Report

on

Evaluation of Compliance of a Ruggedised Laptop Computer Itronix XC6250 with a SB300 series Wireless Modem,

with the FCC 96-326 Guidelines for Evaluating Environmental Effects of Radiofrequency Radiation

Prepared for:

Sierra Wireless, Inc.

13575 Commerce Parkway

Richmond, B.C.

Canada, V6V-2L1

M.Okoniewski, Ph.D., Assoc. Professor
Dept. of Electrical and Computer Engineering,
University of Calgary

May, 1999

Introduction

This report provides results of a numerical evaluation of the maximum specific absorption rate (SAR) produced in the human tissue by a ruggedised Laptop Computer, series XC6250, with a SB300 series modem, here-upon called a device under test or test device. The evaluation is performed for the worst case configurations of the test device and the user's head with respect to the FCC 96-326 Guidelines. The purpose of the evaluation is to establish compliance with the Federal Communication Commission FCC 96-326 Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation, ET Docket No. 93-62, adopted August 1, 1996. The information submitted shows that even under the worst case conditions the device under test meets FCC requirements, specifically:

- whole-body averaged SAR not exceeding 0.08 W/kg,
- SAR averaged over 1 gram of tissue in the head not exceeding 1.6 W/kg.
- SAR averaged over 10 gram of tissue in the hands not exceeding 4.0 W/kg

The format of the information provided follows the list of technical items for SAR evaluation outlined in Supplement C (Edition 97-01) to OET Bulletin 65 (Edition 97-01).

Test Device Setup and System Uncertainties

General Information

- **FCC ID**: KBCXC6250SB300 (SB300 Integration), KBCXC6250SB320 (SB320 Integration)
- **device category**: portable,
- **RF exposure environment**: uncontrolled,
- **test method:** computation with the finite difference time domain (FDTD) method

- **affirmative statement**: the device under test complies with FCC adopted limits; “*For the device user, under the worst-case realistic exposure condition 1g averaged SAR in the head does not exceed the prescribed value of 1.6 W/kg, 10g averaged SAR in hands does not exceed 4.0 W/kg, and the whole-body average SAR does not exceed 0.008 W/kg for the device user. It is unrealistic to expect that a bystander can place his/her head closer to the antenna than the user, while the device is in use*”.

Antenna Description

- **antenna type**: metal strip in protective dielectric sheath
- **antenna location on device**: top, right-hand side of the screen
- **antenna dimensions: length** metal strip: length 150 mm, width 8.5 mm, thickness 0.3mm; protective sheath length 155 mm, width 10.2 mm, thickness 3mm.
- **antenna configuration**: non-retractable, vertical

Test Signal and Output Power

- **test signal**: CW, no time averaging used, frequency 836MHz
- **output power**: maximum 600 mW (specified by the manufacturer).

Test Position and Conditions

- **head and hands position**: the model of the human head is placed as close to the device screen as judged possible for a shortsighted person, who wants to read the text on the screen. Under normal circumstances, the usual and conformable work position is much further away from the computer screen. The head is slightly tilted, as illustrated in Fig.1. Simplified hands are also included, to test if the SAR in hands does not exceed the prescribed limits. As the device is equipped with a “*touch screen*’ capabilities, test position include one hand touching the screen in the top right corner –

the closest distance between antenna and the hand under normal operation. Note that the presence of the hands results in lower power deposition into the operator's head. The following test configurations were considered:

1. Head only, reflecting worst case scenario for head exposure
2. Hands only, for maximum exposure of the hands – hands flat on the keyboard
3. Hands only, for maximum exposure of the hands; left hand on the keyboard, right hand touching top, right corner of the screen, simulating *touch-screen* operator action (the computer has touch-screen capabilities)
4. Head and hands in position 2
5. Head and hands in position 3

- **device position**: Screen is set to be at normal angle to the body of the computer (keyboard) , which results in the worst case scenario for the antenna. (Usually, the screen is tilted 120 degrees with respect to the keyboard, thus increasing the distance between the antenna and the head);
- **antenna position**: plugged into the computer in a vertical position, connected internally with the radio-modem with a coax cable.

Computation Uncertainty

- **description of computational uncertainties**: there are several potential sources of error. The estimated uncertainty associated with them is summarized below:

Anatomical model of the head; anatomy differences	10 %
Dielectric properties of tissues	5 %
Antenna modeling	3 %
Device modeling	3 %
FDTD: stair-casing, dielectric properties averaging	1 %
SAR averaging	1 %

- **estimated total uncertainty** 12 %

Information for SAR Computation

Basic FDTD Parameter Description

- **Domain size**: (orientation of the coordinates shown in Fig. 1)
  - for the computations without the head: 300 x 250 x 410 mm, not includin PML layers. Cell size 2.5 x 2.5 x 2.5 mm^3, time step 4.77 ps
  - for the computations without the head: 300 x 490 x 410 mm, not including PML layers. Cell size 2.5 x 2.5 x 2.5 mm^3, time step 4.77 ps
- **ABC type**: PML, 7 layers, parabolic, reflection –50dB
- **Source excitation**: CW with 50 Ω resistive Voltage source, applied at the antenna connector
- **Total time steps**: 2800
- **Method used to determine steady state**: the following observation criteria are used: (i) electric field probes are place in tissue close to the expected peak SAR (determined after preliminary run), close to the antenna feed and in a farthest corner of the computational domain; the simulation is stopped, when the field changes are less than 0.2% (in spectral domain). (ii) the antenna input impedance changes are below 2%. Both conditions have to be satisfied to deem the computations valid
- **Special FDTD techniques used**:
  - Conformal metals algorithms used to model exactly the metal parts of the computer and the dipole radius in the benchmark problem (see reference Anderson et al, 1996
  - Conformal dielectric algorithm used to model various tissue of the human head
- **Benchmark of FDTD technique & results**

  To demonstrate validity of our FDTD code, as a benchmark problem we computed the far field radiation pattern and input impedance of a dipole in free space. The dipole length was 17.01 cm, and radius 0.039 cm. The mesh used was dx=dy=0.85cm and dz=0.81 cm. The results obtained for the FDTD were compared with those from the method of moments, the NEC code (the analytical solution is available only for infinitely thin wires). Figure 2 shows the radiation patterns in the yz plane (E plane) at the resonant frequency. The two patterns are indistinguishable. A more critical evaluation can be made using the input impedance, as shown in Fig. 3. At the resonant frequency the error in the radiation resistance is less than 0.5 %.

