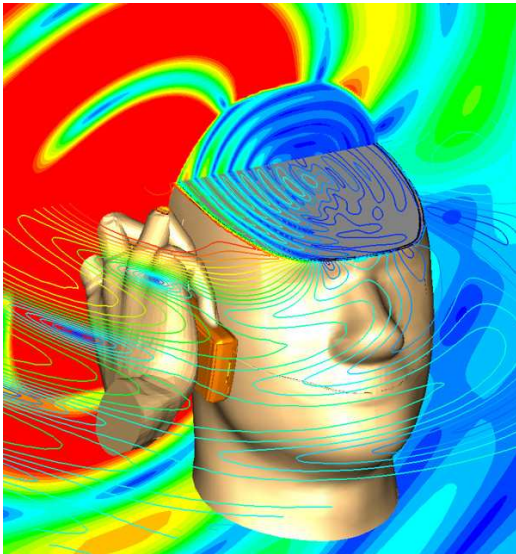


SAR Overview



- Overview
- Definitions & Standards
- SAR in CST MWS
- Tips & Tricks
- Biological Models
- Summary

T. Wittig

Overview and Background

SAR - Specific Absorption Rate

A measure for electromagnetic energy absorbed by biological tissue mass when exposed to radiating device (e.g. mobile phone)

$$SAR = \frac{P}{\rho} = \frac{\sigma E^2}{2\rho} = \frac{J^2}{2\rho\sigma}$$

Unit of SAR: W/kg

P : Power loss density

E : Electric field strength

J : Current density

σ : Conductivity

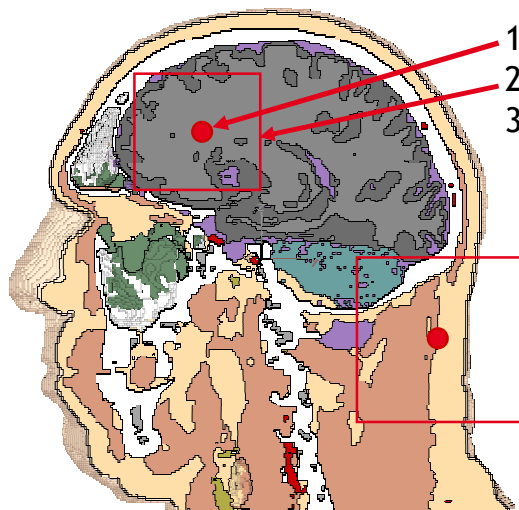
ρ : Density

Typically averaged over pre-defined mass

Definitions

- **Point SAR:** Local SAR without mass or volume averaging
- **Total SAR:** Total power loss in the whole lossy structure divided by its total mass
- **Mass Averaged SAR** (typically 1g or 10g):
 - For each point a cube with a defined mass is found
 - The power loss density is integrated over this cube
 - The integral power loss is divided by the cube's mass
- **Volume Averaged SAR:** Procedure as above, but on fixed volume.
- **Typical Standards, maximum of mass averaged SAR:**
 - US and Canada: **1.6 W/kg averaged over 1g of tissue**
 - EU, Japan, Brazil: **2.0 W/kg averaged over 10g of tissue**

Averaging Procedure



1. Point of avg. SAR calculation
2. Search for 10 g cube (iteratively)
3. Integrate losses in cube

At boundary treatment depends on chosen averaging standard:

IEEE C95.3 / **CST C95.3**

CST legacy

The „constant volume“ assumption uses an averaged cube size:

- Faster (no iterative search for cube with correct mass)
- Only approximative (not according to official SAR standard)

SAR Standards

- Several guidelines and standards specify SAR safety limits (i.e. ICNIRP, IEEE, Cenelec).
- Standards like **IEEE 1528** regulate **measurement methods** for practical assessment of compliance.
- **IEEE C95.3** Annex E specifies SAR averaging scheme for **simulation**.
- CST MICROWAVE STUDIO® has already been **approved by the FCC** (USA) to comply with hex td standard drafts.

