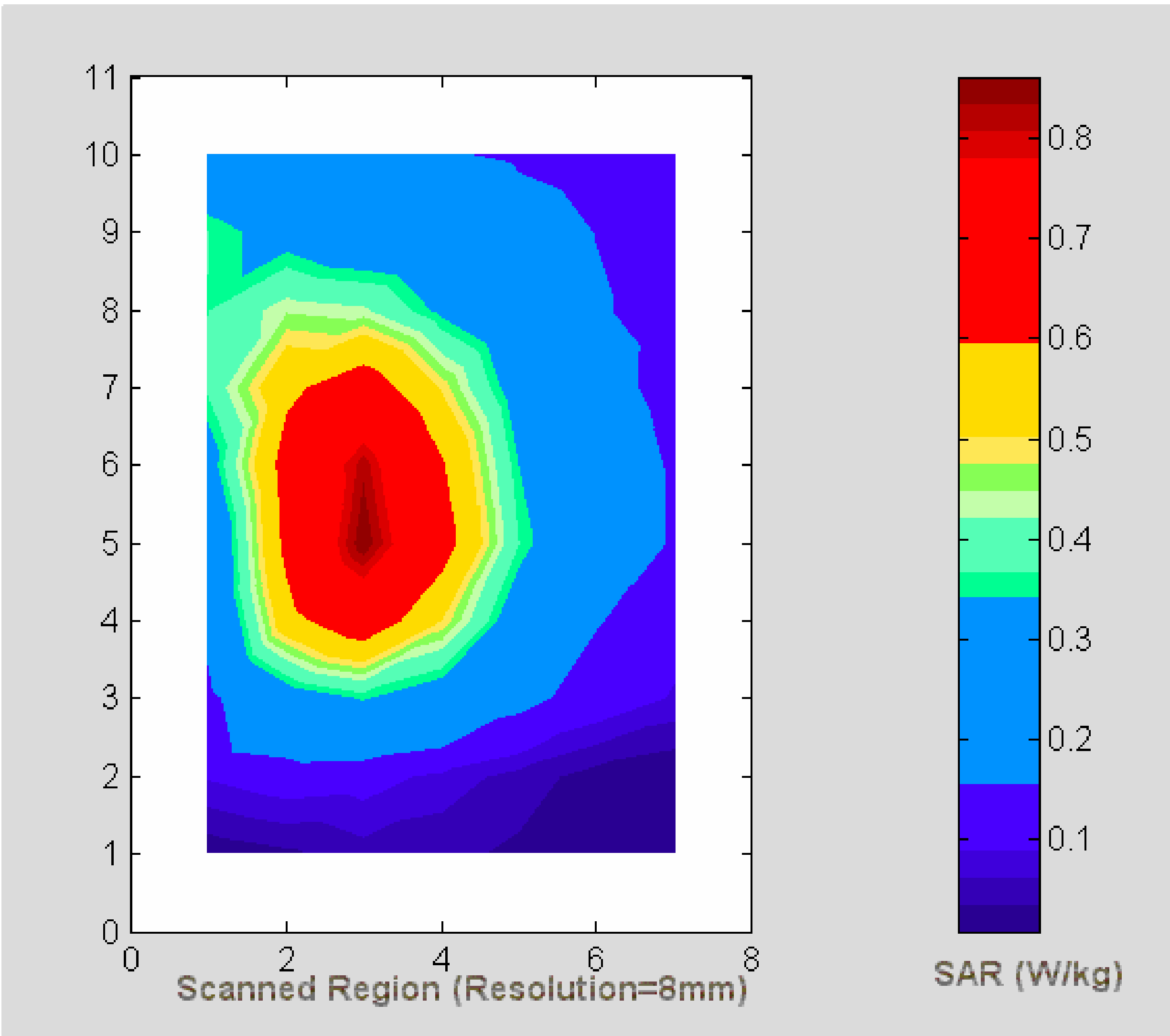


Fig. 11c. Repeated measurements for the three coarse scans each lasting 20 minutes at 5.32 GHz for the Proxim Model 8460 Cardbus Card inserted in a laptop computer pressed against the flat body phantom. Measurement 3 (see Table 2c for the peak 1-g SAR).