Tissue Model Description

- **Source of head model**: CT and MRI scans and segmentation performed at Medical School of the Yale University (see reference Zubal et al., 1994), and improved in our laboratory by application of the skin, refinements to the ear correction of smaller model imperfections
- **Head Model resolution**: 1.1 x 1.1 x 1.4 mm down to the lower jaw, and 3.6 mm below the lower jaw. The FDTD code used automatically resamples the model to the required resolution
- **Head Model shape and complexity**: accurate shape for an average male of 1.76 m height and 75 kg mass, over 30 tissue types segmented, extensive visual examination and editing performed to ensure correct anatomical representation, an anatomist medical doctor consulted during improvements at the University of Victoria.
- **Hand model**: A simple model of a hand was used. The hand was modeled as a collection of blocks, varying in height from 10mm (finger tips) to 40mm (wrist), and resembling in shape the hand of the author. The resolution of the model was 5 x 5 x 5 mm. Three tissue types were used: muscle, fat and bone.
- **Tissue types and dielectric properties**: data used in this test are given in Table 1.

Table 1. Dielectric properties of some tissues used in the evaluation, frequency 836 MHz

Tissue	**ε'**	***s* (S/m)**	**ρ(kgm^{-3})**
skin	41.2	0.84	1040
skull	12.5	0.13	1850
spinal cord	32.7	0.56	1040
spine	12.5	0.13	1850
brain - white	39.1	0.57	1030
brain - gray matter	53.0	0.91	1030
jaw bone	12.5	0.13	1850
muscle	56	0.92	1040
parotid gland	57.6	1.24	1050
lacrimal glands	57.6	1.24	1050
spinal canal	68.8	2.38	1010
tongue	55.5	0.91	1050
hard palate	42.9	0.75	1100
nasal septum	35	0.6	1100
fat	11.4	0.10	920
blood	61.5	1.51	1060
CSF	68.8	2.38	1010
eye - sclera	55.5	1.14	1020
eye - humor	55.5	1.14	1010
lens	46.7	0.77	1100
bone marrow	42	0.8	1060
cartilage	42.9	0.75	1100
pituitary gland	57.6	1.24	1070
ear bones	42.9	0.75	1810

- **Benchmark description & results**

To demonstrate our FDTD code performance for modeling of lossy dielectrics and computation of 1g (cube) peak SAR, a benchmark problem is computed that comprises a resonant dipole at a close distance to a glass sphere containing material whose dielectric properties are the same as the brain tissue. The dipole length is 168 mm and the diameter is 3.6 mm. The dipole is separated 5 mm from the glass sphere. The outer sphere diameter is 223 mm and the glass thickness is 5 mm. The dielectric properties are as follows: for glass $\varepsilon_r = 4$ and $\sigma = 0$, and for the brain $\varepsilon_r = 44$ and $\sigma = 0.90$ S/m. The frequency of computations is 840 Mhz. The computational domain used for this benchmark is 260 mm x 247 mm x 247 mm. Domain termination is PML (7, P, - 40dB). Special algorithms used were:

- Graded meshes, used as follows:
  - (i) around the dipole center: $\Delta x = \Delta y = \Delta z = 1$ mm, 5 grids in each direction;
  - (ii) graded mesh with expansion approx. 1:1.25 till $\Delta x = \Delta y = \Delta z = 2$ mm;
  - (iii) constant $\Delta x = \Delta y = \Delta z = 2$ mm maintained for 17 grids;
  - (iv) further mesh expansion with 1:1.25.
- conformal metals algorithm used to model exactly the diameter of the dipoles (see reference Andersen et al., 1996),
- conformal dielectrics algorithm used to model the sphere, and
- automatic computation of mass-averaged SAR algorithm.

Excitation is: Gausian pulse, centered at 0.84 or 1.9 GHz (two separate runs at each frequency), and $\Delta f = 800$ MHz, 50 Ω source; impedance computed from the electric field in the dipole gap and the magnetic fields around the contour centered on the gap with correction for $\Delta t/2$.

Summary results are given in Tables 2 and Fig. 4.

Table 2. Impedance and voxel peak SAR, 1 g SAR and 10 g SAR,
all values normalized to 1 W dipole output power at f=840 MHz.

Impedance(Ω)	SAR (W/kg) per 1 W		
	Voxel (peak)	1 g (peak)	10 g (peak)
48.5 + j 5.75	17.33	12.13	7.6

Test Device Model Description

- The device under test consists of the following main components: main bottom part with keyboard, screen part and battery. The model of the main part consists of the internally metallized dielectric box (dielectric constant 3), with the battery compartment. Batteries are assumed to be metallized. The box is protected using a layer of rubber ($\varepsilon=4$, $\sigma=10^{-7}$). The keyboard keys are modeled as a loss-less dielectric with a dielectric constant of 2 (to account for the combination of air and plastic that actually constitutes the key). The computer screen part is similarly modeled as a metallic box covered with dielectric and protective layer of rubber. The screen is represented by a low loss dielectric having dielectric constant of 7. The screen part, and the main part are connected by a metallized box connector. In the right part of the screen a non-metallized well is created housing the coax line that feeds the antenna. All shapes are maintained close to the actual shapes (minor protrusions and rounded corners were not considered). Special consideration is given to model the metal parts and connections between them accurately, as they may constitute radiating elements in the structure. Figure 1 gives two external views of the device.
- The antenna is modeled as a metal strip covered in dielectric. Actual dimensions are specified and special FDTD algorithms are used to model them in the FDTD grid. 50 Ω resistive voltage source is used to connect the antenna with the feed line.

- The verification of our FDTD modeling is performed by comparing the free space antenna radiation pattern of the device measured by the manufacturer with computed results – Fig. 5.

