SAR COMPLIANCE TESTING OF AMBIT MICROSYSTEMS 802.11 a/b/g MINI PCI BUILT INTO AGENCY SERIES PP2170 LAPTOP COMPUTER

MODEL: J07H069.01
FCC ID: MCLJ07H06901

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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 Ambit Microsystems 802.11 a/b/g Mini PCI built into Agency Series PP2170 Laptop Computer (FCC ID# MCLJ07H06901). The photographs of the Agency Series Laptop Computer with built-in Ambit Microsystems 802.11 a/b/g Mini PCI Wireless Antennas are given in Figs. 1a, b, c and Fig. 2, respectively. Even though two 802.11 a/b antennas are built into the lid with the computer screen for diversity, only one of the two antennas is active at any given time. Each of the Ambit 802.11a Wireless Antennas operates over the frequency band 5.18 to 5.825 GHz in base or turbo modes with conducted power levels given in Table 1.

For SAR measurements, three configurations of the wireless PC relative to the experimental phantom have been used. These are as follows:

a. **Configuration 1** is for the wireless PC placed on a user's lap. For this configuration, 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 bottom side of the laptop computer shown in Fig. 1b was pressed against it (see Fig. 3). Due to the possible shielding effect of the keyboard, the SARs were extremely low and close to the noise level of the measuring system (estimated to be on the order of

0.02 W/kg), both when the top cover is opened up as for normal operation as well as for the case when the top cover is closed shut and the base of the PC is pressed against the bottom of the planar phantom shown in Fig. 4.

b. For a bystander, the "end-on" SAR values were determined for configurations 2 and 3 of the wireless PC relative to the flat phantom. These configurations are:

Configuration 2: Edge-on placement of the PC screen at 90° relative to the flat phantom (see Fig. 6). The cover of the PC was left open and the edge of the PC screen with the 802.11 a/b antennas was placed parallel to the bottom of the flat phantom with a spacing of 2.5 cm.

Configuration 3: End-on placement of the PC with the planar phantom at a distance of 2.5 cm from the broadside direction of the 5 GHz 802.11 a/b antennas (see Fig. 7). For this configuration, the PC was operated with the top cover closed and the top cover was placed parallel to the base of the planar phantom at a distance of 2.5 cm prescribed in [3]. This configuration corresponds to the situation when a bystander is standing close to the back of the PC cover at a distance of 2.5 cm.

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. 4. 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. 5) on which the laptop computer with the 802.11 a/b wireless antennas (see Figs. 1 and 2) is supported. A plastic holder (see Fig. 5) can be moved up or down so that the base of the PC (for Configuration 1) is pressed against the base of the flat phantom for determination of SAR for above-lap position. Similarly, for "end-on" SAR determination, Configuration 2, the laptop computer screen is mounted sideways (at 90°) on the plastic holder and moved up so that the edge of the screen with the 802.11 a/b wireless antennas was pressed against the bottom of the flat phantom with a spacing of 2.5 cm (see Fig. 6). A second bystander, Configuration 3, where an individual may be as close as 2.5 cm behind the top cover was also used for SAR measurements. As seen in Fig. 7 for this configuration, the PC was operated with the top cover closed and the top cover was placed parallel to the planar phantom at a distance of 2.5 cm as prescribed in [3].

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. 6, 7). As seen both in Figs. 6 and 7, a one-inch thick Styrofoam block was used under the base of the phantom both to provide 2.5 cm spacing and 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. 8a,b). The triaxial (3 dipole) E-field probe shown in Fig. 9 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 date for the calibration of the E-field probe closest to the SAR tests given here was February 13, 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. 10. 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. 11. 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 measured SAR distribution for the peak 1-g SAR region using this system verification dipole for the day of SAR measurements, February 13, 2003, is given in Appendix B. Also given in Appendix B is the dipole SAR plot for this date of device testing. The peak 1-g SAR is 35.366 W/kg. The measured 1-g SAR is in excellent agreement with the FDTD-calculated 1-g SAR of 35.8 W/kg for this dipole. Also as expected, the measured SAR plot is 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 2 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 2. From Table 2, 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 2, 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. 12) 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

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

VI. The Measured SAR Distributions

The RF power output measured for the Ambit Microsystems 802.11a Wireless Antenna is given in Table 1. For SAR measurements, we selected frequencies of 5.26 and 5.785 GHz for the base mode and 5.25 and 5.8 GHz for the turbo mode. The various frequencies and modes were selected both for their highest power outputs as well as to cover the different frequency bands planned for this wireless device. As recommended in Supplement C, Edition 01-01 [3], the stability of the conducted power was determined by repeated SAR measurements at the same location for each of the selected channels. The variability of the SAR thus determined for three repeated measurements over a 60-minute time period was within ± 0.1 dB (± 2.5%).

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%.

As previously mentioned, the Ambit Microsystems 802.11 a/b antenna are built into the two sides of the cover for this PC (see Fig. 2). On account of the shielding effect of the keyboard, the SARs determined for the Above-lap position with the base of the PC pressed firmly against the base of the phantom (called Configuration 1 – see Fig. 3) were extremely low and within the noise levels for the SAR measurement system (~ 0.02 W/kg). We, therefore, focused all of the SAR measurements on Configurations 2 and 3 defined in Section I. The coarse scans for the four measurements for the Edge-on Configuration 2 (defined in Section I) 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. 2. 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. 13a-d, respectively. The SARs are given for xy planes at heights z of 1, 3, 5, 7, and 9 mm from 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 $23.1 \pm 0.2^{\circ}C$.

The coarse scans measurements for the four measurements for the End-on Configuration 3 are shown in Fig. 14a-d, respectively. The corresponding SAR distributions for the peak 1-g SAR are given in Tables 7-10, respectively. As mentioned in Section I, this Configuration 3 corresponds to the placement of the PC at a distance of 2.5 cm from the broadside direction of the 5 GHz 802.11a wireless antenna (see Fig. 7). This configuration corresponds to a situation when a bystander is standing behind the PC cover at a distance of 2.5 cm. The z-axis scan plots taken at the highest SAR locations for each set of tests are given in Fig. 15 and 16, respectively.

The peak 1-g SARs for the various configurations of the Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antennas (FCC ID# MCLJ07H06901) 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 Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antennas (FCC ID# MCLJ07H06901), the measured peak 1-g SARs vary from nearly 0 to 0.416 W/kg which are smaller than 1.6 W/kg.

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Table 1. Average conducted RF power outputs measured at various frequencies for the Ambit Microsystems 802.11a Wireless Antenna for base and turbo modes.

Frequency GHz	Average Power dBm
Normal Mode	
5.18	13.5
5.24	17.0
5.26	17.0
5.32	14.0
5.745	17.0
5.785	17.0
5.825	17.0
Turbo Mode	
5.21	15.0
5.25	15.0
5.29	15.0
5.76	17.0
5.80	17.0

Table 2. 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 3. **Edge-on position (Configuration 2).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the base mode at 5.26 GHz.

1-g SAR = 0.172 W/kg

a. At depth of 1 mm

0.277	0.270	0.277	0.274	0.251
0.288	0.296	0.257	0.302	0.271
0.280	0.286	0.314	0.320	0.294
0.279	0.285	0.277	0.290	0.261
0.275	0.275	0.319	0.306	0.310

b. At depth of 3 mm

0.206	0.202	0.205	0.207	0.191
0.212	0.217	0.196	0.221	0.214
0.207	0.216	0.232	0.231	0.214
0.210	0.220	0.210	0.218	0.200
0.206	0.209	0.234	0.237	0.242

c. At depth of 5 mm

0.148	0.149	0.148	0.152	0.143
0.153	0.155	0.147	0.158	0.166
0.150	0.159	0.168	0.162	0.151
0.156	0.167	0.155	0.159	0.150
0.151	0.156	0.168	0.182	0.189

d. At depth of 7 mm

0.105	0.111	0.106	0.111	0.107
0.110	0.109	0.110	0.113	0.126
0.109	0.117	0.121	0.112	0.104
0.118	0.125	0.114	0.115	0.111
0.109	0.115	0.120	0.140	0.150

e. At depth of 9 mm

0.074	0.086	0.079	0.082	0.083
0.084	0.079	0.084	0.085	0.096
0.083	0.090	0.091	0.082	0.074
0.095	0.096	0.085	0.085	0.083
0.081	0.088	0.091	0.112	0.126

Table 4. **Edge-on position (Configuration 2).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the base mode at 5.875 GHz.

1-g SAR = 0.257 W/kg

a. At depth of 1 mm

0.408	0.421	0.443	0.438	0.424
0.464	0.438	0.456	0.449	0.437
0.439	0.444	0.477	0.468	0.449
0.420	0.468	0.467	0.451	0.468
0.433	0.427	0.491	0.495	0.482

b. At depth of 3 mm

0.295	0.307	0.321	0.316	0.305
0.325	0.323	0.328	0.330	0.320
0.319	0.325	0.350	0.342	0.330
0.310	0.335	0.343	0.326	0.342
0.316	0.321	0.354	0.355	0.358

c. At depth of 5 mm

0.206	0.218	0.225	0.220	0.212
0.218	0.231	0.228	0.236	0.227
0.225	0.231	0.249	0.242	0.235
0.223	0.232	0.244	0.228	0.242
0.225	0.236	0.246	0.246	0.259

d. At depth of 7 mm

0.142	0.151	0.156	0.150	0.146
0.144	0.162	0.156	0.167	0.158
0.157	0.162	0.174	0.167	0.164
0.159	0.159	0.169	0.157	0.167
0.157	0.172	0.167	0.168	0.184

e. At depth of 9 mm

0.103	0.107	0.112	0.107	0.105
0.103	0.115	0.114	0.122	0.113
0.114	0.119	0.125	0.118	0.119
0.117	0.114	0.120	0.111	0.118
0.115	0.130	0.117	0.122	0.134

Table 5. **Edge-on position (Configuration 2).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the turbo mode at 5.25 GHz.

1-g SAR = 0.229 W/kg

a. At depth of 1 mm

0.404	0.433	0.434	0.416	0.405
0.383	0.416	0.413	0.441	0.417
0.387	0.398	0.427	0.424	0.417
0.397	0.401	0.427	0.405	0.427
0.370	0.369	0.428	0.409	0.411

b. At depth of 3 mm

0.295	0.311	0.315	0.300	0.296
0.280	0.299	0.293	0.313	0.299
0.282	0.290	0.306	0.305	0.302
0.287	0.293	0.302	0.292	0.306
0.267	0.280	0.309	0.296	0.302

c. At depth of 5 mm

0.208	0.215	0.220	0.207	0.208
0.198	0.205	0.198	0.212	0.205
0.198	0.203	0.210	0.210	0.210
0.199	0.206	0.203	0.202	0.210
0.186	0.207	0.215	0.207	0.217

d. At depth of 7 mm

0.143	0.145	0.149	0.137	0.141
0.137	0.134	0.128	0.139	0.135
0.135	0.137	0.139	0.138	0.141
0.133	0.139	0.131	0.135	0.139
0.125	0.151	0.146	0.143	0.153

e. At depth of 9 mm

0.101	0.102	0.102	0.090	0.094
0.098	0.086	0.084	0.093	0.089
0.093	0.094	0.092	0.091	0.096
0.088	0.093	0.085	0.092	0.094
0.085	0.113	0.101	0.104	0.112

Table 6. **Edge-on position (Configuration 2).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the turbo mode at 5.8 GHz.