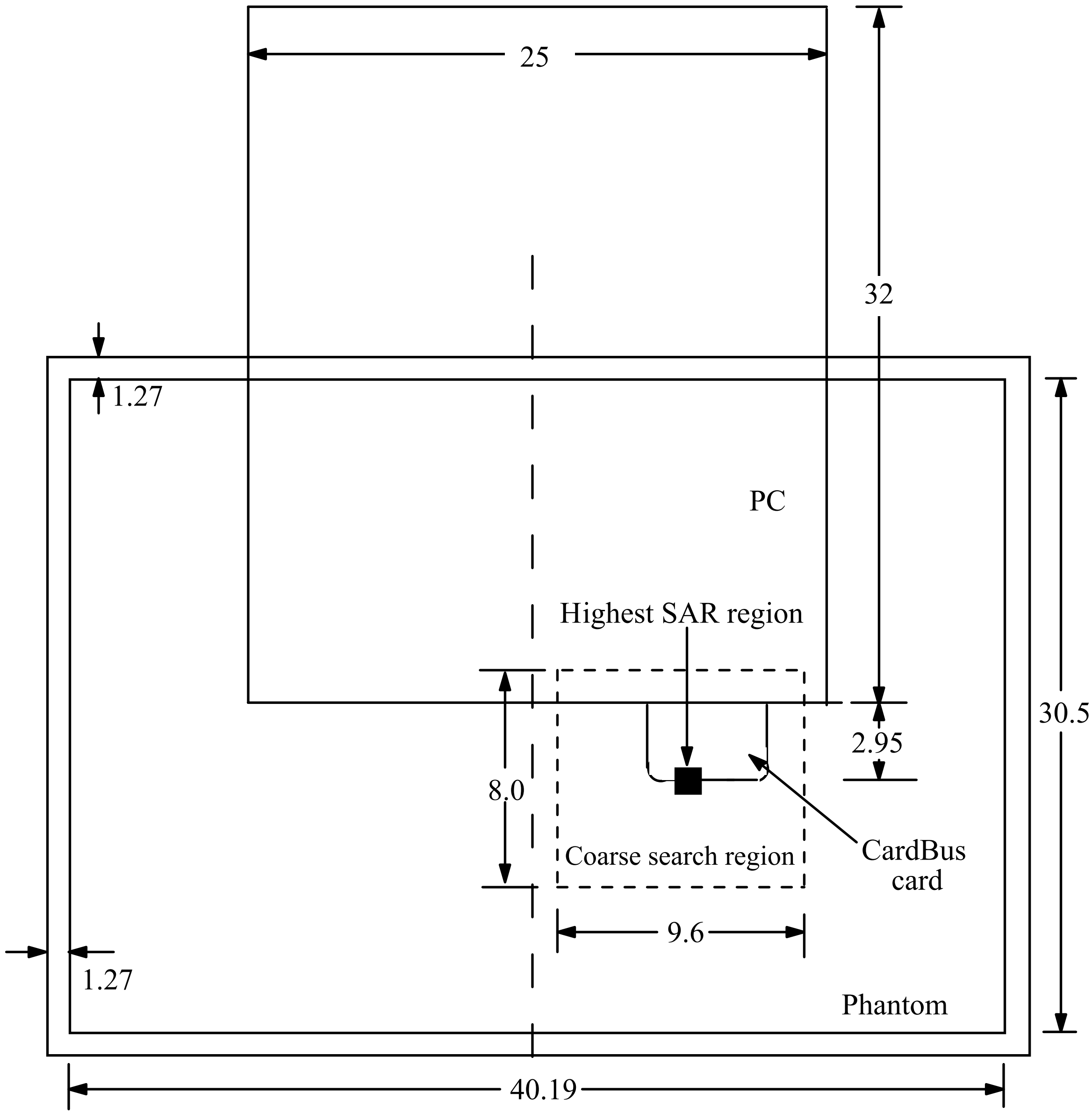
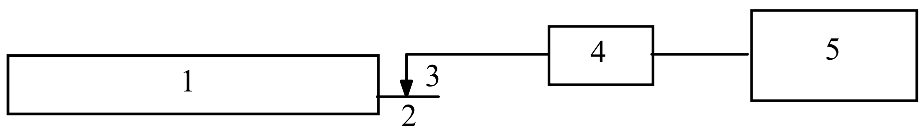


Fig. 12. Illustration of the peak SAR location with respect to the phantom and the Proxim Model 8460 Cardbus Card for the **Above-lap position**. All dimensions are in cm.