SAR Computation, Procedures and Results

- **Power level** used for SAR normalization is 0.6 W, as specified by the manufacturer.
- **Test configuration**: Computations are performed with and without the head for the following configurations (as shown in Figs 1):
  1. Head only, reflecting worst case scenario for head exposure
  2. Hands only, for maximum exposure of the hands – hands flat on the keyboard
  3. Hands only, for maximum exposure of the hands; left hand on the keyboard, right hand touching top, right corner of the screen, simulating *touch-screen* operator action (the computer has touch-screen capabilities)
  4. Head and hands in position 2
  5. Head and hands in position 3
- **Computations are performed** for the above configurations. If the head is included in the test, it is tilted to more accurately reflect a real position and centered with respect to the screen. This results in a separation between the screen and the eyes of 25 cm. The neck and torso are not included, as other researchers in their published papers indicated that the error associated with such model is negligible.
- **Time averaging**: not used.
- **Summary of the results** is given in Table 3, showing the peak 1g SAR in the head, peak 10 g SAR in the hands and the body averaged SAR. Additionally the coordinates of the peak SARs and SAR gradients are recorded in the table. The body averaging is done over head and hands mass only (or head or hands only for some configurations). Figure 6a shows the location of the maximum 1g SAR in the head for the test with no hands. The red surfaces correspond to iso-surfaces of SAR of 0.2 W/kg. Maximum

SAR for this configuration -- 0.049 W/kg is within these surfaces. Figure 6b shows the cross-section with the peak 1g SAR. Note that the maximum value of SAR for this configuration is very low. In Figure 7 the configuration without the head is considered. In this test the *touch screen* action of the user is simulated. One hand is resting on the keyboard while the other is touching the screen in the top right corner – in close proximity to the antenna. Figure 7a illustrates the geometry, while Figure 7b shows 10g averaged iso-surfaces of SAR of 0.1 W/kg. Maximum SAR for this configuration, 0.71W/kg is within these surfaces, immediately next to the screen (finger-tips). Large gradients observed correspond to rapid decay of fields with the distance and within lossy media. In Figure 8 the result of the test that involved the head and both hands are illustrated. Red iso-surfaces illustrate the location of 1g averaged SAR within the head –the surface shows SAR of 0.02 W/kg. Green iso-surface depicts 10g averaged SAR of 0.1 W/kg within hands. In Fig 9 shows a cross-section with the peak 1g SAR in the head for the same configuration. It is worth noticing that in all configuration SAR within the head was very low. The presence of hands generally reduces the value of SAR inside the head, as expected. SAR remains well below limits even for the hand touching the screen in the close proximity to the antenna.

Table 3. Summary of the computed results; 836 MHz, 600mW output power

Configuration		**1g (head)**	**10 g (hands)**	**Body average**
Head only	SAR [W/kg]	0.049	-	0.002
	Location [mm]	160 x 200 x 140	-	-
	Gradient [W/kgm]	$-3.1a_x-3.0e_y-3.2a_z$	-	-
No head, hands on the keyboard,	SAR [W/kg]	-	0.17	0.006
	Location [mm]	-	245 x 185 x 70	-
	Gradient [W/kgm]	-	$-14a_x+16e_y-15a_z$	-
No head, left hand on the keyboard, right touching the screen	SAR [W/kg]	-	0.71	0.015
	Location [mm]	-	245 x 185 x 240	-
	Gradient [W/kgm]	-	$35a_z$	-
Head and hands on the keyboard	SAR [W/kg]	0.041	0.25	0.004
	Location [mm]	160 x 200 x 140	245 x 425 x 70	-
	Gradient [W/kgm]	$-3.5a_x-3.6e_y-3.9a_z$	$-22a_x - 22a_z$	-
Head and left hand on the keyboard, right touching the screen	SAR [W/kg]	0.026	0.68	0.01
	Location [mm]	140 x 165 x 235	243 x 428 x 250	-
	Gradient [W/kgm]	$-0.4a_x-0.16e_y$	$-59a_x - 64a_z$	-

- **The location of the peak SAR** is done by an automatic SAR processing algorithm (reference Caputa et all, 1988)
- **SAR 1 (10) gram** averaging procedure is done as follows:

The electric field components in each voxel are interpolated to the voxel center, i. e. the total field used to compute voxel SAR is based on 12 field components. A special algorithm is used to compute 1 g SARs, that is based on a low pass adaptive 3D spatial filter. The filter has a cube shaped mask, that changes its volume via an adoption mechanism responding to changes in the density of tissue. In the design of the filter it is assumed that within one voxel, the mass and absorbed power are uniformly distributed. In general, the cube volume of the required mass comprises a number of full voxels in its core, and fractions of voxels in its outermost layer. For the case of a uniform mesh used, the algorithm to compute the averaged SAR in a SAR sampling point (X in Fig. 10) proceeds as follows:

- A sequence of cubes of increasing size (single voxel, 3 x 3 x 3, 5 x 5 x 5, etc.) is built by adding a layer of voxels to the previous cube until its mass is equal or larger than the required mass. In each expansion step it is verified that at least one voxel with tissue is present on every face of the new layer and that inside the cube the percentage of empty voxels does not exceed a preset value (typically 5%). If this is not satisfied, the SAR is considered indeterminate and the algorithm proceeds to the next SAR sampling point. The last cube in the sequence with a mass less than required is considered the *core* of the sought cubic volume.
- A cubic equation is solved to compute the fraction $f = dx/\Delta x$ of the additional layer that needs to be added to the core in order to obtain the required averaging mass. This equation is $cf^3 + ef^2 + sf - k = 0$, where c is the total mass of 8 corners, e is the total mass of 12 edges, s is the total mass of 6 sides, $f = dx/\Delta x$, and k is the required fraction of the outer layer mass.

- The power of core elements and weighted power contributions of the sides, edges and corners are added using appropriate powers of f as weights. SAR is computed by dividing thus obtained total power by the required mass.