SAR Standards under Development

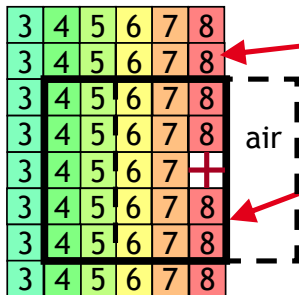
- A **simulation standard** IEEE 1528.X is in development
 - 1528.1 requirements for hexahedral time domain codes (end of 2007)
 - 1528.2 application to cars with passenger/bystander (~2008)
 - 1528.3 application to mobile phones near head (~2008)
 - 1528.4 requirements for tetrahedral frequency domain codes
- **CST participates in standards committee.**

SAR Averaging Standards

IEEE C95.3

If one face of the averaging cube is outside the tissue, the cube is invalid and an inner SAR value is copied:

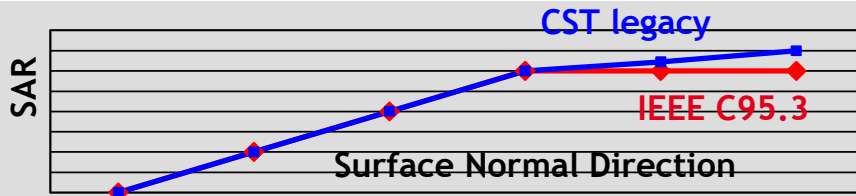
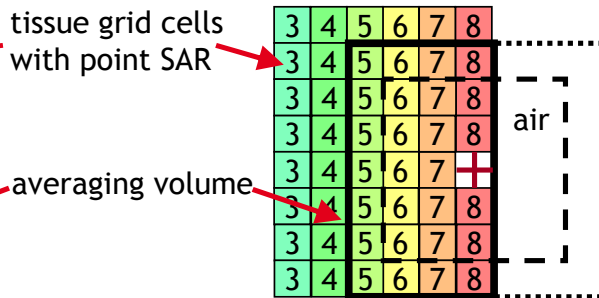
- flat curve at boundary
- closer to measurement setup



CST legacy

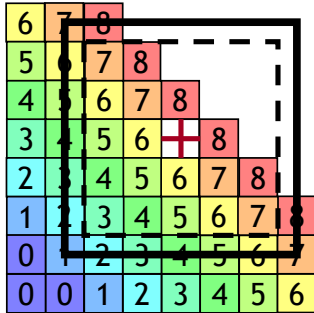
Averaging cube at the boundary is increased until the biological mass reached 10 g

- slowly rising curve at boundary
- Invariant to structure rotation



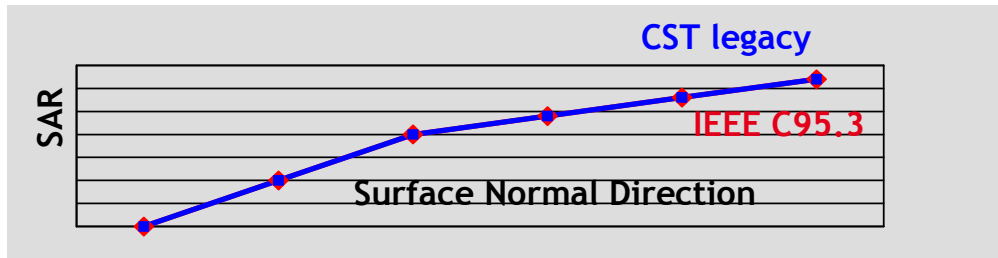
SAR Averaging Standards

Same structure but 45° rotation:



CST Legacy delivers similar result to previous 0° case

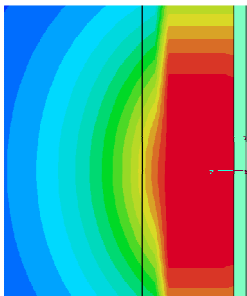
IEEE C95.3 gives the same result as CST legacy, but different compared to 0° case (**rotationally inconsistent**)



SAR Averaging Standards

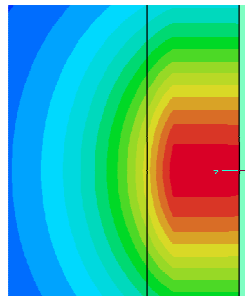
For points with invalid averaging volume ...