1. Laptop computer
2. Proxim Model 8460 Cardbus Card.
3. Coaxial output for conducted power measurement.
4. HP Model 8481A Power Sensor.
5. HP Model 436A Power Meter.

Fig. 13. The microwave circuit arrangement used for conducted power measurements for Proxim Model 8460 Cardbus Card.

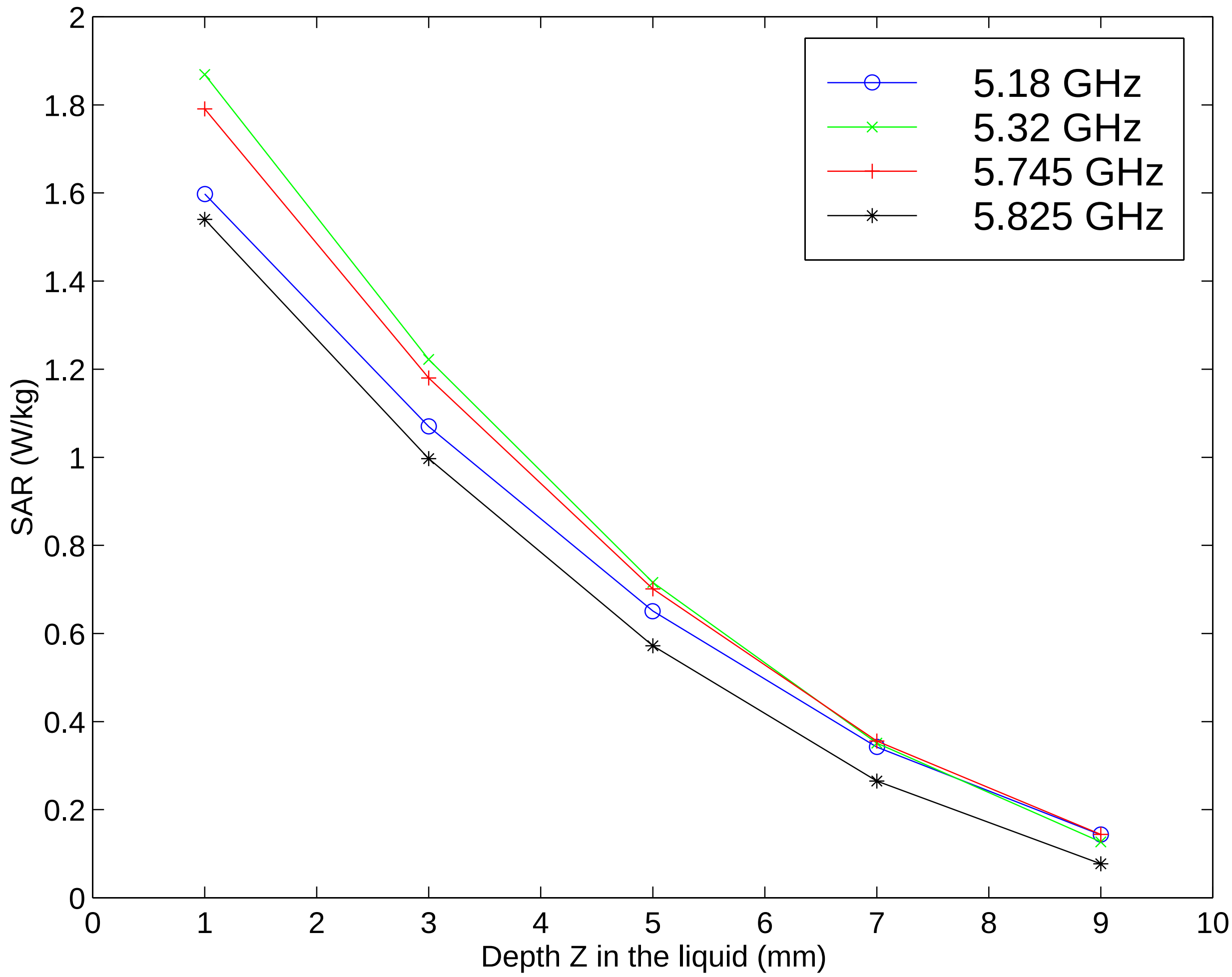


Fig. 14. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 3-5 -- Above-lap position) for Proxim Model 8460 Cardbus Card.