References

1. J. Anderson, M. Okoniewski and S. S. Stuchly, “Practical 3D contour/staircase treatment of metals in FDTD”, *IEEE Microwave & Guided Wave Letters,* Vol 6, No 3, 1966
2. K. Caputa, M. Okoniewski and M. A. Stuchly, “An algorithm for computations fo the power deposition in human tissue”, *IEEE Trans Electromag. Comat*., submitted for publication, 1988
3. A. Taflove, *“Computational Electromagnetics: The Finite-Difference Time-Domain Method”*, Artech House Publications, 1995
4. I. G. Zubal, et al, “Computerized three-dimensional d\segmented human anatomy*”, Med. Phys. Biol*, Vol 21, pp 299-302, 1944

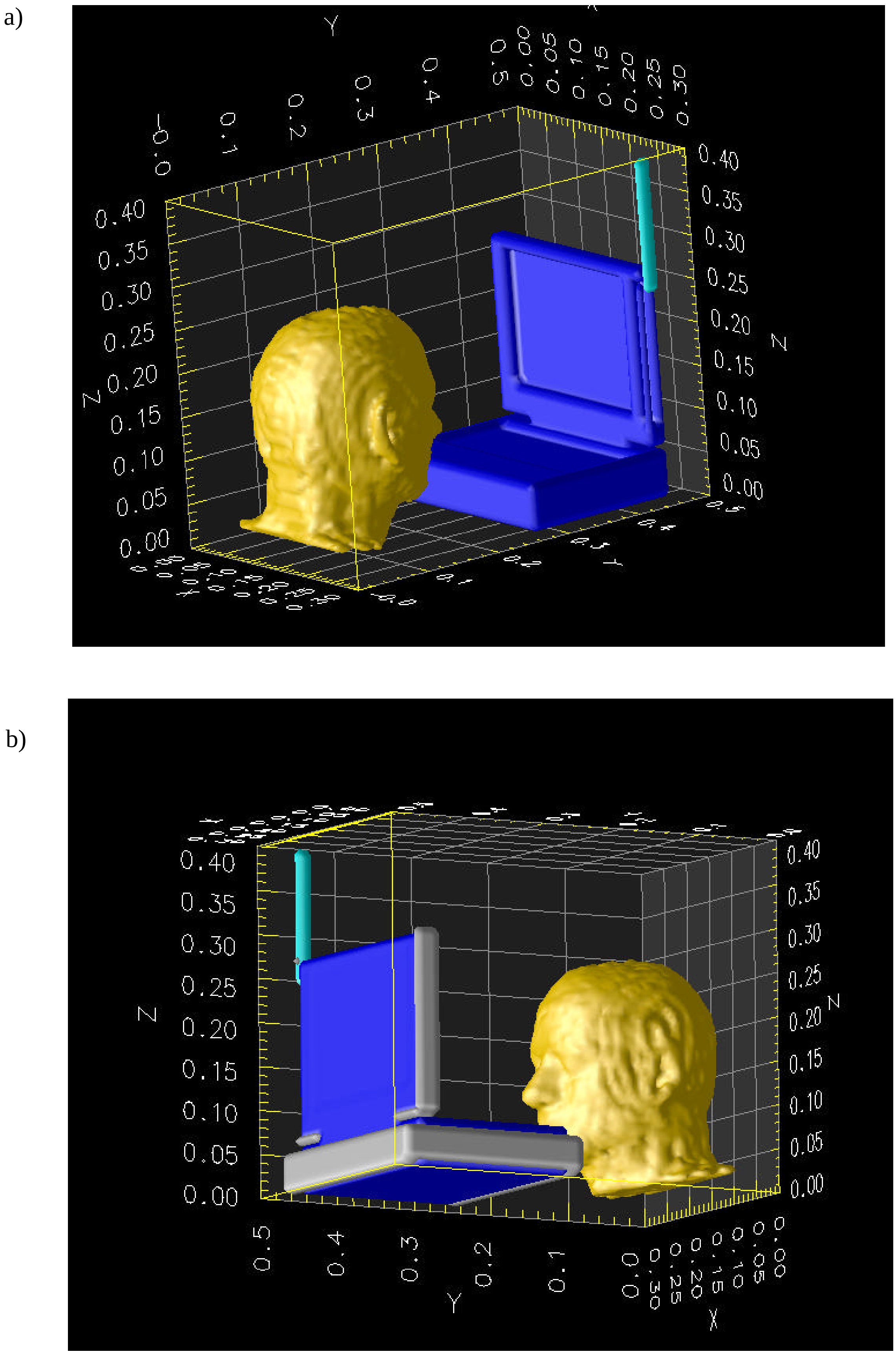

Figure 1 Illustration of the test device and the head model. Note that the models are rendered, thus some distortions of the dimensions occur, most notably antenna. a) metal parts, b) metal parts and protective rubber bumpers