... the **maximum** valid averaged SAR from the surrounding is taken.



IEEE C95.3

... the **closest** valid averaged SAR from the surrounding is taken.



CST C95.3

Note: Only differences in plot, **maximum** averaged SAR value stays the same for both procedures.

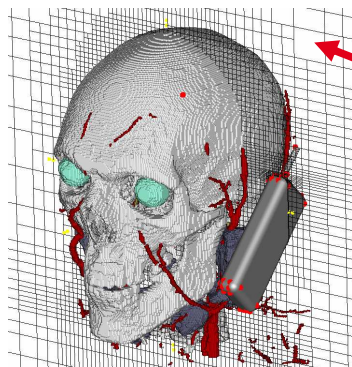
Advantages of CST MWS for SAR

- Direct **CAD import** from various formats, intuitive **parameterization** of imported data, automatic healing if required
- Excellent geometry approximation due to **PBA** and **TST**: NO staircase representation used!
- **Subgridding** available for high detail level
- **Broadband material definition**: Multiple frequencies can be evaluated in one simulation run
- Full control of the **reference power** (input or accepted power)



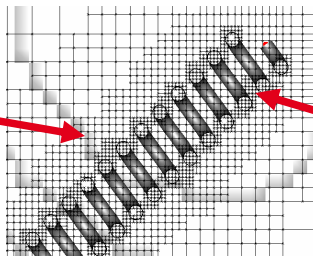
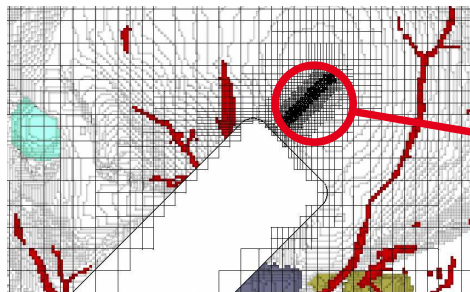
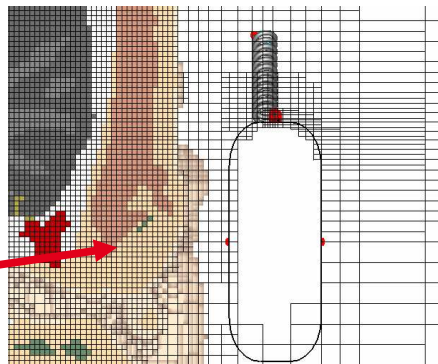
Return loss, near fields, farfields, power loss and SAR distribution of an antenna can be obtained for all required frequencies in **ONE simulation run!**