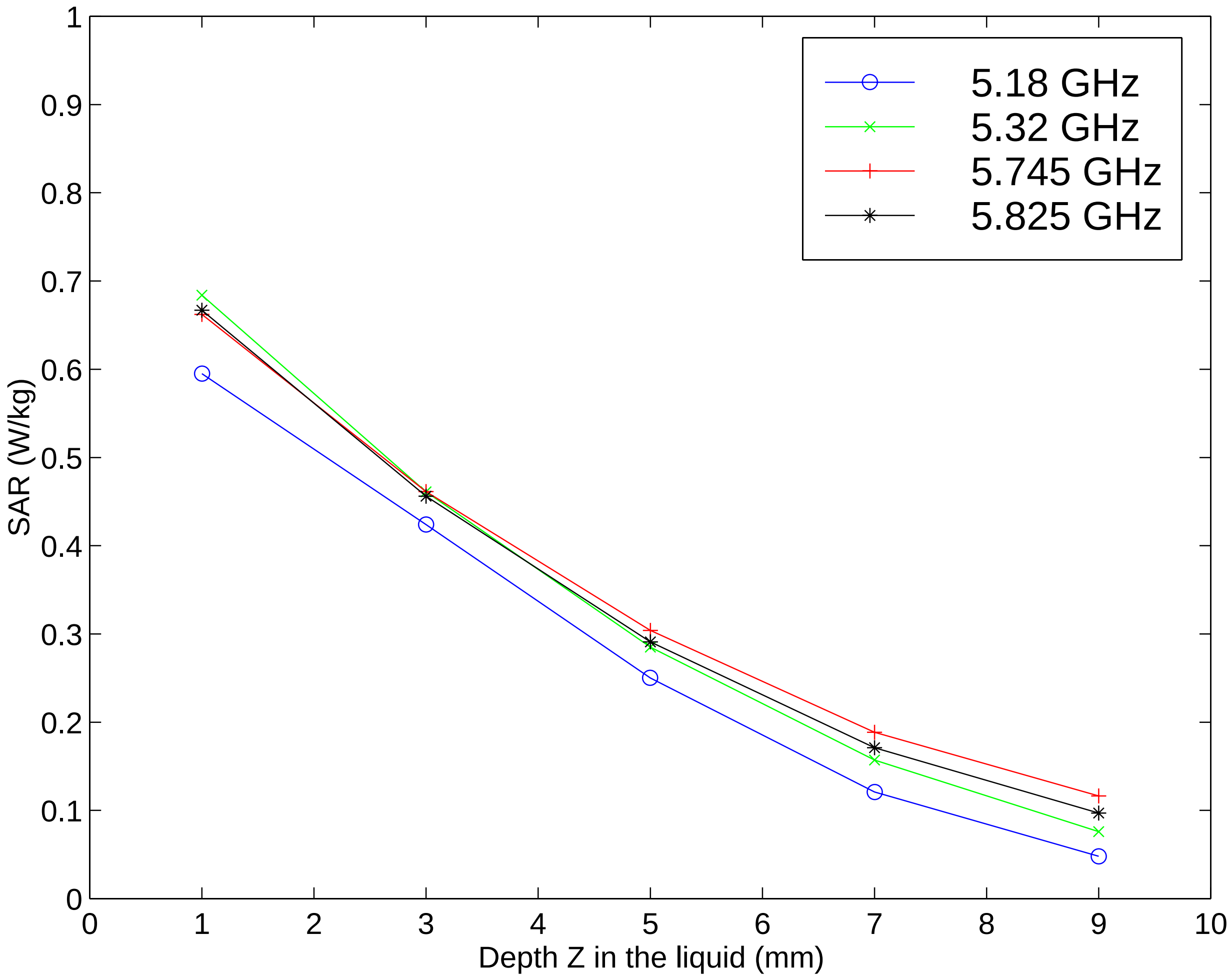


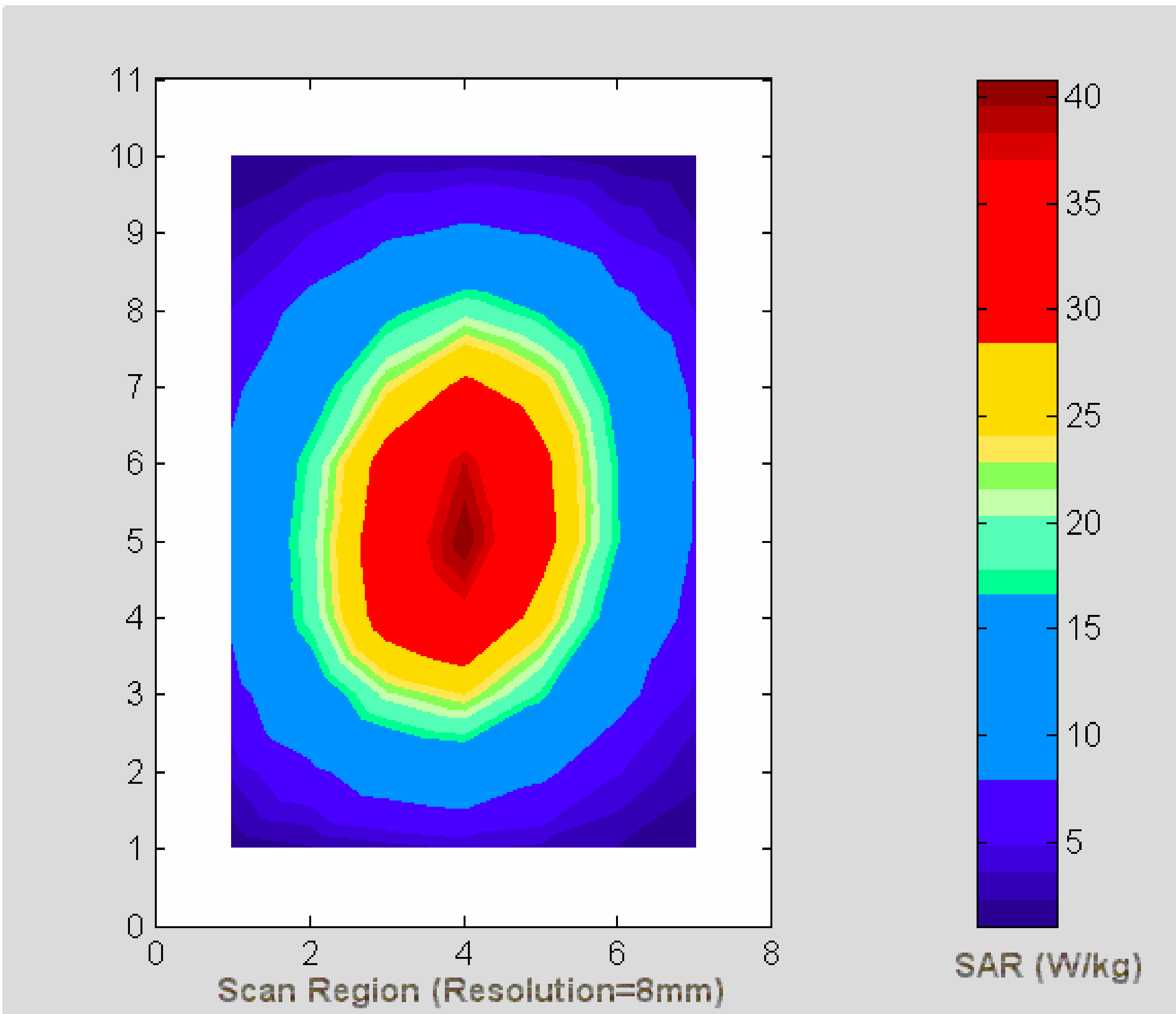
Fig. 15. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 7-10 -- End-on position) for Proxim Model 8460 Cardbus Card.