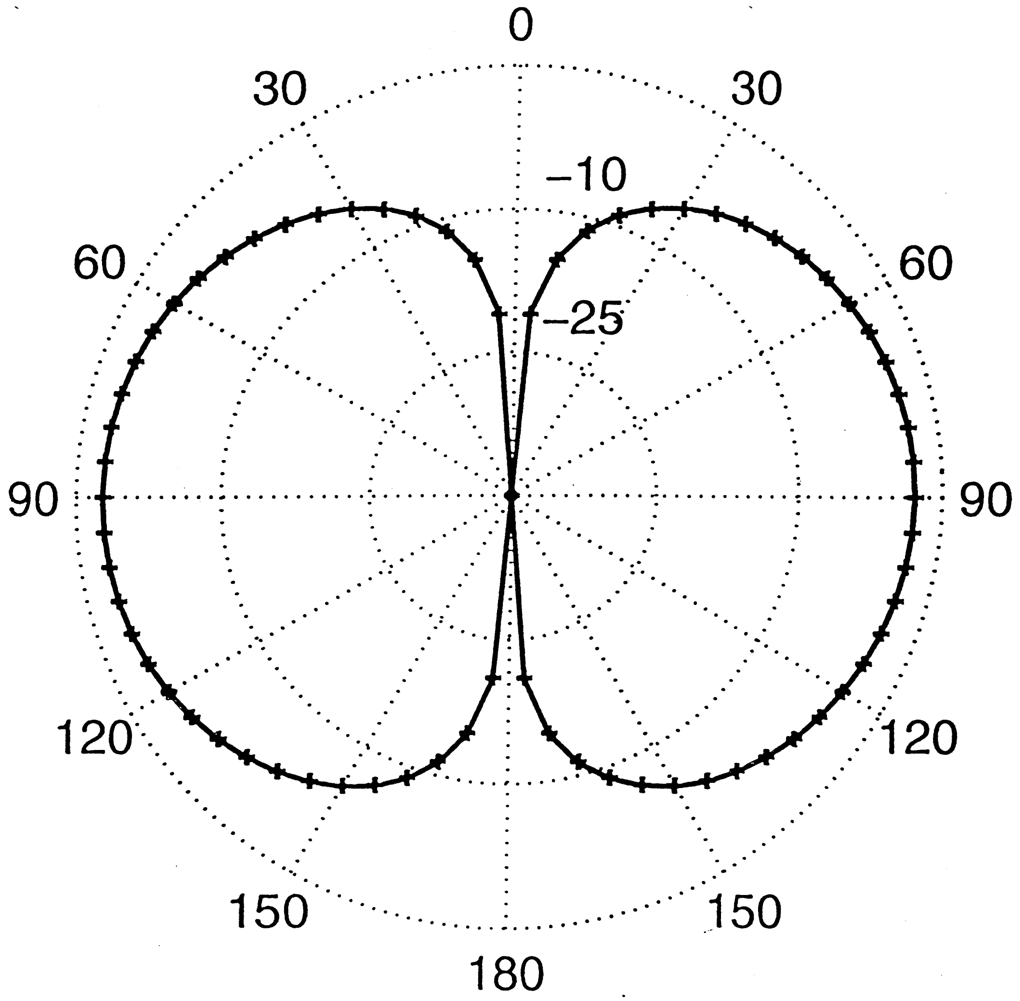

Fig 2. Far-field radiation pattern for a resonant dipole at 836 MHz; solid line - FDTD results, crosses - the NEC results

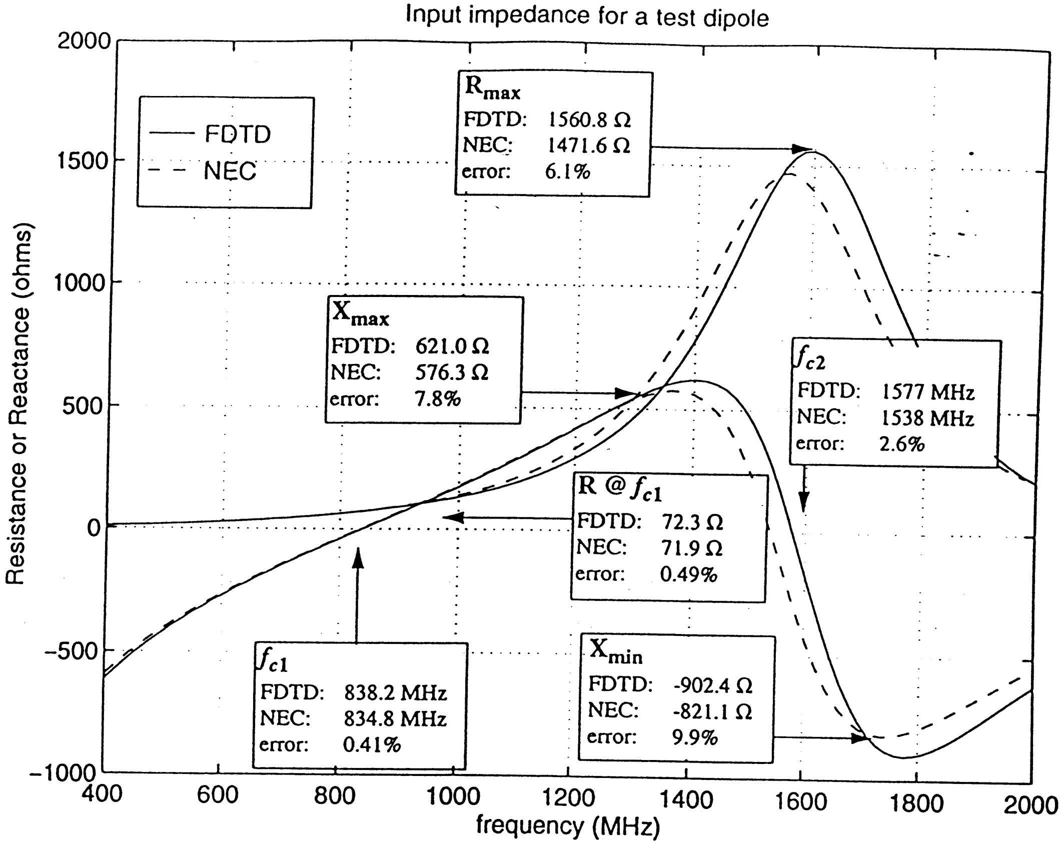

Fig. 3. Input impedance of the test dipole; solid line - FDTD results, dashed line the NEC results.

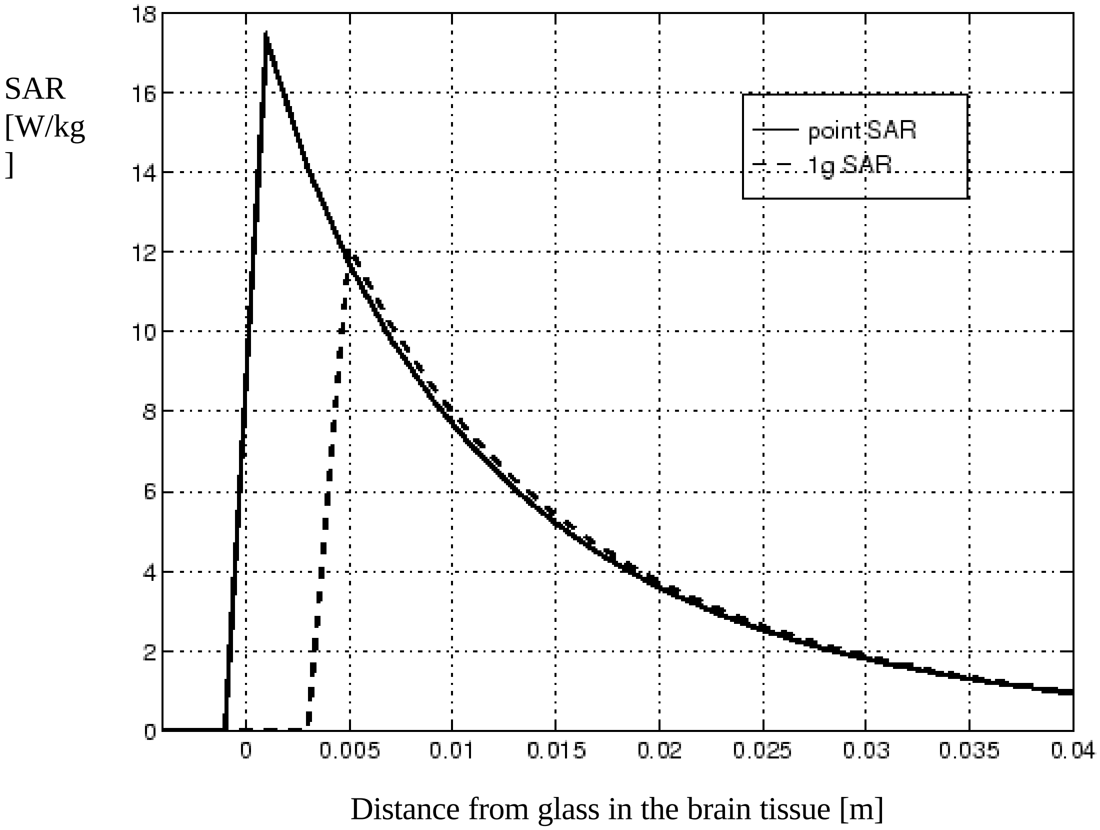

Figure 4. Voxel SAR (solid line), and 1g SAR (dashed line) at 840 MHz, output power of antenna 1W.