1-g SAR = 0.177 W/kg

a. At depth of 1 mm

0.263	0.293	0.293	0.304	0.295
0.300	0.307	0.297	0.299	0.283
0.315	0.292	0.329	0.312	0.302
0.304	0.305	0.328	0.288	0.305
0.275	0.292	0.302	0.296	0.311

b. At depth of 3 mm

0.202	0.219	0.214	0.221	0.216
0.227	0.225	0.220	0.220	0.211
0.230	0.218	0.235	0.230	0.223
0.221	0.229	0.240	0.212	0.221
0.209	0.221	0.225	0.222	0.239

c. At depth of 5 mm

0.152	0.158	0.153	0.157	0.155
0.167	0.161	0.158	0.156	0.153
0.162	0.160	0.163	0.166	0.159
0.156	0.168	0.170	0.153	0.156
0.156	0.164	0.164	0.164	0.182

d. At depth of 7 mm

0.113	0.112	0.110	0.112	0.111
0.121	0.114	0.114	0.109	0.111
0.113	0.117	0.112	0.119	0.112
0.109	0.124	0.120	0.110	0.110
0.115	0.123	0.119	0.122	0.140

e. At depth of 9 mm

0.085	0.080	0.084	0.085	0.084
0.089	0.084	0.085	0.079	0.084
0.081	0.089	0.081	0.089	0.082
0.079	0.095	0.088	0.084	0.084
0.088	0.097	0.090	0.095	0.114

Table 7. **End-on position (Configuration 3).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the base mode at 5.26 GHz.

1-g SAR = 0.416 W/kg

a. At depth of 1 mm

0.695	0.701	0.701	0.688	0.713
0.702	0.727	0.717	0.725	0.722
0.699	0.723	0.732	0.734	0.718
0.711	0.727	0.728	0.713	0.715
0.680	0.693	0.705	0.693	0.704

b. At depth of 3 mm

0.513	0.520	0.518	0.511	0.523
0.519	0.530	0.526	0.526	0.525
0.514	0.521	0.536	0.532	0.524
0.517	0.534	0.533	0.523	0.523
0.499	0.508	0.512	0.505	0.519

c. At depth of 5 mm

0.369	0.374	0.373	0.367	0.372
0.373	0.374	0.373	0.369	0.369
0.367	0.361	0.379	0.372	0.369
0.364	0.380	0.378	0.311	0.370
0.353	0.360	0.359	0.356	0.370

d. At depth of 7 mm

0.263	0.265	0.266	0.259	0.259
0.263	0.258	0.260	0.253	0.253
0.257	0.245	0.263	0.253	0.251
0.252	0.264	0.262	0.244	0.255
0.245	0.249	0.245	0.245	0.260

e. At depth of 9 mm

0.194	0.192	0.197	0.184	0.186
0.190	0.183	0.186	0.178	0.177
0.185	0.171	0.187	0.177	0.172
0.181	0.188	0.184	0.173	0.180
0.173	0.174	0.169	0.172	0.186

Table 8. **End-on position (Configuration 3).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the base mode at 5.875 GHz.

1-g SAR = 0.334 W/kg

a. At depth of 1 mm

0.582	0.587	0.583	0.376	0.577
0.592	0.599	0.599	0.582	0.584
0.589	0.604	0.613	0.601	0.589
0.584	0.593	0.612	0.595	0.570
0.573	0.598	0.583	0.572	0.565

b. At depth of 3 mm

0.423	0.429	0.425	0.309	0.422
0.434	0.439	0.436	0.427	0.427
0.429	0.437	0.440	0.434	0.423
0.420	0.431	0.440	0.428	0.420
0.417	0.437	0.428	0.418	0.415

c. At depth of 5 mm

0.299	0.304	0.300	0.251	0.299
0.310	0.313	0.307	0.303	0.303
0.302	0.305	0.304	0.301	0.292
0.291	0.304	0.306	0.296	0.300
0.293	0.309	0.304	0.295	0.295

d. At depth of 7 mm

0.209	0.213	0.209	0.202	0.209
0.219	0.219	0.213	0.212	0.210
0.209	0.210	0.206	0.203	0.198
0.198	0.210	0.208	0.200	0.211
0.203	0.215	0.212	0.204	0.206

e. At depth of 9 mm

0.153	0.156	0.152	0.163	0.151
0.162	0.158	0.153	0.152	0.150
0.150	0.150	0.145	0.141	0.139
0.140	0.152	0.146	0.141	0.153
0.145	0.155	0.151	0.144	0.148

Table 9. **End-on position (Configuration 3).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the turbo mode at 5.25 GHz.

1-g SAR = 0.293 W/kg

a. At depth of 1 mm

0.469	0.499	0.498	0.480	0.494
0.516	0.489	0.506	0.513	0.512
0.486	0.508	0.519	0.516	0.511
0.484	0.523	0.497	0.484	0.483
0.472	0.498	0.492	0.504	0.495

b. At depth of 3 mm

0.355	0.370	0.371	0.365	0.365
0.379	0.363	0.376	0.382	0.374
0.357	0.369	0.384	0.380	0.373
0.362	0.383	0.358	0.358	0.362
0.351	0.368	0.369	0.380	0.378

c. At depth of 5 mm

0.263	0.268	0.270	0.272	0.263
0.272	0.263	0.273	0.276	0.265
0.254	0.260	0.275	0.272	0.267
0.263	0.271	0.249	0.258	0.265
0.255	0.264	0.270	0.280	0.284

d. At depth of 7 mm

0.193	0.193	0.195	0.200	0.188
0.194	0.188	0.196	0.196	0.184
0.179	0.180	0.194	0.191	0.182
0.189	0.188	0.170	0.183	0.191
0.184	0.188	0.198	0.207	0.213

e. At depth of 9 mm

0.146	0.145	0.146	0.151	0.142
0.146	0.139	0.145	0.142	0.132
0.131	0.131	0.139	0.139	0.129
0.139	0.134	0.121	0.134	0.140
0.137	0.139	0.151	0.159	0.165

Table 10. **End-on position (Configuration 3).** The SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer for the turbo mode at 5.8 GHz.

1-g SAR = 0.325 W/kg

a. At depth of 1 mm

0.581	0.617	0.572	0.572	0.590
0.571	0.590	0.597	0.571	0.571
0.572	0.571	0.565	0.562	0.549
0.582	0.578	0.587	0.558	0.576
0.565	0.569	0.559	0.552	0.569

b. At depth of 3 mm

0.424	0.444	0.414	0.411	0.430
0.417	0.426	0.428	0.417	0.413
0.414	0.417	0.412	0.407	0.399
0.417	0.419	0.423	0.409	0.415
0.409	0.408	0.410	0.408	0.420

c. At depth of 5 mm

0.301	0.307	0.288	0.284	0.303
0.294	0.296	0.295	0.294	0.289
0.290	0.294	0.291	0.285	0.279
0.288	0.293	0.295	0.290	0.288
0.285	0.281	0.291	0.294	0.302

d. At depth of 7 mm

0.210	0.207	0.195	0.192	0.210
0.204	0.200	0.199	0.203	0.198
0.198	0.203	0.200	0.194	0.191
0.194	0.201	0.201	0.202	0.197
0.194	0.189	0.204	0.209	0.214

e. At depth of 9 mm

0.153	0.143	0.134	0.134	0.149
0.146	0.138	0.138	0.143	0.141
0.139	0.143	0.140	0.136	0.134
0.136	0.143	0.143	0.145	0.141
0.137	0.131	0.146	0.155	0.157

Table 11. The peak 1-g SARs measured for the Ambit Microsystems 802.11a Wireless Antenna built into Agency Series PP2170 Laptop Computer (FCC ID# MCLJ07H06901).

1-g SAR in W/kg

PC position relative to the flat phantom	Spacing to the bottom of the phantom	5.26 GHz base mode	5.785 GHz base mode	5.25 GHz turbo mode	5.80 GHz turbo mode
Configuration 1 – "**Above-lap**" bottom of PC pressed against bottom of the flat phantom	0 cm	< 0.02*	< 0.02*	< 0.02*	< 0.02*
Configuration 2 – "Edge-on" placement; edge of the PC at 90° and at a distance of 2.5 cm from the base of the phantom (see Fig. 6)	2.5 cm	0.172	0.257	0.229	0.177
Configuration 3 – "End-on" placement; top cover parallel and at a distance of 2.5 cm from the base of the phantom (see Fig. 7)	2.5 cm	0.416	0.334	0.293	0.325

* Too low to measure, within the noise limit of the SAR measurement system.

a. Top cover closed.

Fig. 1. Photograph of the Agency Series Laptop Computer with built-in Ambit Microsystems 802.11 a/b/g Mini PCI Wireless Antennas.

b. View from bottom side of the laptop computer.

Fig. 1. Photograph of the Agency Series Laptop Computer with built-in Ambit Microsystems 802.11 a/b/g Mini PCI Wireless Antennas.

c. Top cover with screen open.

Fig. 1. Photograph of the Agency Series Laptop Computer with built-in Ambit Microsystems 802.11 a/b/g Mini PCI Wireless Antennas.

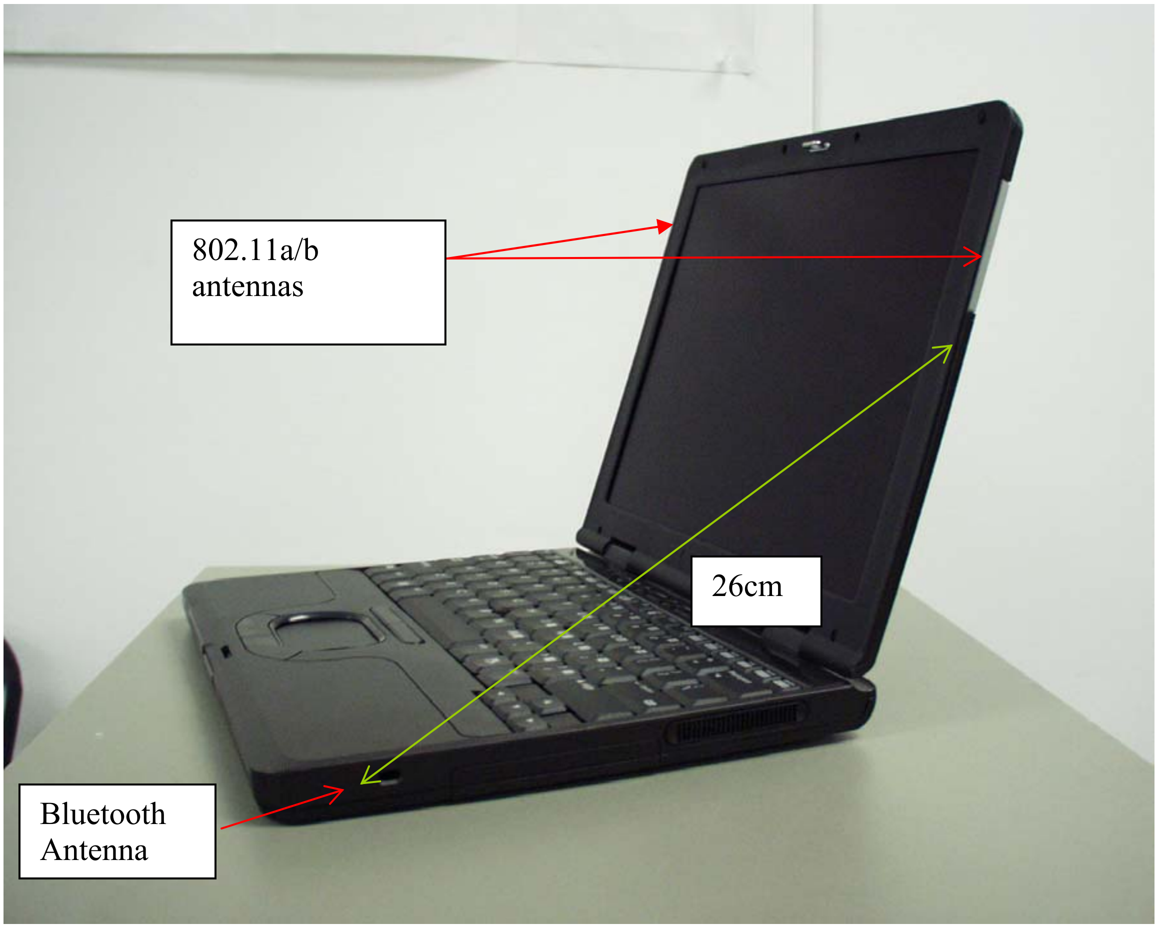


Fig. 2. Photograph of the Agency Series Laptop Computer showing the placement of the Ambit Microsystems 802.11 a/b wireless antennas against the two sides of the lid with the computer screen.