PBA, TST and Subgridding



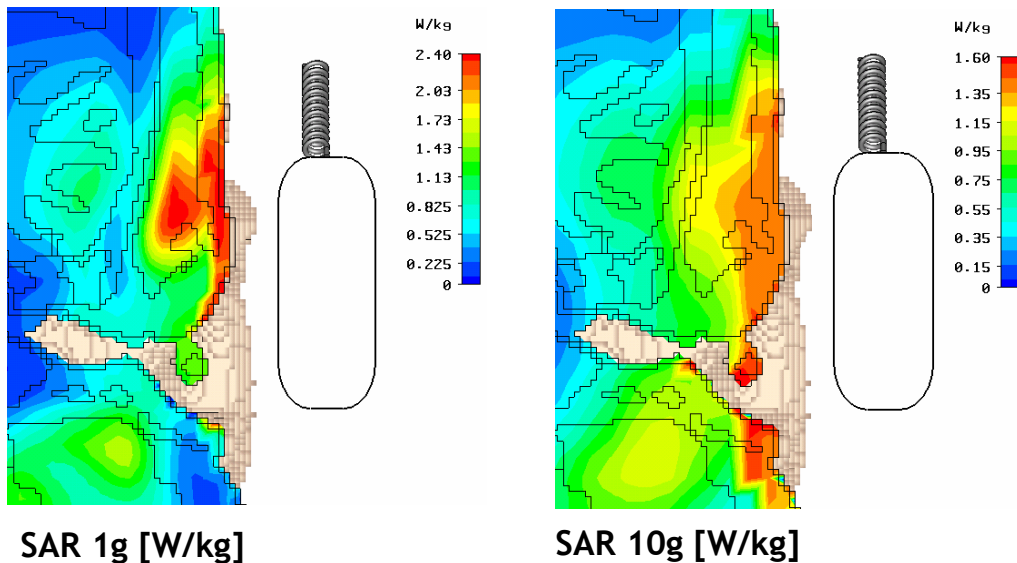
30mm grid
at open
boundary

1mm voxel
resolution
near ear



0.3mm grid
at helix
with SmartGrid™

Visible Human SAR



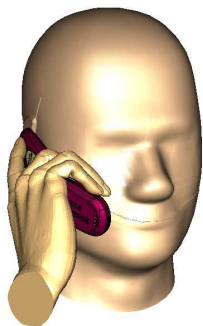
Subgridding allows **high resolution SAR** evaluation in critical regions

Performance Summary

	SAM No Subgrid	SAM Subgrid	Voxel No Subgrid	Voxel Subgrid
Mesh cells	2.1 M	163k	2.9 M	288k
Solver time	5,486 s	568 s	7,281 s	1,867 s
SAR time 1g	209 s	39 s	781 s	140 s
SAR time 10g	1,080 s	51 s	4,292 s	185 s
Acceleration	Factor 10		Factor 5.6	

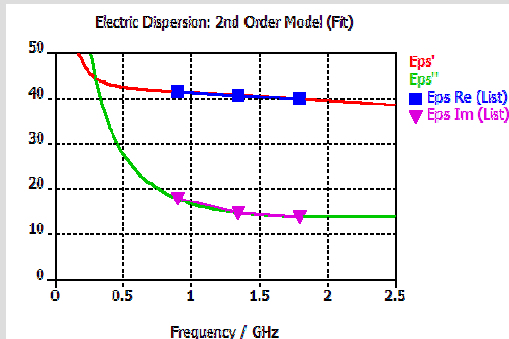
Software performance on Intel Xeon 3 GHz, 2 GB RAM
(Hardware acceleration will increase performance by additional factor)

Dispersive Broadband Simulation



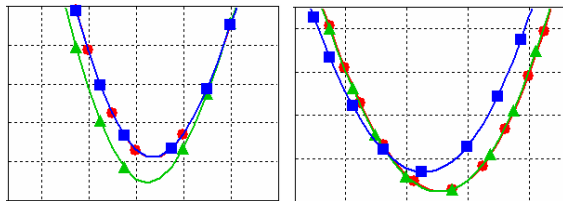
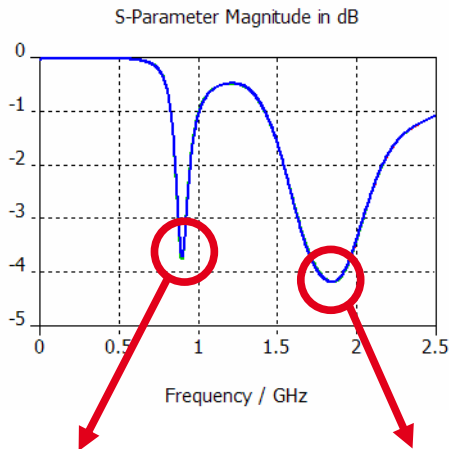
Typical requirement for dual band phones:

	$\text{Re}(\epsilon_r)$	$\text{Im}(\epsilon_r)$
0.9 GHz	41.5	17.98 (= 0.9 S/m)
1.8 GHz	40.0	13.98 (= 1.4 S/m)



Frequency dependent
material definition:
Second order dispersive
fit for tabulated values,
**only one simulation run
required**

Dispersive Broadband Simulation



Compared material settings:

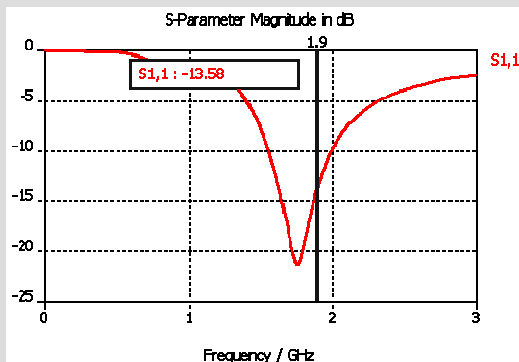
- Constant settings for 0.9 GHz
sim. time 45 min.
- Constant settings for 1.8 GHz
sim. time 45 min.
- Dispersive broadband fit
total sim. time: 57 min.

Dispersive fit agrees
perfectly in both bands
for only 25% extra
simulation time

Reference Power

- **Measured** SAR typically refers to **maximum power** of mobile phone
- Simulation requires a reference power, default in CST MWS:

Ports: **1 W PEAK input power**



For poorly matched antennas input and radiated power can differ significantly

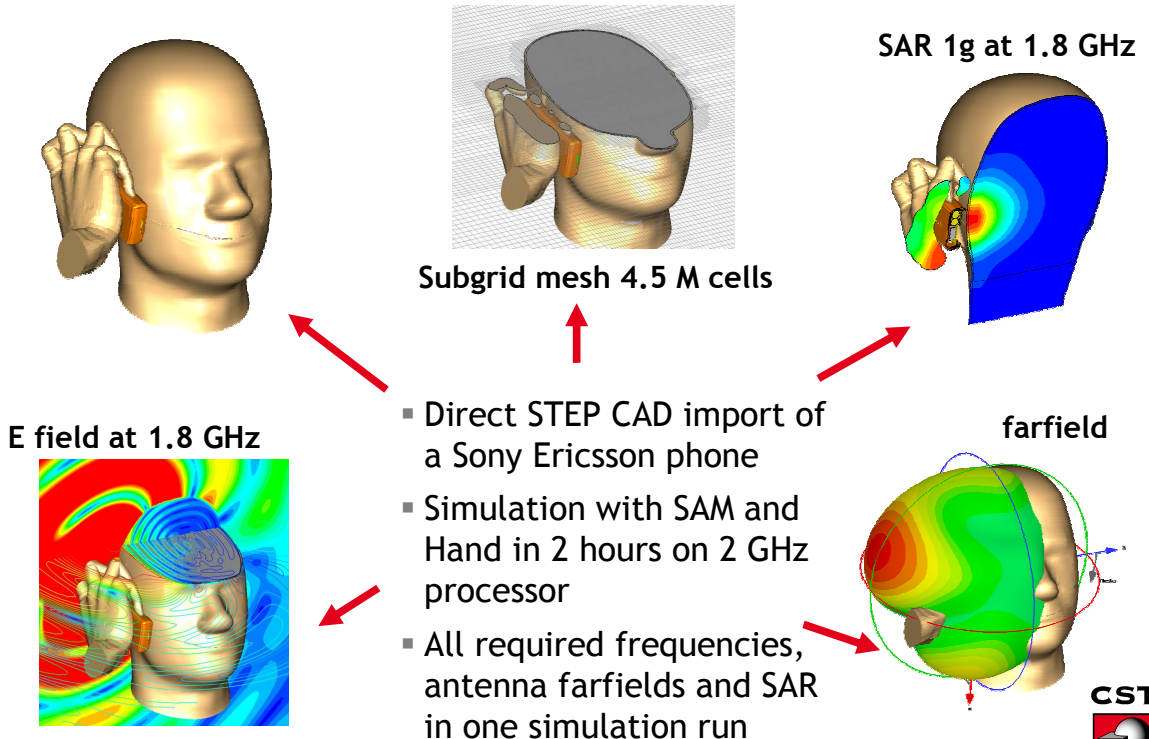
$$P_{rad} = (1 - S_{11}^2) P_{in}$$

Macros -> Results -> Calculate delivered power

alternative setting: **1 W RMS accepted power**
(= power radiated by loss-free antenna)