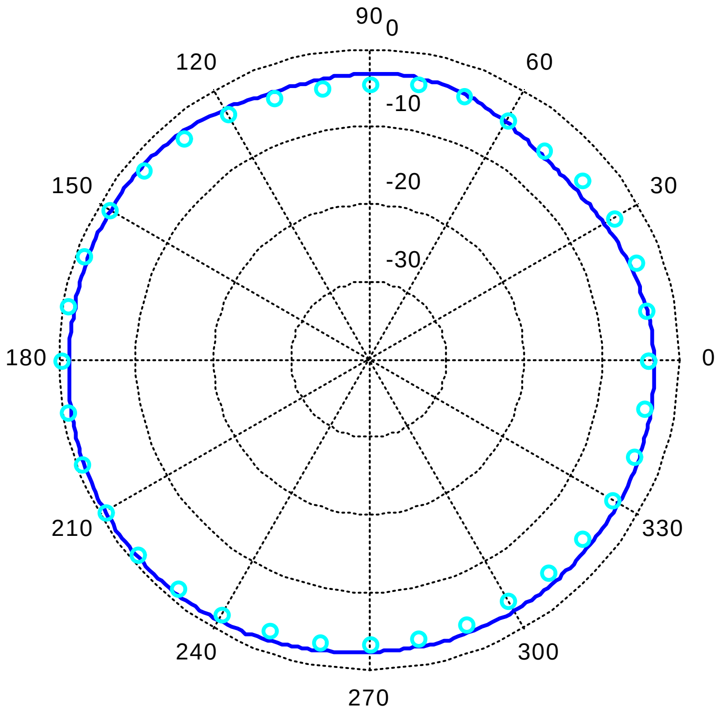

Figure 5. Measured (solid blue line) and simulated (cyan dots) radiation pattern of the device in free space.

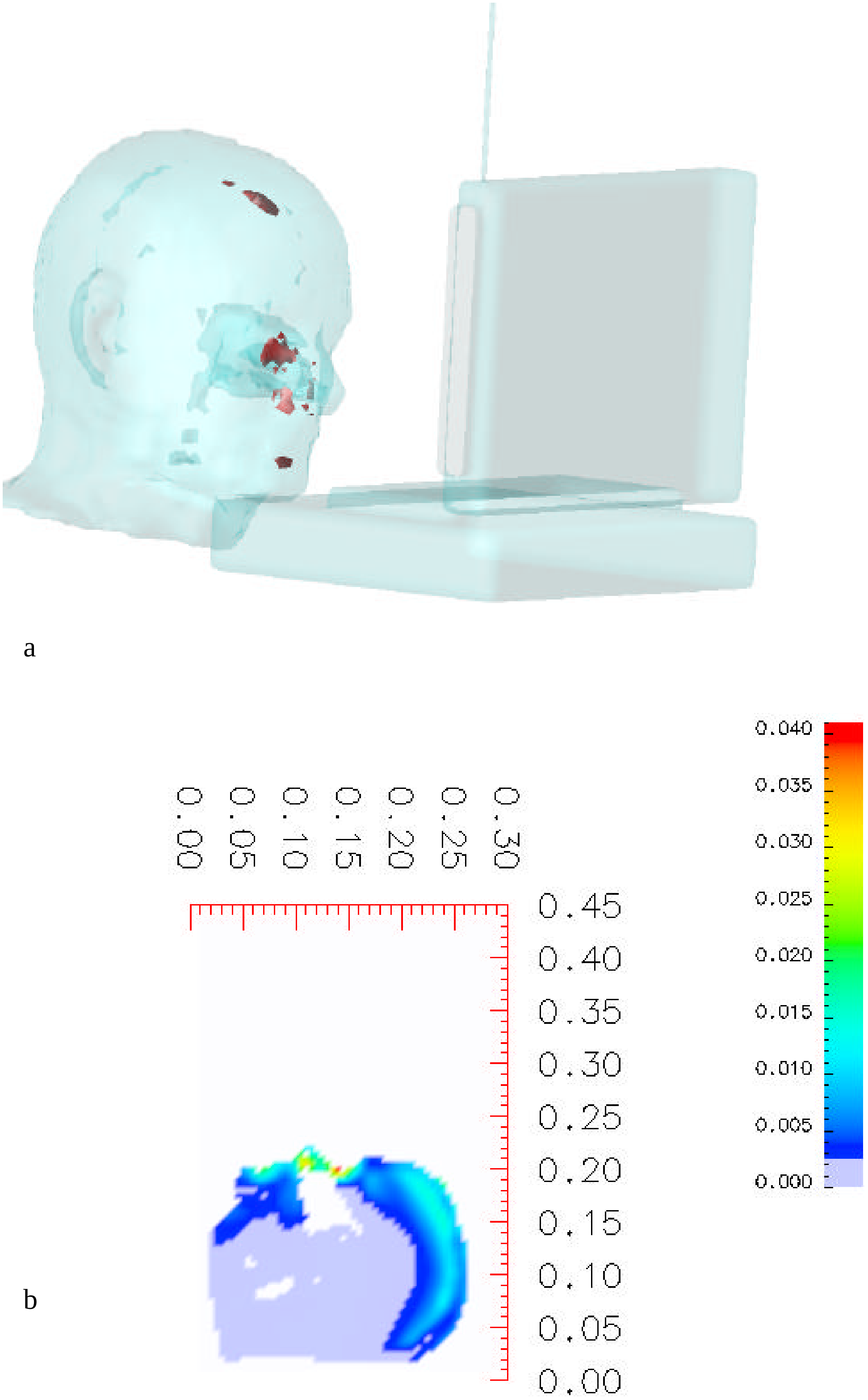

Figure 6. Location of maximum 1g SAR a) 0.2 W/kg isosurfaces. b) cross-section of the head showing zy plane of maximum 1g averaged SAR