APPENDIX B

SAR System Verification for August 7-9, 2002

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

For August 7, 2002 - The dipole SAR Plot



1-g SAR = 35.980 W/kg

a. At depth of 1 mm

53.540	56.782	58.408	58.053	55.885
54.440	57.892	59.527	59.106	57.058
54.265	58.088	60.246	60.161	58.160
53.558	57.616	60.107	60.315	58.830
52.464	56.667	59.159	59.731	58.380

b. At depth of 3 mm

41.799	44.135	45.271	44.942	43.356
42.465	44.951	46.101	45.758	44.232
42.448	45.168	46.646	46.526	45.038
41.975	44.867	46.568	46.646	45.487
41.191	44.175	45.921	46.222	45.146

c. At depth of 5 mm

31.932	33.528	34.270	33.968	32.853
32.411	34.108	34.869	34.592	33.494
32.498	34.330	35.270	35.126	34.058
32.206	34.155	35.230	35.211	34.330
31.668	33.666	34.811	34.910	34.074

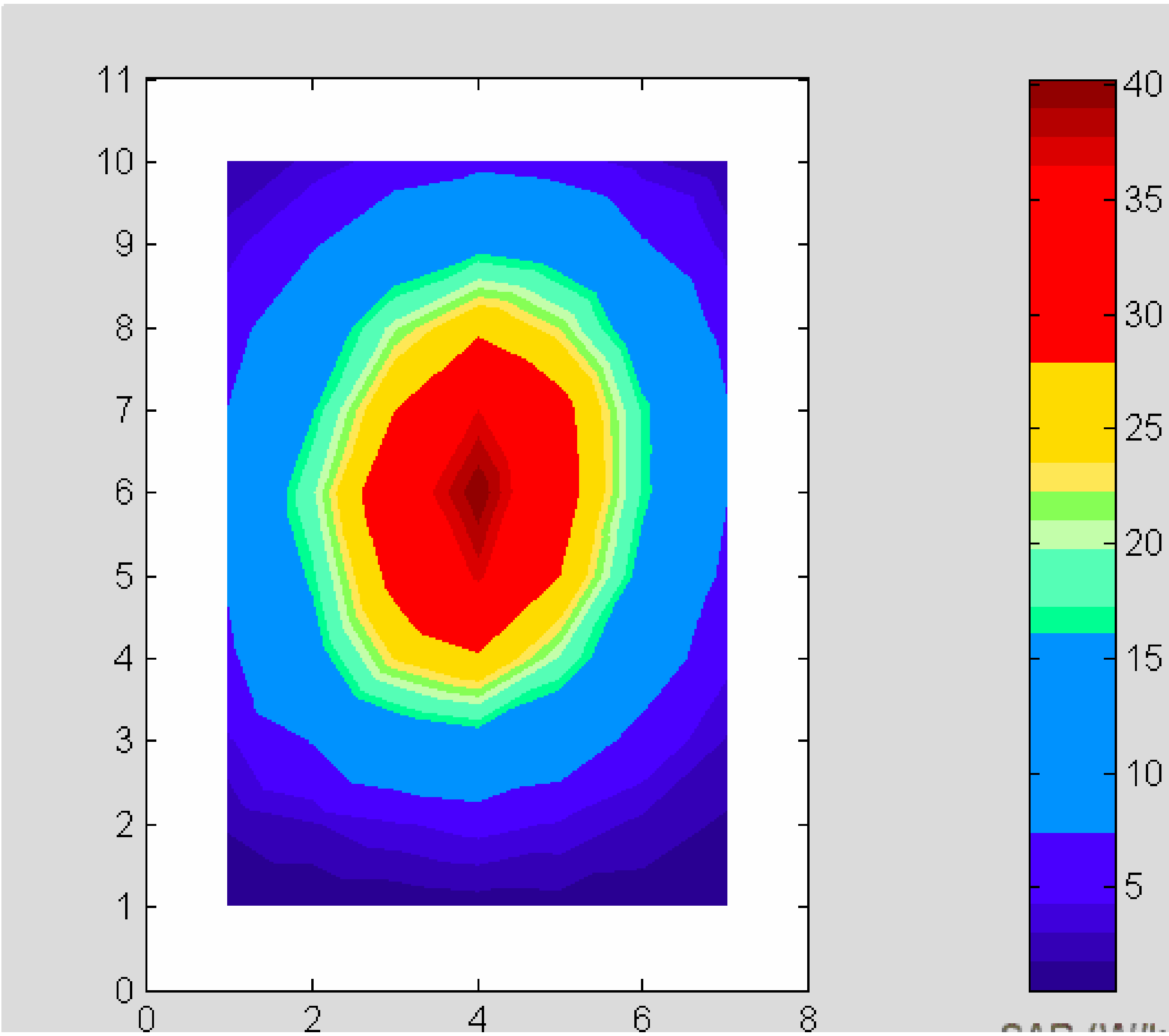
d. At depth of 7 mm

23.939	24.961	25.406	25.131	24.378
24.277	25.364	25.830	25.608	24.845
24.417	25.572	26.116	25.962	25.221