Plane Wave: 1 V/m electric field strength

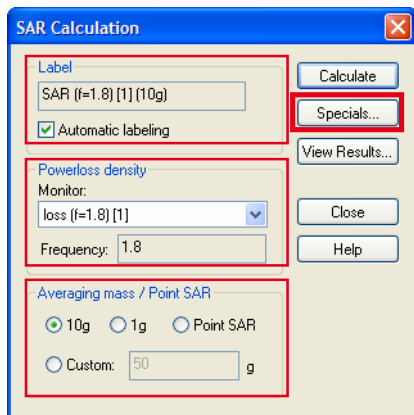
Example: CAD mobile phone



SAR Handling in CST MICROWAVE STUDIO®

Pre-conditions before start of simulation:

- A power-loss **monitor** needs to be defined **at frequencies of interest**.
- All materials used for mass averaging need to have **mass density ρ** .

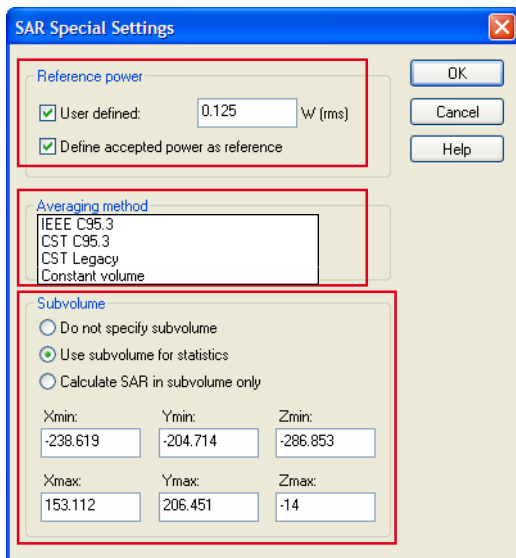


Define labeling

Choose the Powerloss monitor

Definition of averaging mass
or Point SAR

SAR Special Settings



The screenshot shows the 'SAR Special Settings' dialog box. It has a blue title bar with a close button. The dialog is divided into three main sections, each highlighted with a red rectangular box:

- Reference power:** Contains a checked checkbox for 'User defined:' with a text input field set to '0.125' and the unit 'W (rms)'. Below it is another checked checkbox labeled 'Define accepted power as reference'.
- Averaging method:** A list box containing four options: 'IEEE C95.3', 'CST C95.3', 'CST Legacy', and 'Constant volume'.
- Subvolume:** Contains three radio buttons: 'Do not specify subvolume', 'Use subvolume for statistics' (which is selected), and 'Calculate SAR in subvolume only'. Below the radio buttons are six text input fields for bounding box coordinates: Xmin: -238.619, Ymin: -204.714, Zmin: -286.853, Xmax: 153.112, Ymax: 206.451, and Zmax: -14.

On the right side of the dialog, there are three buttons: 'OK', 'Cancel', and 'Help'.

Define reference power,
Port input or accepted power

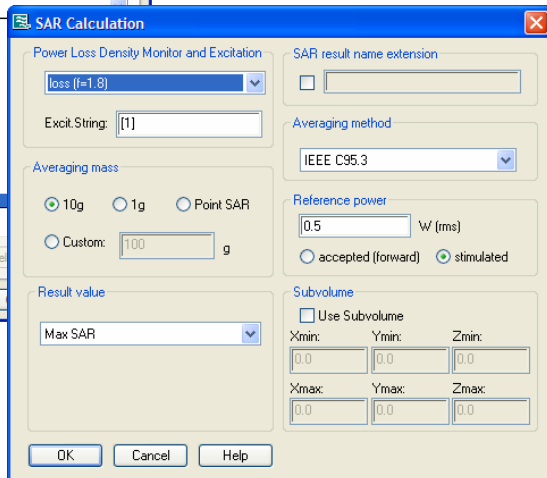
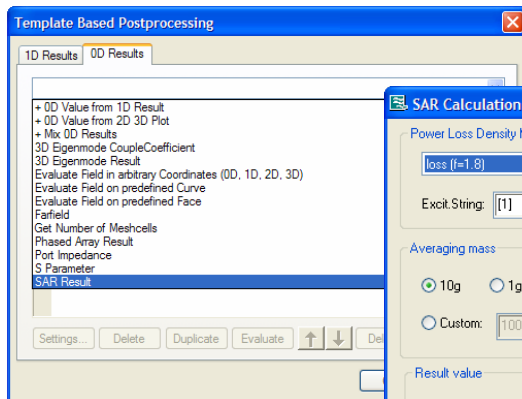
Choose averaging method