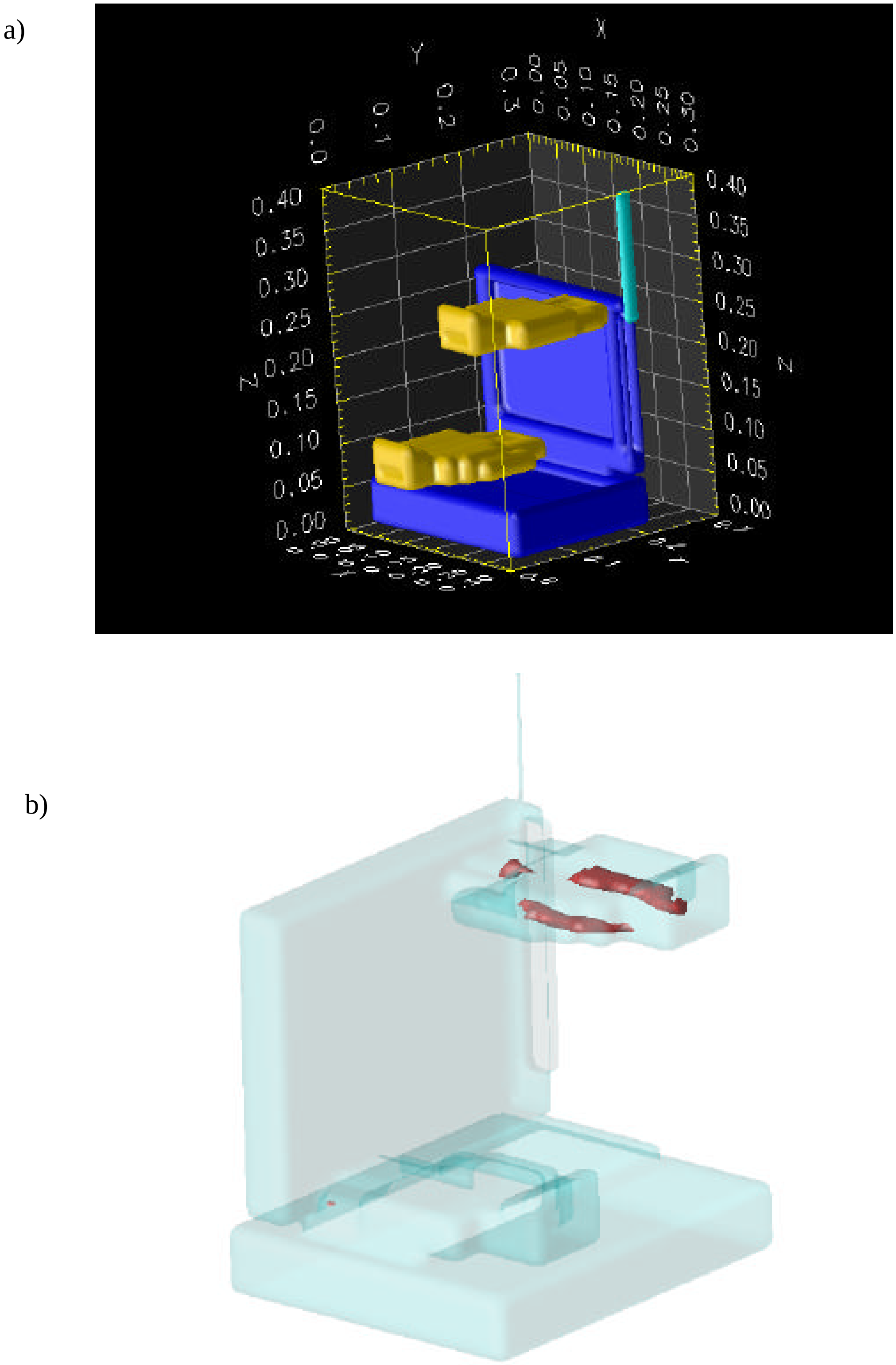

Figure 7. a) geometry of a test with no head, and with one hand on the keyboard and the other touching the screen; b) isosurfaces corresponding to 10g average SAR of 0.1W/kg