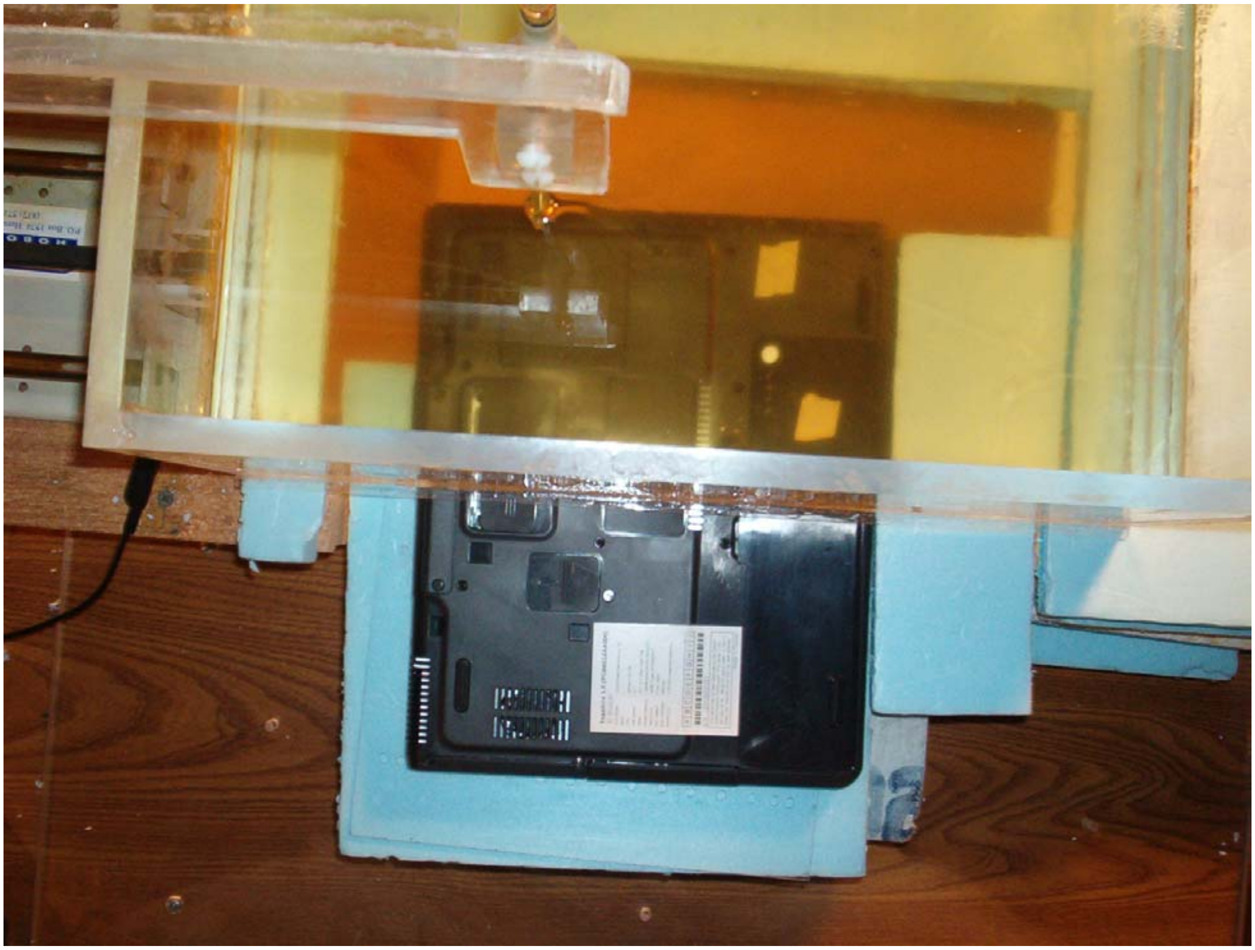


Fig. 3. Photograph of the bottom of Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antennas pressed against the base of the planar phantom. This is **Configuration 1** for SAR testing.

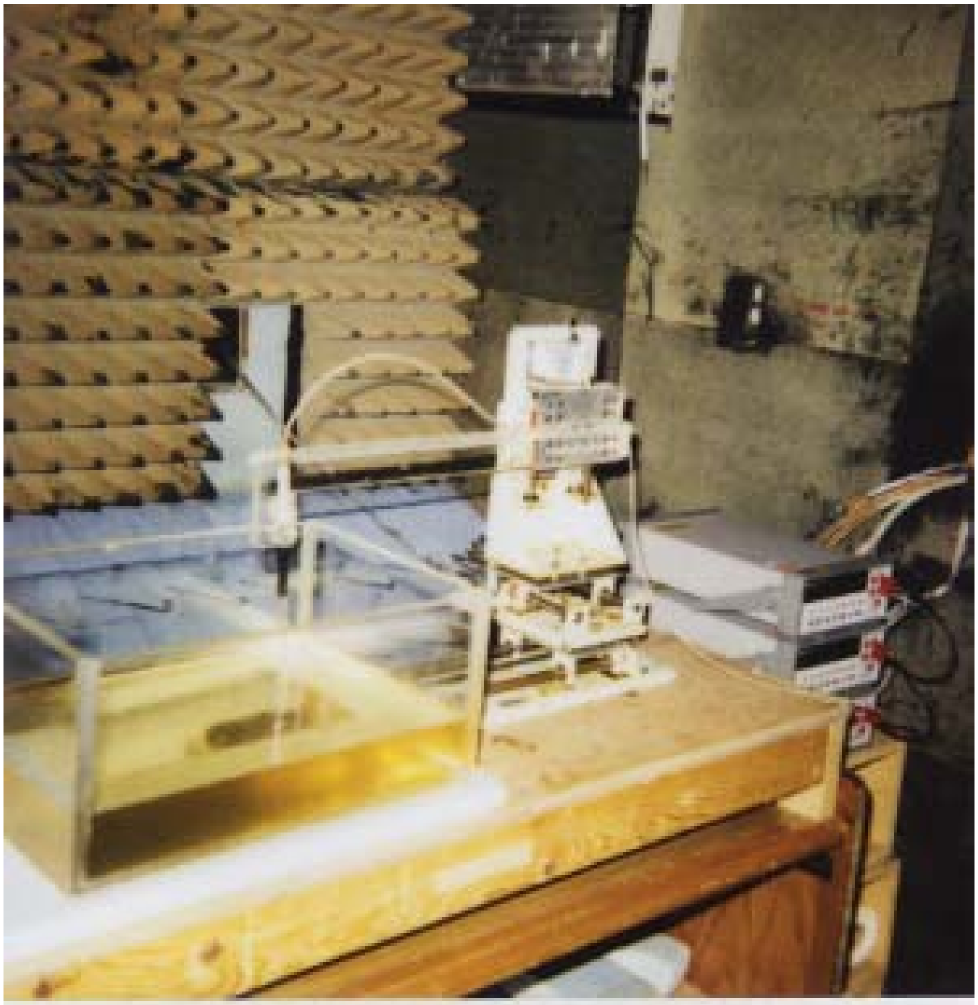


Fig. 4. Photograph of the three-dimensional stepper-motor-controlled SAR measurement system using a planar phantom (see Figs. 3, 6, and 7 for a detailed examination of the placement of Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antennas relative to this phantom).

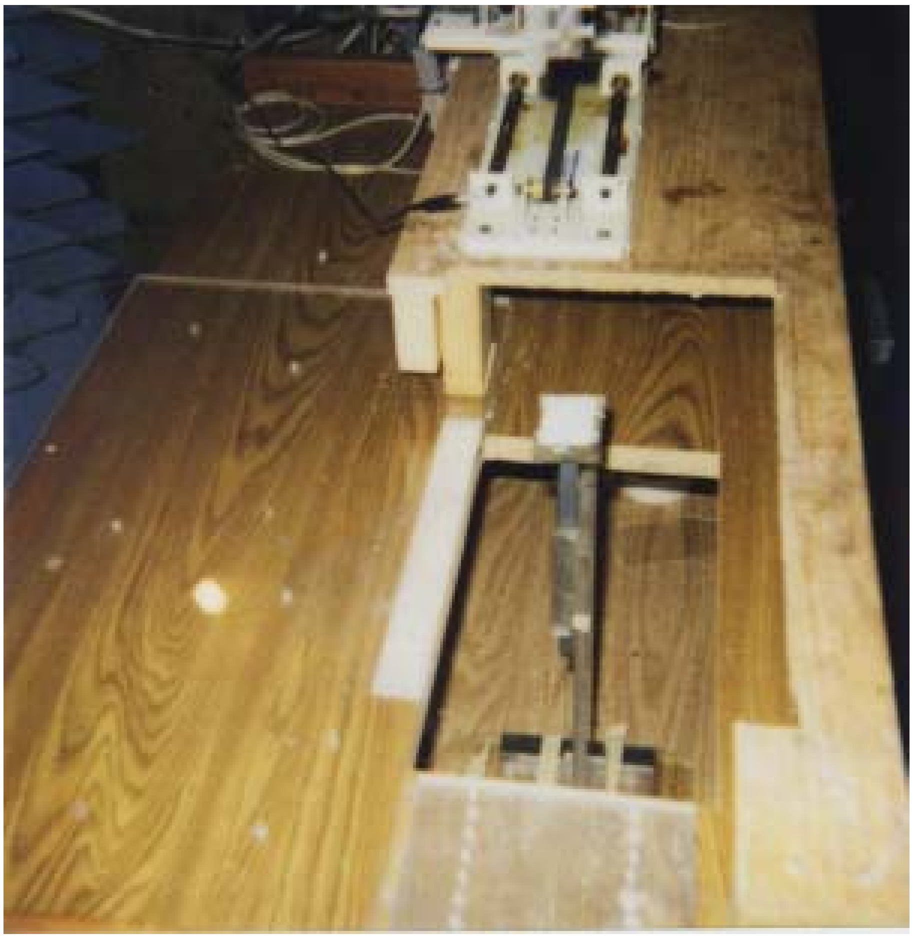


Fig. 5. The plastic holder used to support the portable PC with the Ambit 802.11a Wireless Antenna (shown in Figs. 1, 2).