24.253	25.481	26.093	26.011	25.357
23.894	25.141	25.829	25.796	25.165

e. At depth of 9 mm

17.819	18.434	18.679	18.430	17.930
18.063	18.718	18.985	18.806	18.285
18.203	18.896	19.185	19.034	18.526
18.115	18.844	19.157	19.045	18.570
17.869	18.599	18.975	18.881	18.419

For August 8, 2002 - The Dipole SAR Plot



1-g SAR = 35.485 W/kg

a. At depth of 1 mm

55.529	57.013	56.504	54.382	50.729
56.585	58.336	57.963	55.748	51.865
57.354	59.229	58.808	56.445	52.483
57.498	59.351	59.146	57.062	53.085
56.769	58.938	58.837	56.789	52.855

b. At depth of 3 mm

43.319	44.350	43.941	42.377	39.642
44.170	45.381	45.046	43.404	40.579
44.763	46.072	45.715	43.992	41.075
44.848	46.160	45.964	44.414	41.529
44.287	45.797	45.685	44.164	41.258

c. At depth of 5 mm

33.081	33.749	33.425	32.310	30.333
33.754	34.536	34.236	33.062	31.091
34.197	35.051	34.750	33.542	31.480
34.231	35.106	34.921	33.809	31.805
33.806	34.791	34.673	33.583	31.528