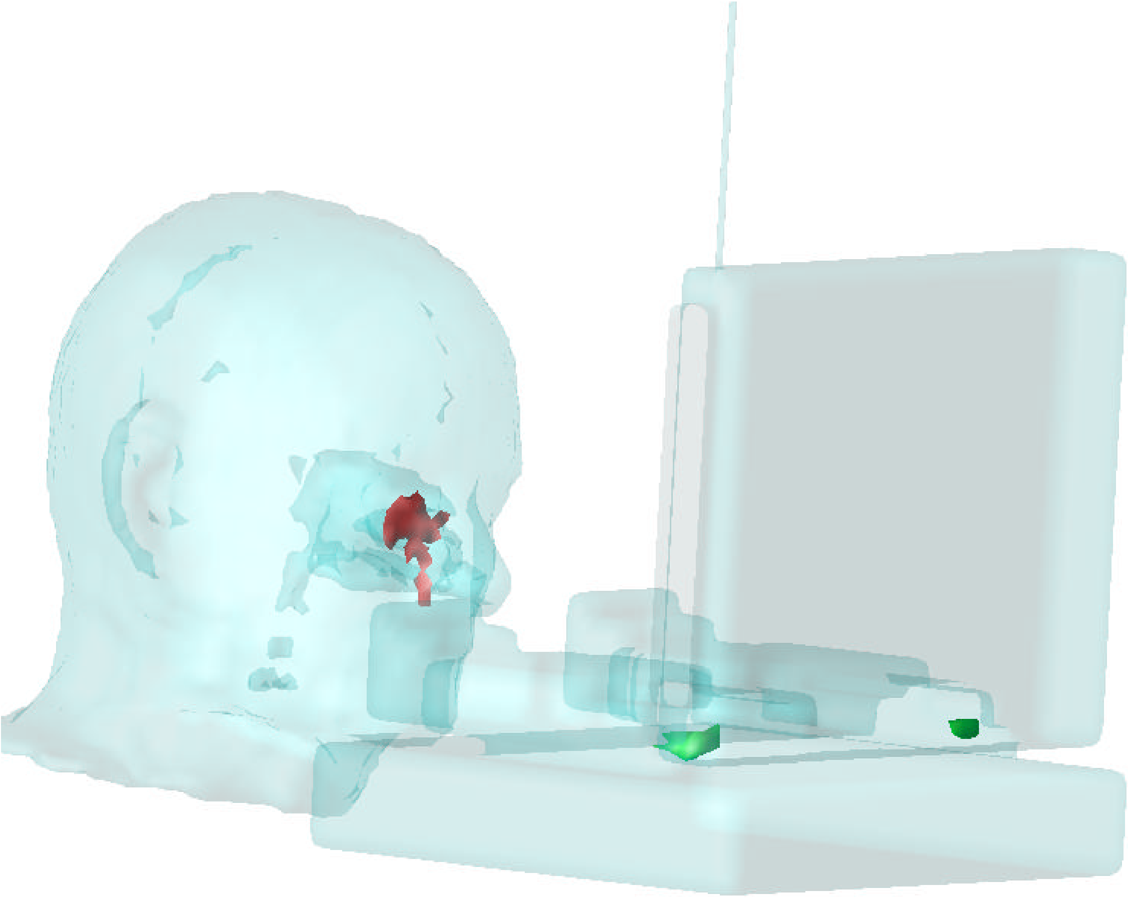

Figure 8. Configuration with head and hands on the keyboard. Red isosurfaces represent 1g averaged SAR of 0.02W/kg inside the head. Green isosurfaces correspond to 0.1 W/kg 10g averaged SAR in the hands.

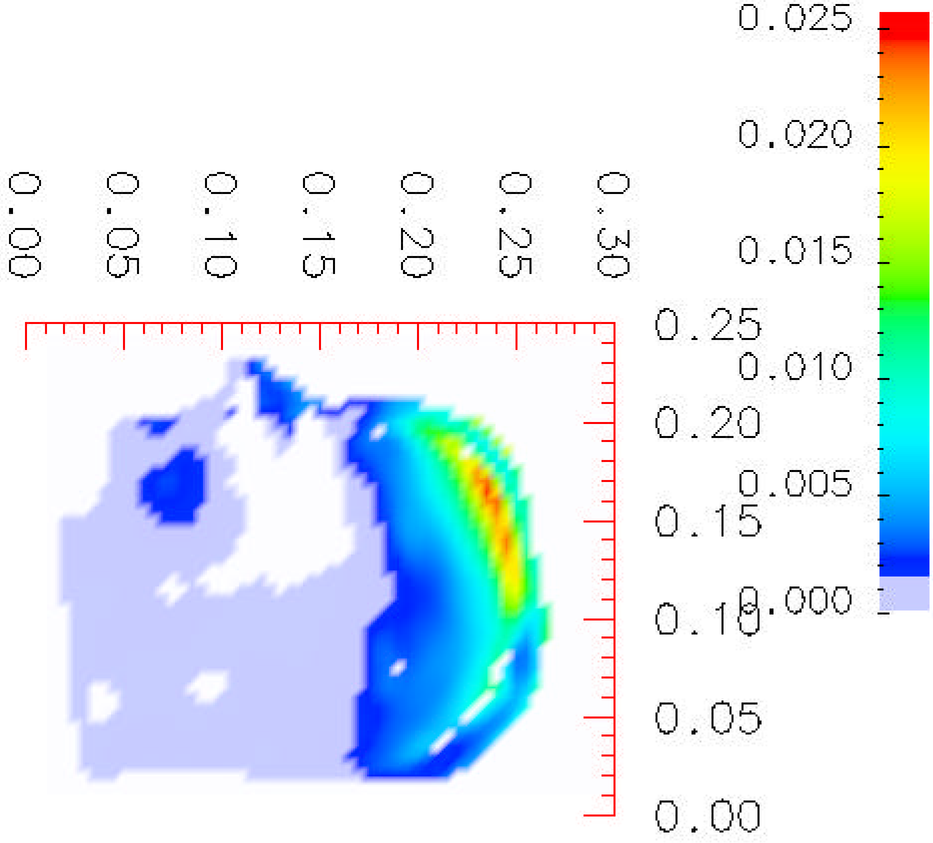

Figure 9. Location of maximum 1g SAR. Cross section of the head showing yz plane of maximum 1g averaged SAR for configuration with left hand on the keyboard and right hand touching the screen.

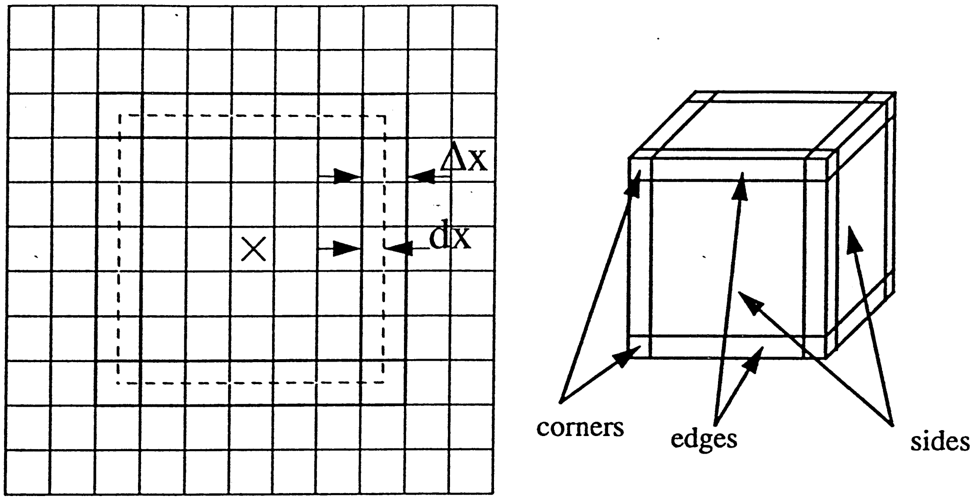

Fig. 10, Mass-averaged SAR algorithm, construction of the core, and the cube of the specifies mass.