Fig. 6. Photograph of Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antenna with edge of the PC at 90° and at a distance of 2.5 cm from the base of the planar phantom. This is **Configuration 2** for SAR testing and represents the case of a bystander at a distance of 2.5 cm from the side of the laptop computer. Note that left and right side 802.11a antennas are identical and the left side 802.11a antenna is used for SAR measurements.

Fig. 7. Photograph of the Agency Series PP2170 Laptop Computer with Ambit Microsystems 802.11a Wireless Antenna with top cover closed and placed parallel to the bottom of the phantom at a distance of 2.5 cm. This is **Configuration 3** for SAR testing and represents the case of a bystander at a distance of 2.5 cm from the back of the cover of the laptop computer. As for Fig. 6, both the right and left side 802.11a antennas are identical and the left side 802.11a antenna is used for SAR measurements.

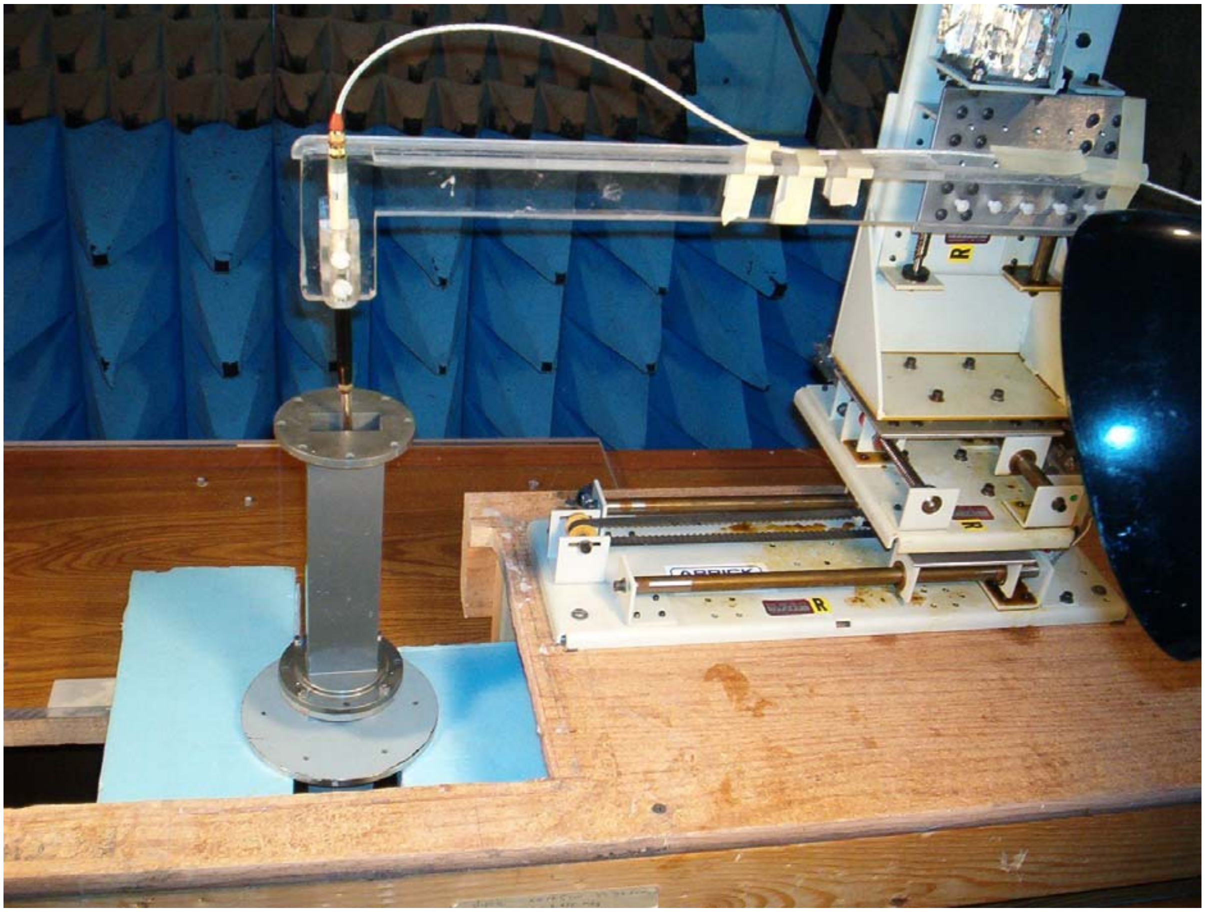


Fig. 8a. A photograph of the waveguide setup used for calibration of the Narda Model 8021 E-field probe in the frequency band 5.2-5.8 GHz.

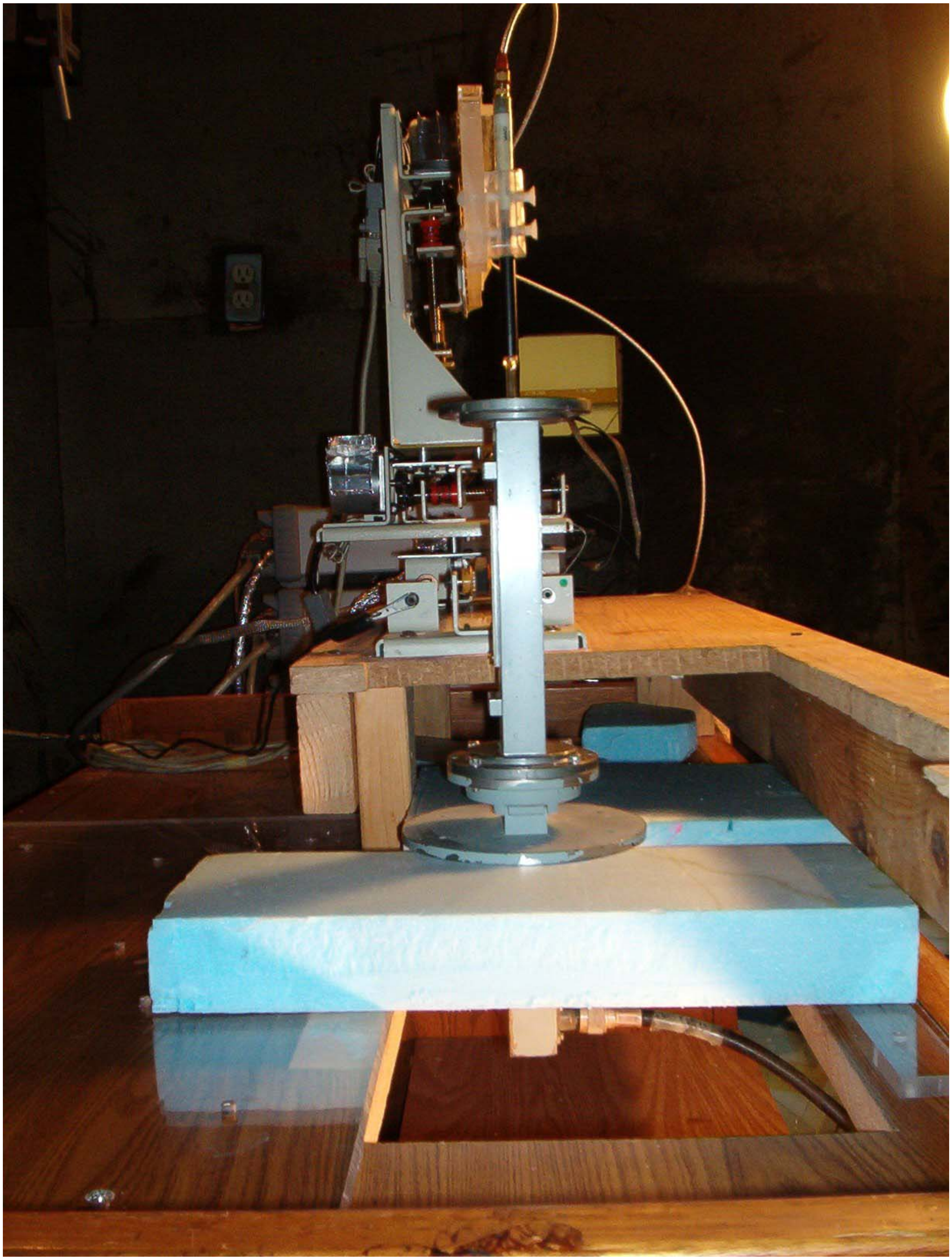
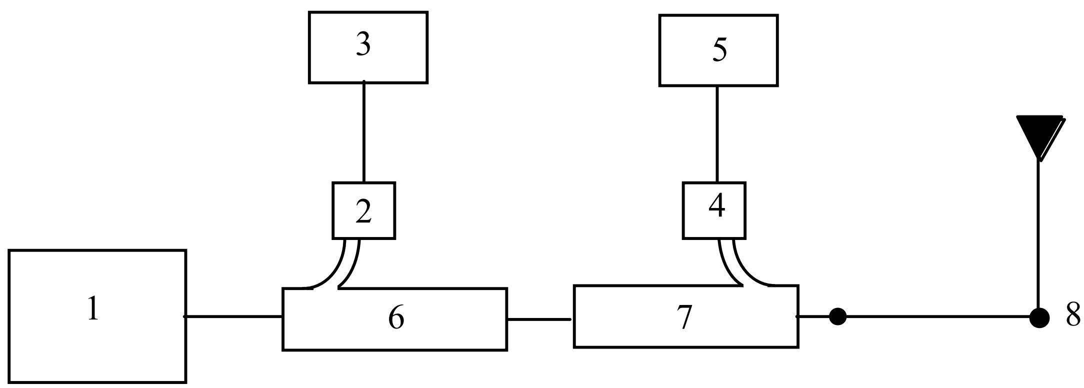


Fig. 8b. Photograph of the waveguide setup showing also the coax to waveguide coupler at the bottom used to feed power to the vertical waveguide containing the tissue-simulant fluid.

Fig. 9. Photograph of the Narda Model 8021 Broadband Electric Field Probe used for SAR measurements.