Restrict volume for:

- maximum search and statistics
- reduced computational effort

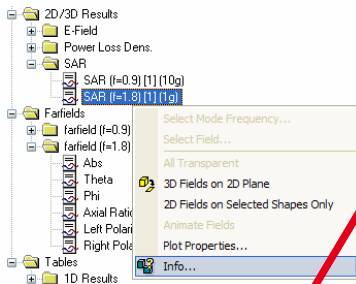
Template Based Postprocessing

Alternatively: Postprocessing Templates can be defined



Available as 1D and 0D
result template

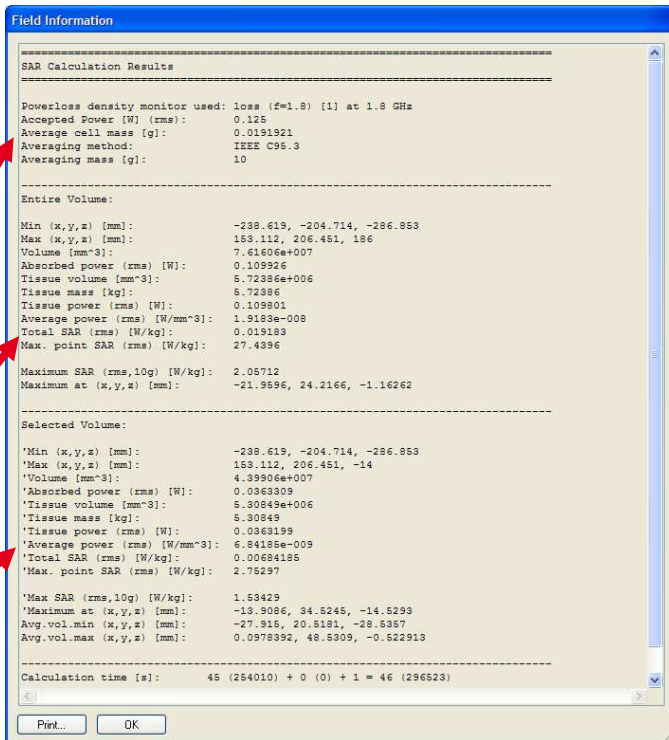
SAR Results



General
information

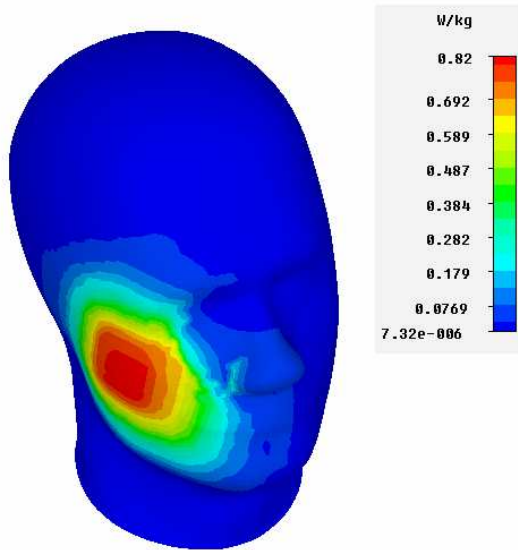
Statistics for
total volume
(e.g. head + hand)

Statistics for
Subvolume
(e.g. just head)