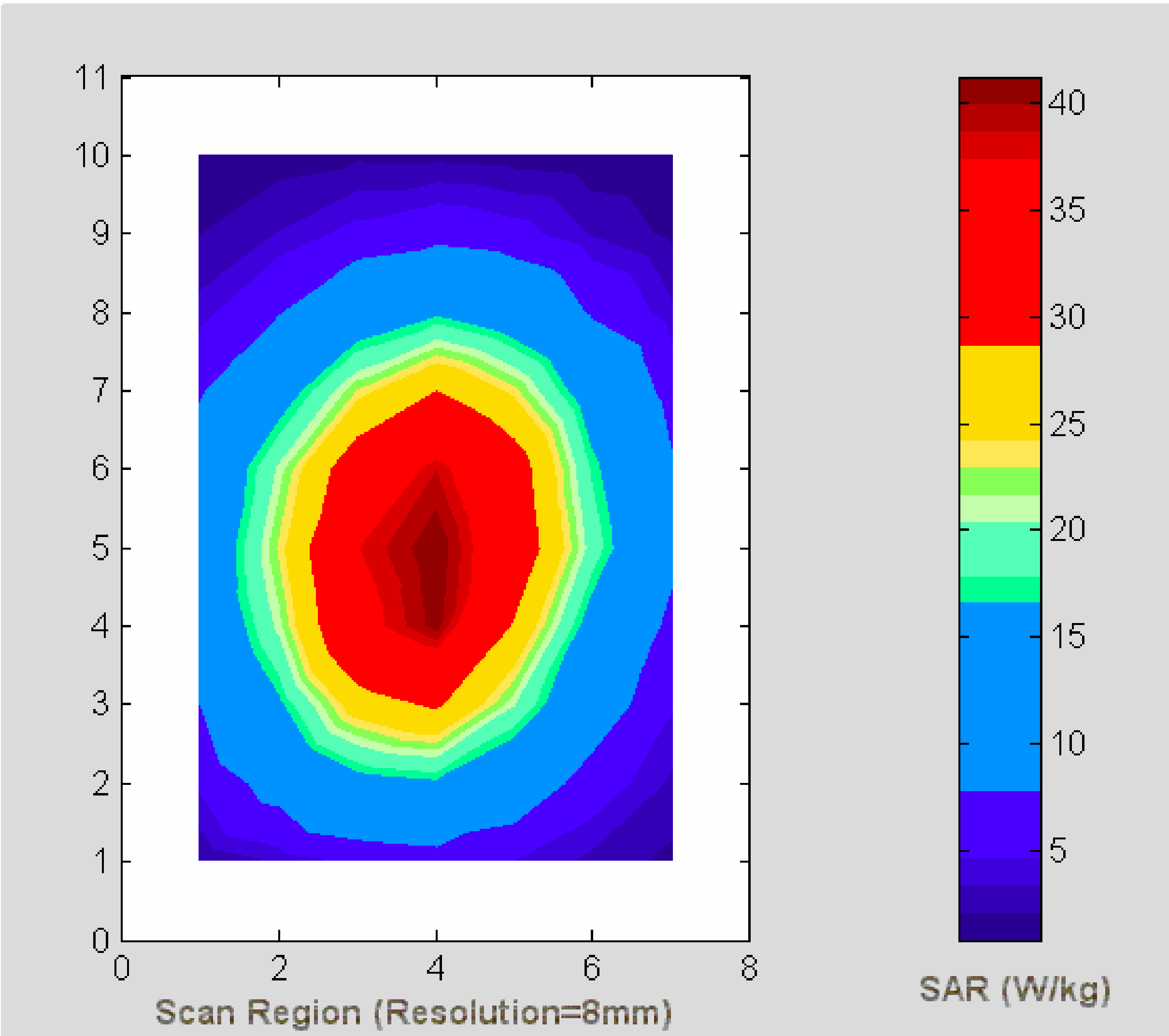
d. At depth of 7 mm

24.816	25.209	24.957	24.182	22.803
25.337	25.800	25.532	24.723	23.401
25.657	26.166	25.911	25.094	23.697
25.645	26.190	26.018	25.246	23.912
25.326	25.919	25.800	25.044	23.668

e. At depth of 9 mm

18.524	18.730	18.536	17.993	17.050
18.920	19.175	18.934	18.386	17.510
19.143	19.417	19.200	18.648	17.726
19.091	19.412	19.254	18.726	17.850
18.846	19.182	19.067	18.548	17.675

For August 9, 2002 - The Dipole SAR Plot



1-g SAR = 36.256 W/kg

a. At depth of 1 mm

54.321	57.030	57.980	56.712	54.443
54.689	57.769	59.030	58.280	55.919
54.770	58.047	59.484	58.866	56.511
54.565	58.024	59.611	59.115	56.862
53.785	57.352	59.177	58.844	56.824

b. At depth of 3 mm

42.239	44.287	45.074	44.254	42.617
42.830	45.103	46.069	45.540	43.791
43.069	45.462	46.529	46.050	44.316
43.002	45.498	46.662	46.258	44.578
42.443	45.033	46.334	46.055	44.492

c. At depth of 5 mm

32.144	33.645	34.281	33.811	32.679
32.868	34.483	35.201	34.846	33.598
33.209	34.883	35.648	35.285	34.055
33.242	34.961	35.778	35.453	34.242
32.858	34.657	35.534	35.301	34.125

d. At depth of 7 mm

24.037	25.105	25.602	25.382	24.630
24.803	25.910	26.424	26.199	25.340
25.190	26.309	26.840	26.571	25.729
25.284	26.414	26.958	26.700	25.855
25.030	26.223	26.778	26.582	25.720

e. At depth of 9 mm

17.918	18.665	19.035	18.969	18.468
18.634	19.384	19.738	19.598	19.016
19.013	19.741	20.106	19.908	19.338
19.127	19.856	20.203	20.000	19.416
18.958	19.731	20.065	19.897	19.279

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