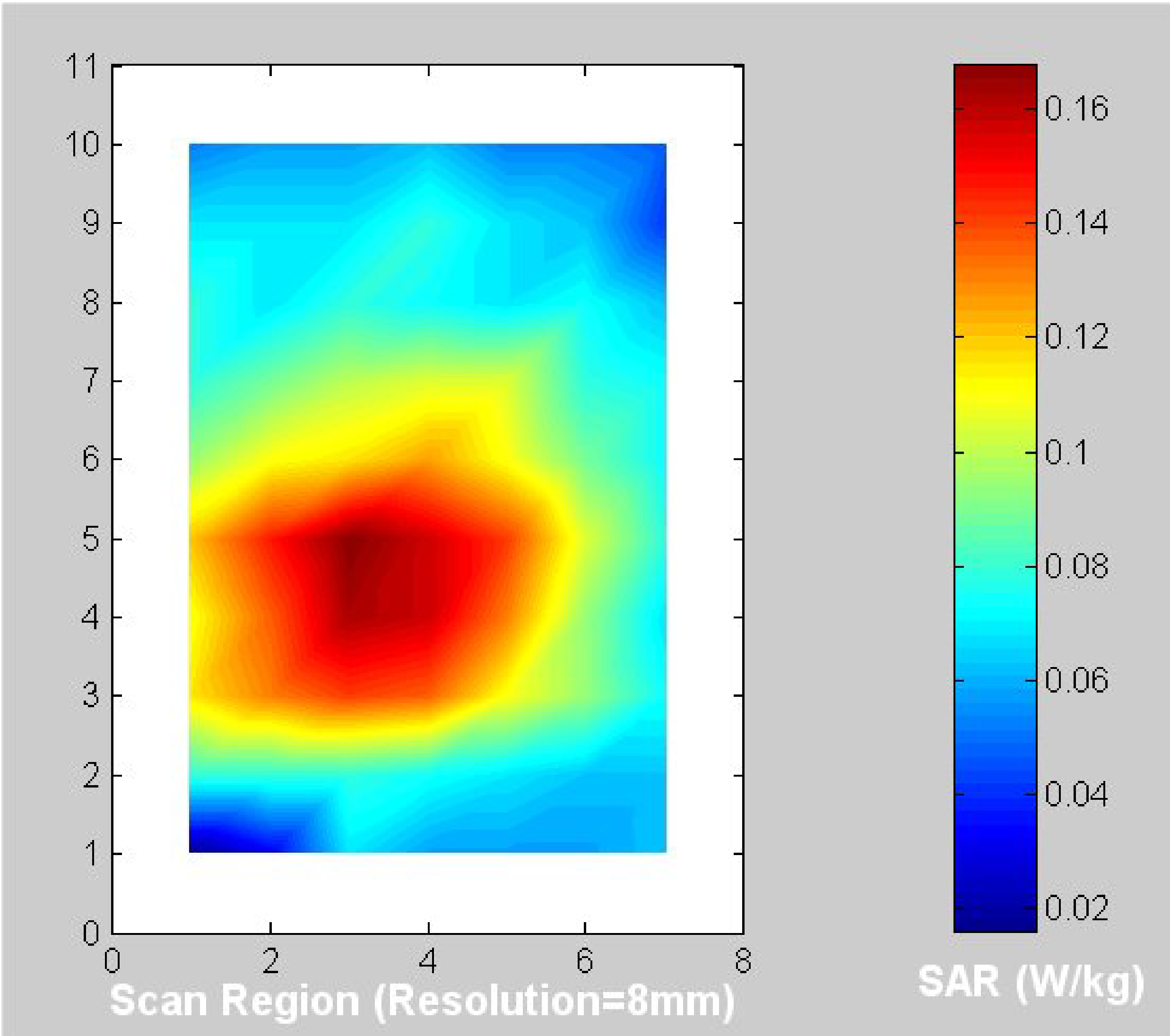
Fig. 10. Photograph of the half-wave dipole at 1900 MHz used for system verification.



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.

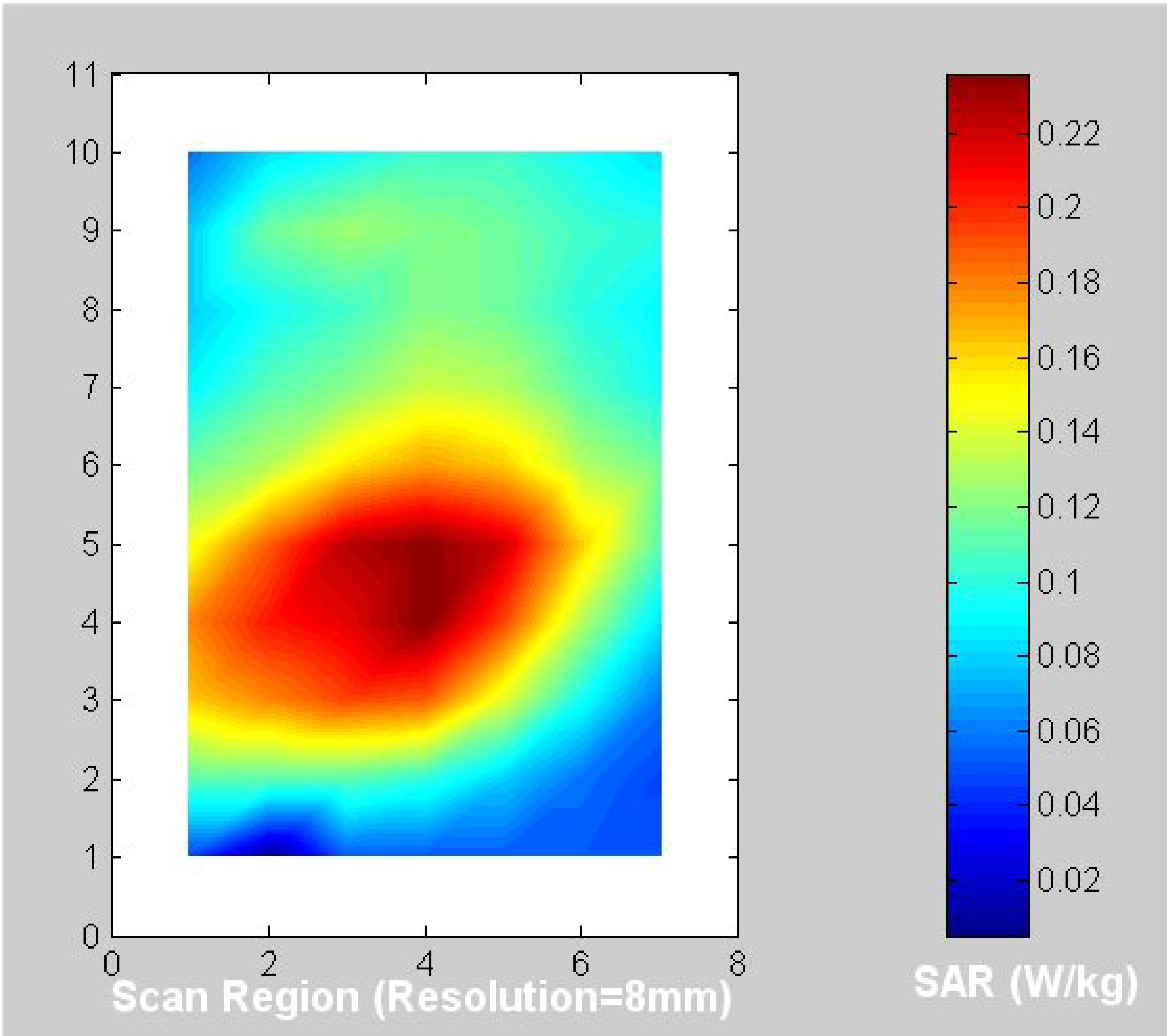
Fig. 11. The microwave circuit arrangement used for SAR system verification.

Fig. 12. Photograph of the Hewlett Packard Model 85070B Dielectric Probe. This is an open-circuited coaxial line probe.



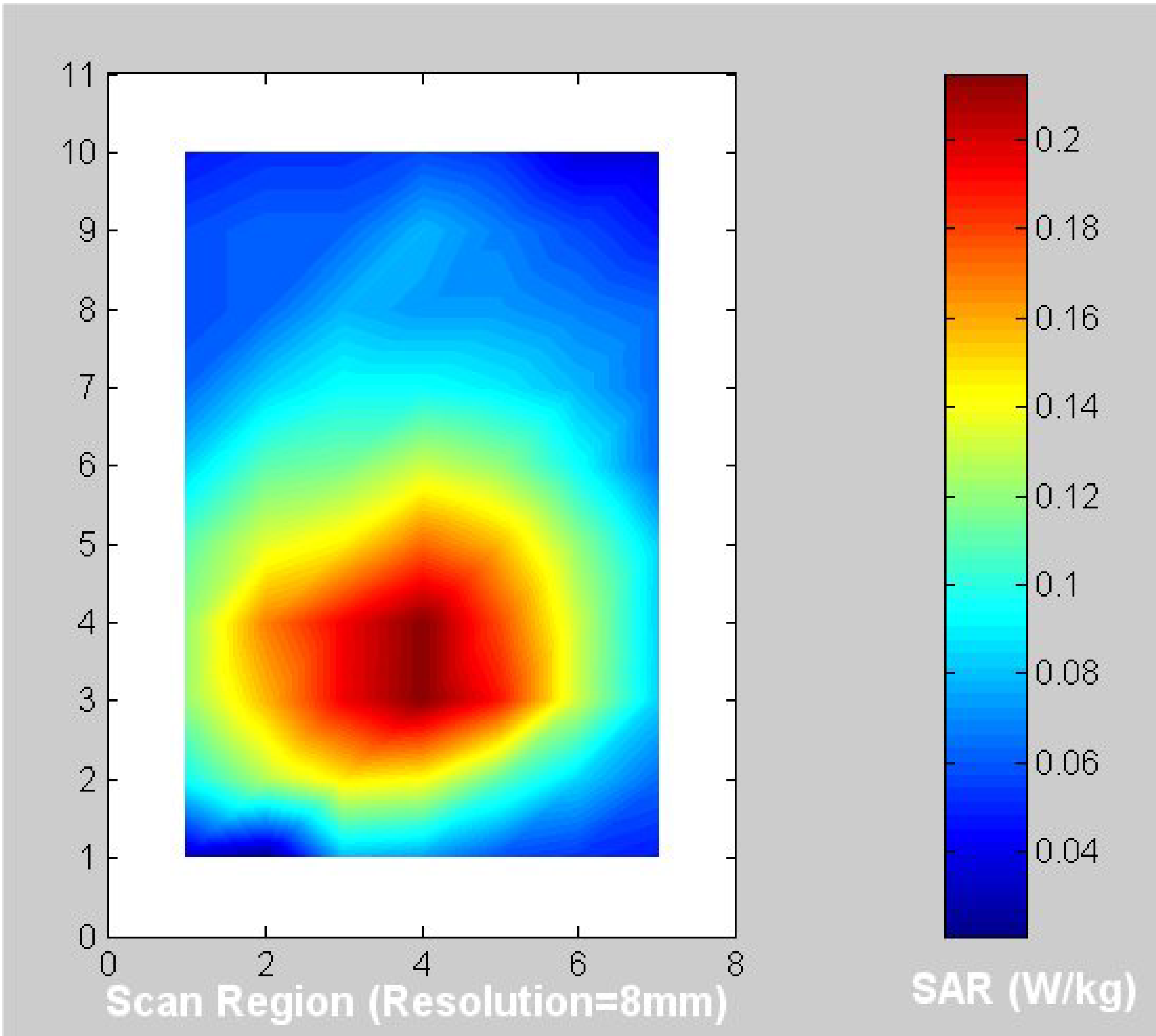
a. 5.26 GHz base mode (see Table 3 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Edge-on** placement of the PC at 90° relative to the flat phantom (**Configuration 2,** see Fig. 6). The edge of the PC screen with the 802.11a Card was placed at a distance of 2.5 cm from the bottom of the flat phantom.



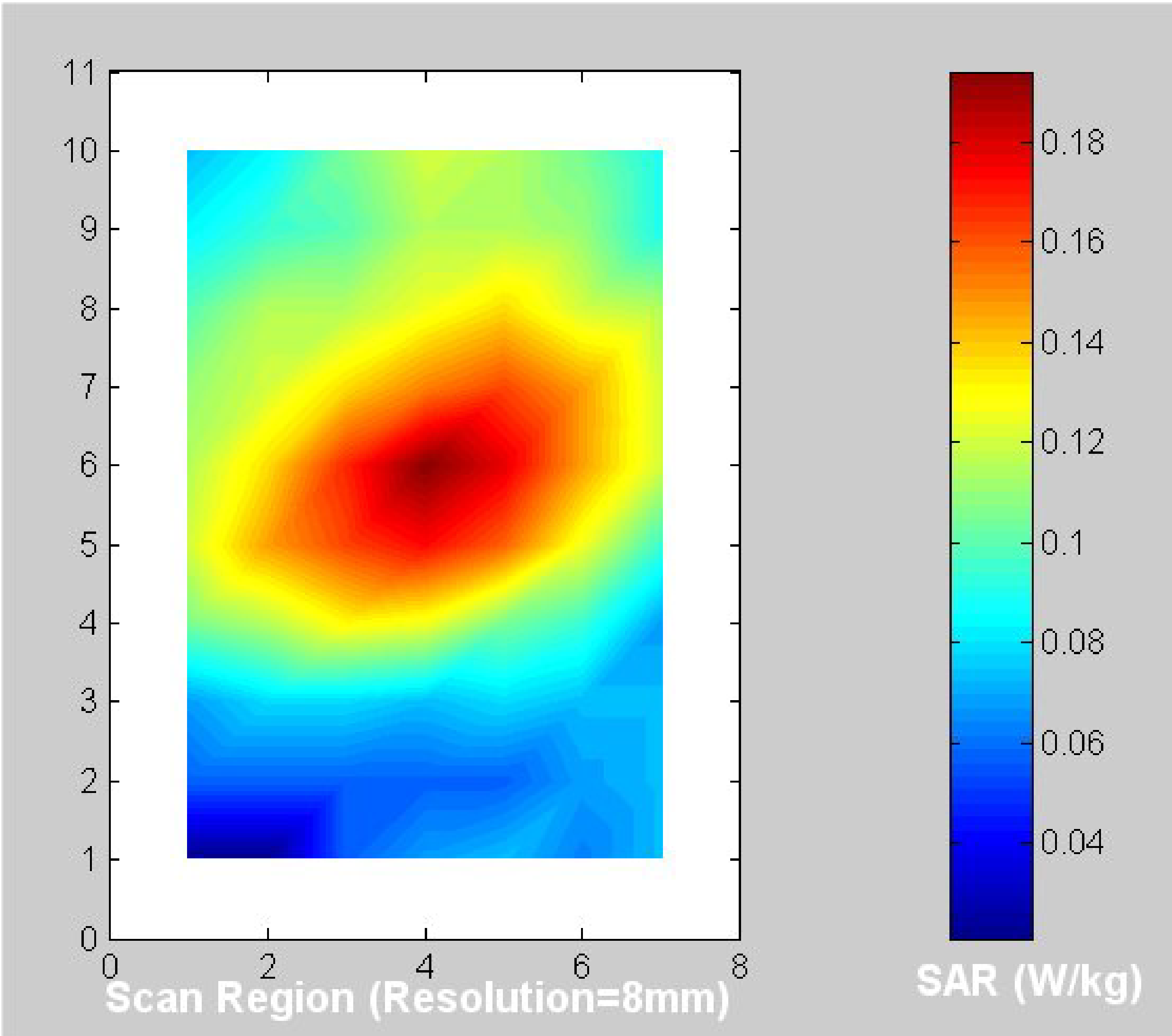
b. 5.785 GHz base mode (see Table 4 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Edge-on** placement of the PC at 90° relative to the flat phantom (**Configuration 2,** see Fig. 6). The edge of the PC screen with the 802.11a Card was placed at a distance of 2.5 cm from the bottom of the flat phantom.



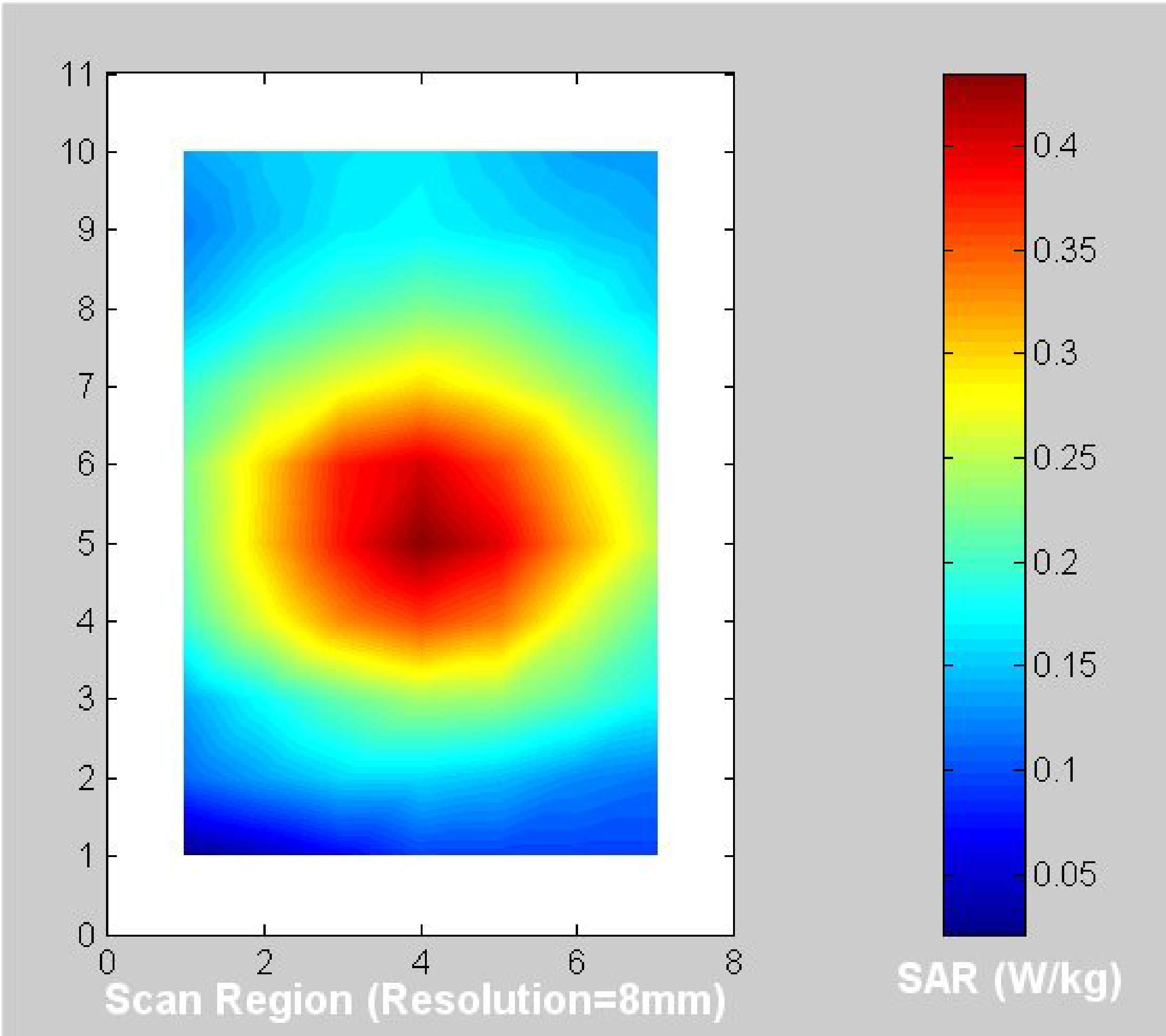
c. 5.25 GHz turbo mode (see Table 5 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Edge-on** placement of the PC at 90° relative to the flat phantom (**Configuration 2,** see Fig. 6). The edge of the PC screen with the 802.11a Card was placed at a distance of 2.5 cm from the bottom of the flat phantom.



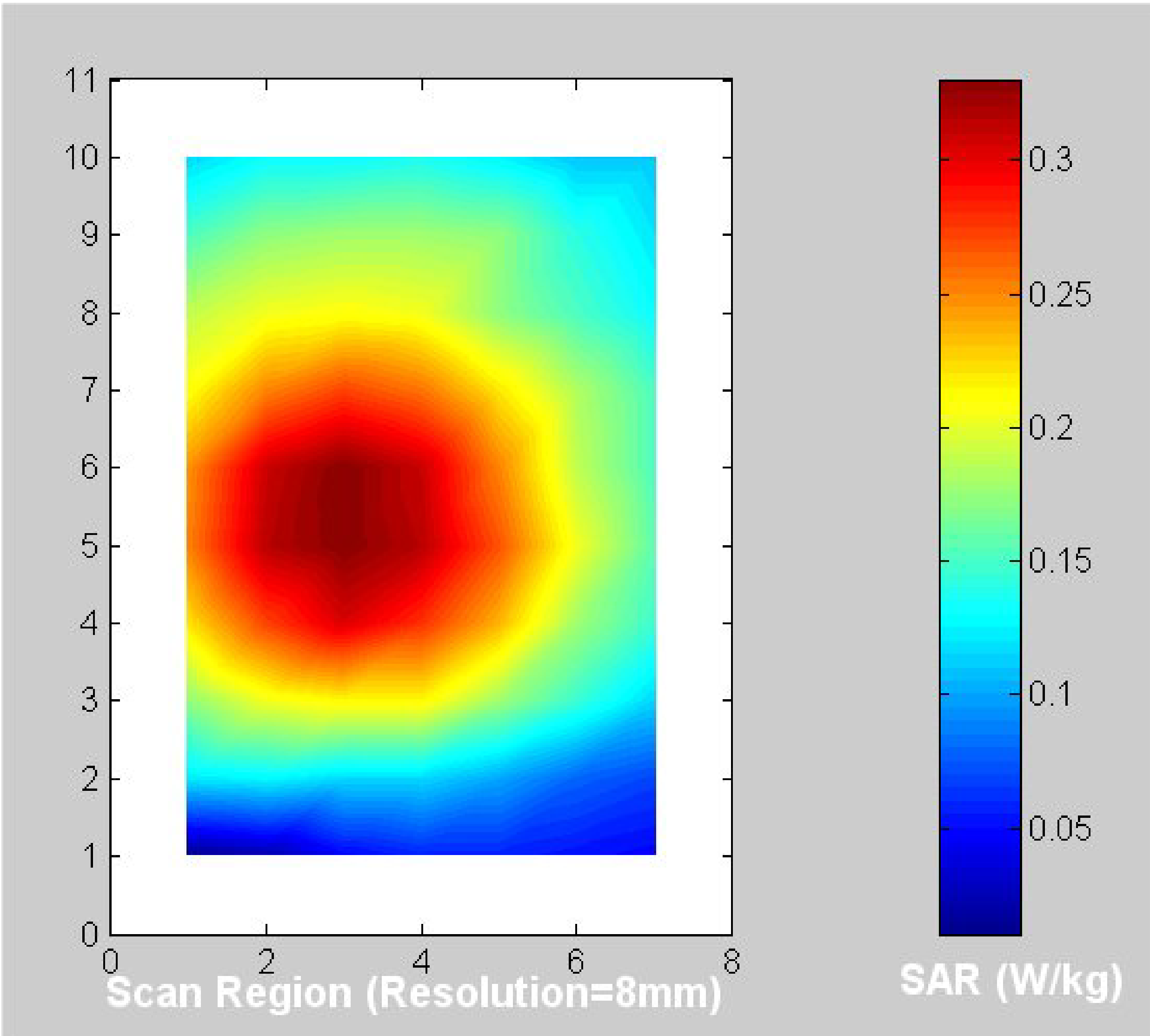
d. 5.80 GHz turbo mode (see Table 6 for the peak 1-g SAR).

Fig. 13. Coarse scans for the SAR measurements for the **Edge-on** placement of the PC at 90° relative to the flat phantom (**Configuration 2,** see Fig. 6). The edge of the PC screen with the 802.11a Card was placed at a distance of 2.5 cm from the bottom of the flat phantom.



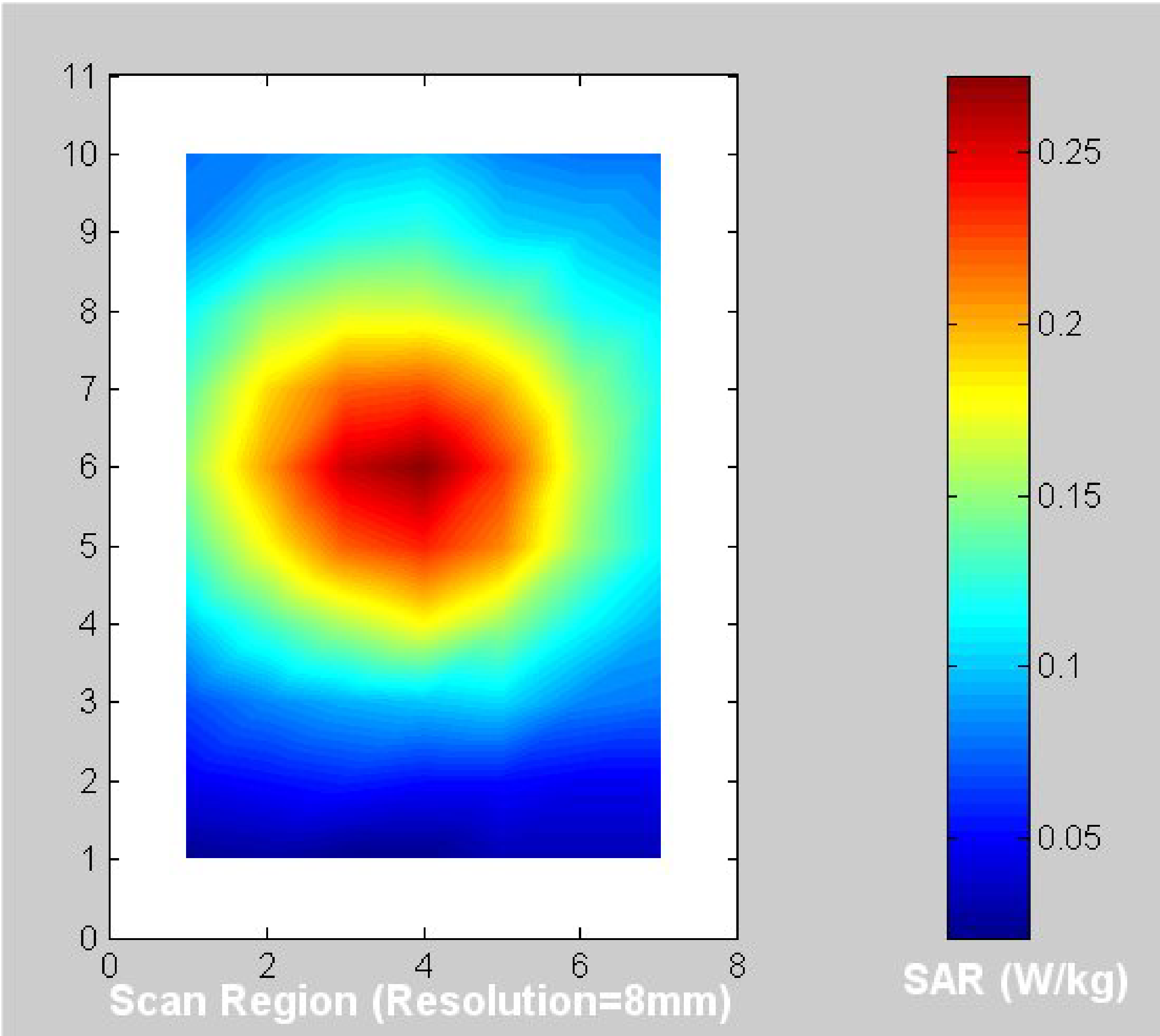
a. 5.26 GHz base mode (see Table 7 for the peak 1-g SAR).

Fig. 14. Coarse scans for the SAR measurements for the **End-on position (Configuration 3,** see Fig. 7**)**. The cover of the PC was placed parallel to the base of the planar phantom at a distance of 2.5 cm.



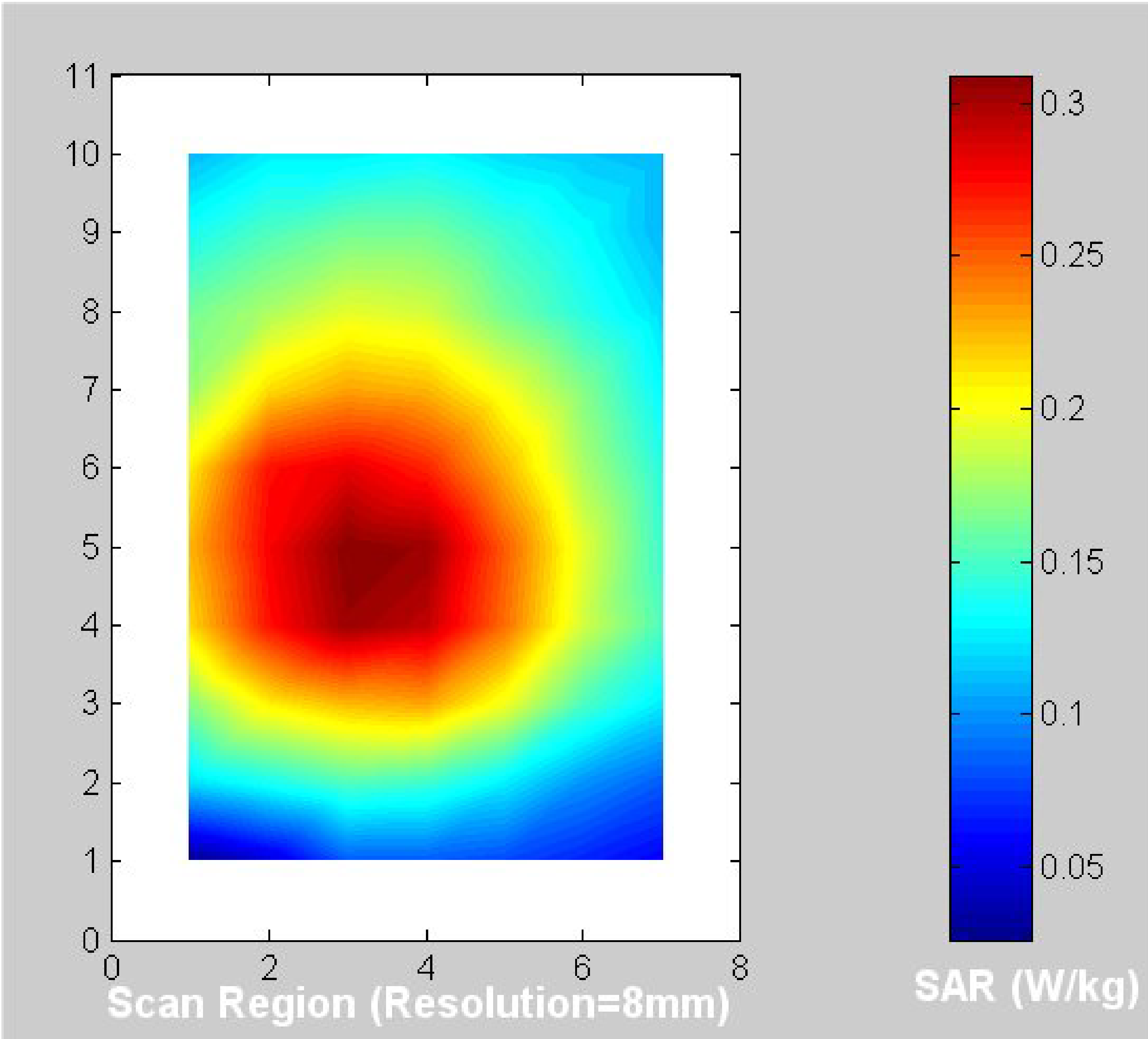
b. 5.785 GHz base mode (see Table 8 for the peak 1-g SAR).

Fig. 14. Coarse scans for the SAR measurements for the **End-on position (Configuration 3,** see Fig. 7**)**. The cover of the PC was placed parallel to the base of the planar phantom at a distance of 2.5 cm.



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

Fig. 14. Coarse scans for the SAR measurements for the **End-on position (Configuration 3,** see Fig. 7**)**. The cover of the PC was placed parallel to the base of the planar phantom at a distance of 2.5 cm.



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

Fig. 14. Coarse scans for the SAR measurements for the **End-on position (Configuration 3,** see Fig. 7**)**. The cover of the PC was placed parallel to the base of the planar phantom at a distance of 2.5 cm.

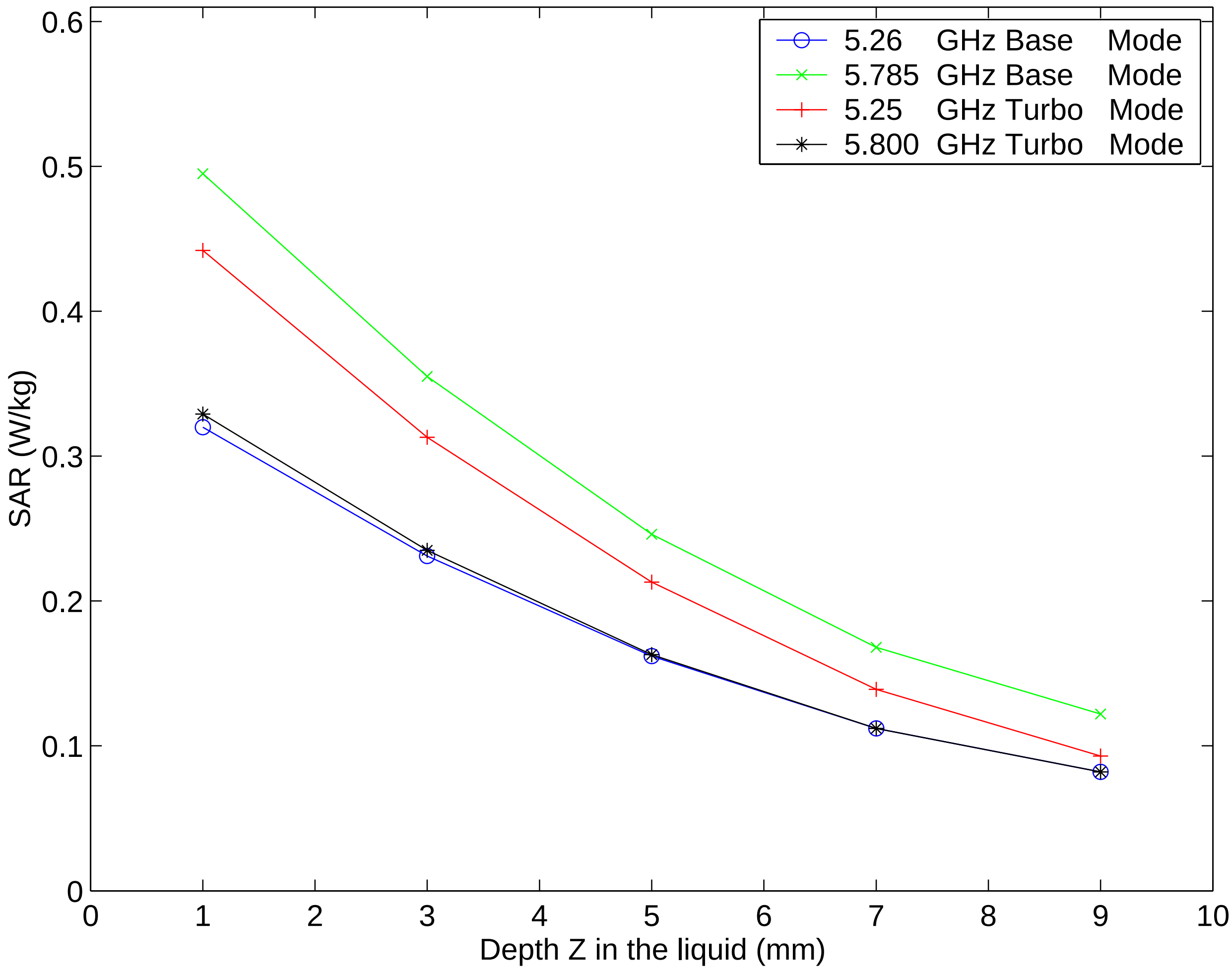


Fig. 15. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 3-6 for **Configuration 2**) for Ambit 802.11a Wireless Antenna built into an Agency Series PP2170 Laptop Computer.

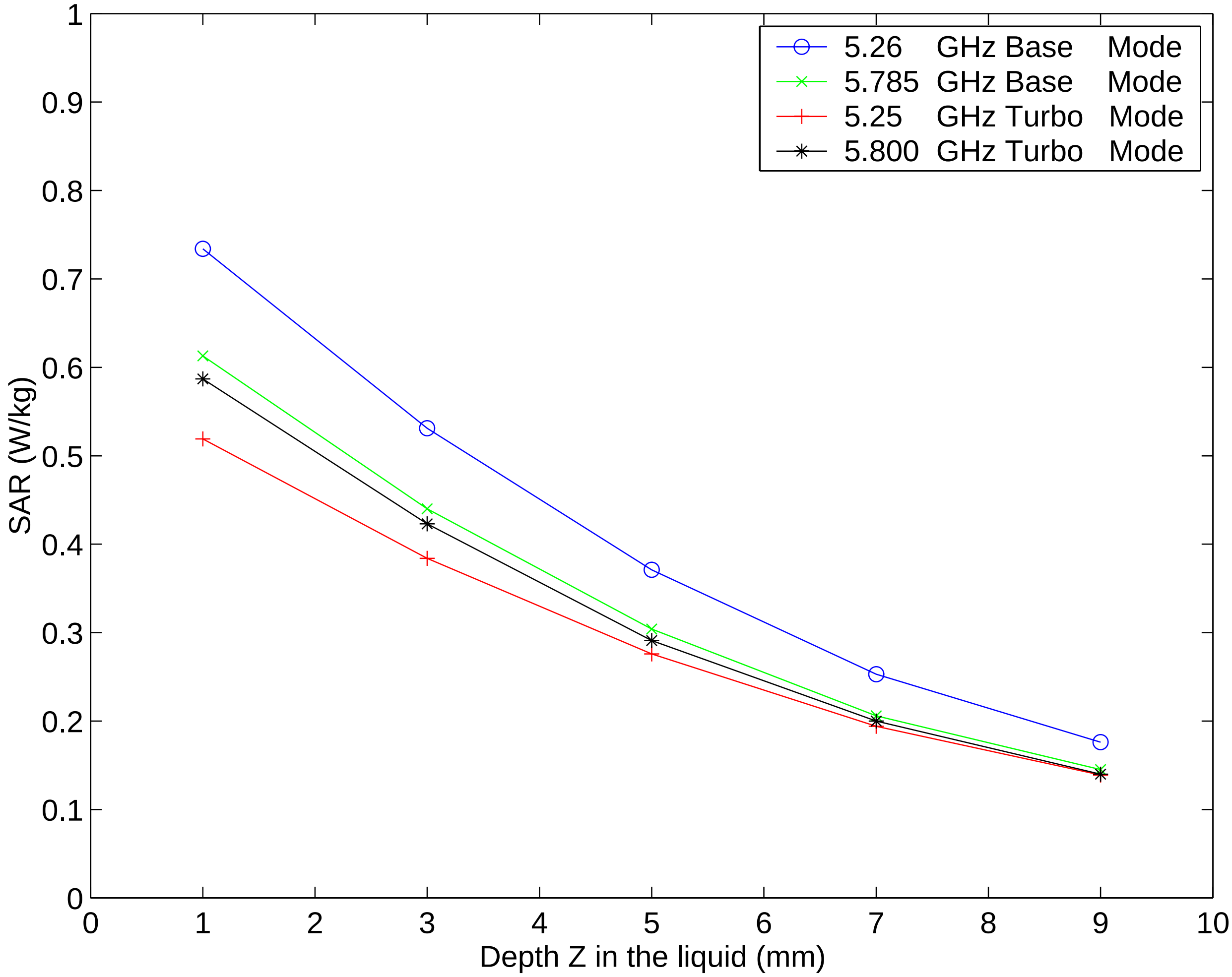


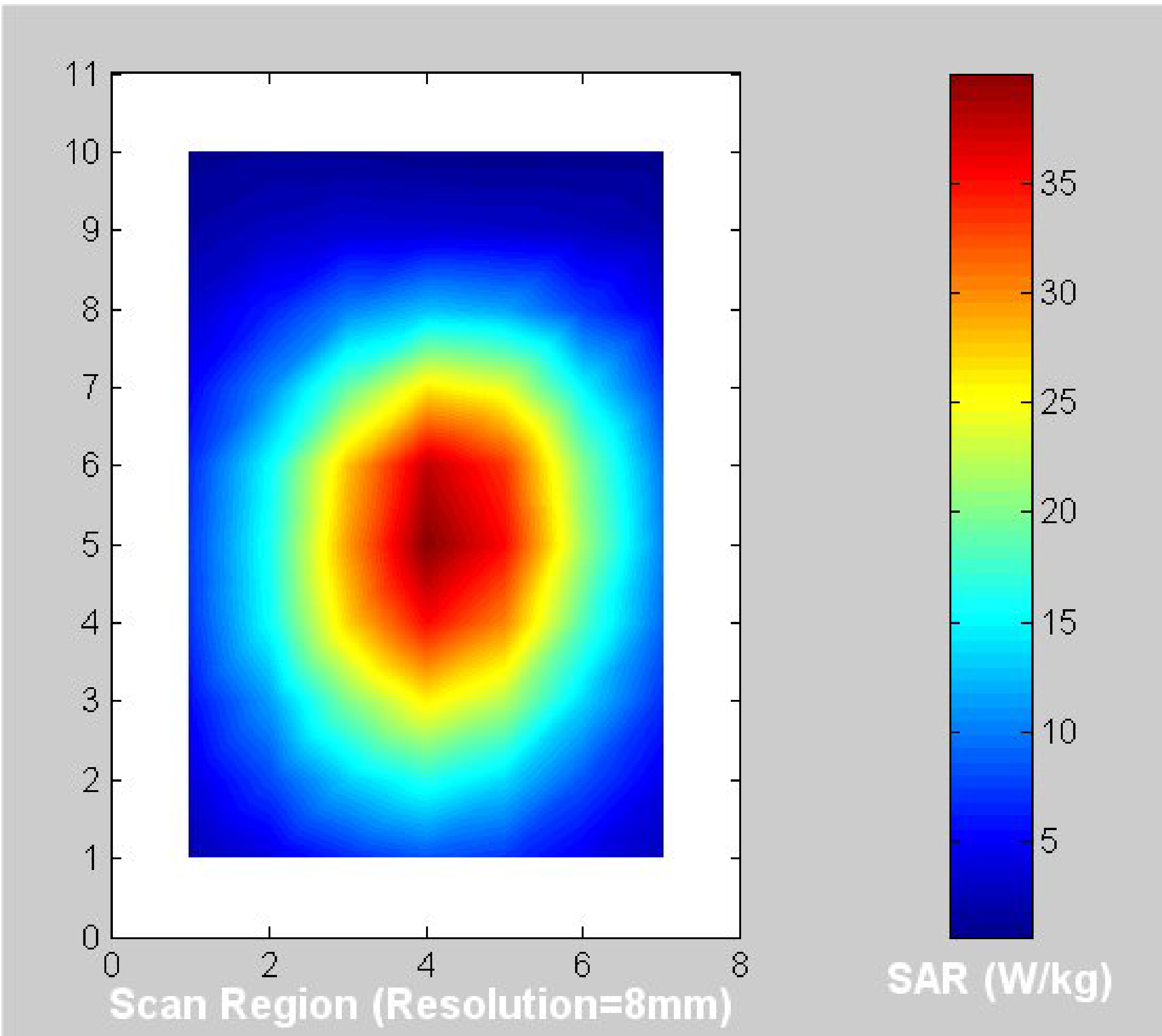
Fig. 16. Plot of the SAR variations as a function of depth Z in the liquid for locations of highest SAR (from Tables 7-10 for **Configuration 3**) for Ambit 802.11a Wireless Antenna built into an Agency Series PP2170 Laptop Computer.

APPENDIX B

SAR System Verification for February 13, 2003

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

For February 13, 2003 - The dipole SAR Plot



1-g SAR = 35.366 W/kg

a. At depth of 1 mm

53.204	55.572	56.397	55.693	53.264
53.869	56.377	57.484	56.890	54.452
53.916	56.528	57.651	57.1391	54.748
53.198	55.800	57.149	56.765	54.561
52.082	54.836	56.043	55.769	53.657

b. At depth of 3 mm

41.874	43.595	44.236	43.751	41.959
42.485	44.296	45.107	44.672	42.907
42.539	44.443	45.288	44.895	43.157
42.004	43.941	44.912	44.631	43.013
41.190	43.167	44.094	43.894	42.343

c. At depth of 5 mm

32.278	33.472	33.954	33.639	32.366
32.834	34.080	34.647	34.337	33.117
32.902	34.224	34.833	34.540	33.328
32.518	33.903	34.568	34.369	33.223
31.946	33.298	33.983	33.841	32.748

d. At depth of 7 mm

24.416	25.203	25.549	25.356	24.485
24.915	25.729	26.105	25.886	25.081
25.004	25.873	26.285	26.074	25.262
24.740	25.688	26.117	25.977	25.192
24.351	25.228	25.708	25.610	24.872

e. At depth of 9 mm

18.288	18.788	19.023	18.903	18.316
18.729	19.243	19.481	19.319	18.801
18.847	19.388	19.647	19.498	18.958
18.670	19.295	19.559	19.456	18.919
18.404	18.958	19.270	19.201	18.716

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