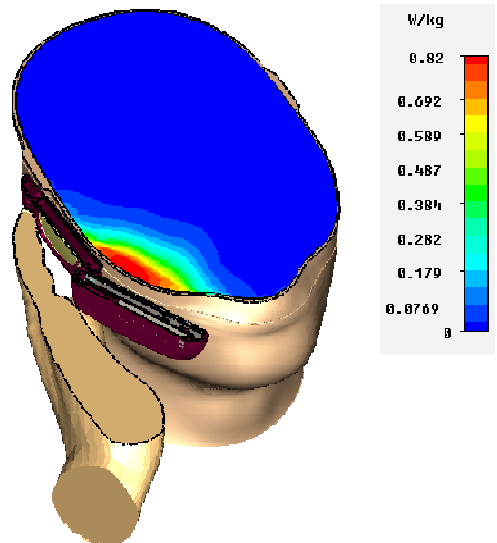


Visualization of SAR

2D or 3D plot including information about position of the maximum

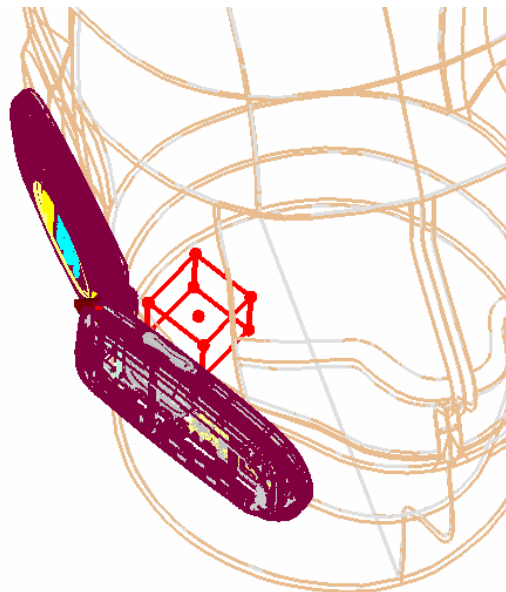
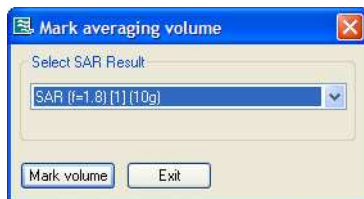
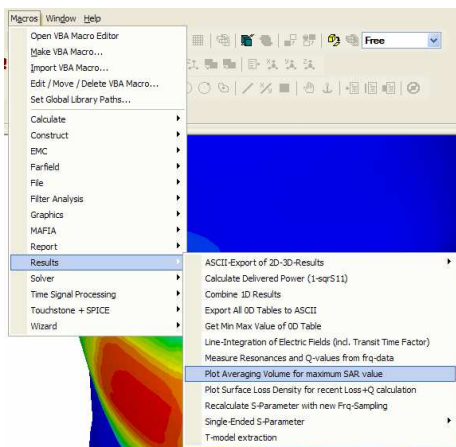


Type	SAR (rms)
Monitor	SAR (f=1.8) [1] (10g)
Maximum-3d	0.819908 W/kg at -19.8712 / 3.24869 / -24.6462
Frequency	1.8



Type	SAR (rms)
Monitor	SAR (f=1.8) [1] (10g)
Plane at y	3.24869
Maximum 2d	0.8199 W/kg at 20.9191 / 2.19700 / 25.6691
Frequency	1.8

Visualization of Max. SAR Cube



Tips & Tricks

- Set mesh type to **FPBA** to create more accurate results
- Power Loss Monitor averages at material boundaries
 - Use **refined mesh at boundaries**
 - Point SAR based E-field monitor (through templates)
- Material consideration:
 - Lossless masses are counted for the total mass
 - Lossy mass-free materials are not considered for the total loss
- **Hint: To exclude materials from SAR calculation, you may just set their mass density to zero!**

Summary

SAR simulations with CST MICROWAVE STUDIO®

- All advantages of CST MWS (PBA, TST, MSS, ...) apply to SAR simulations
- Frequency dependent materials: Broadband SAR in one simulation run
- One tool for both antenna design and SAR verification
- Support of various standards, participation in IEEE standard committees
- Intuitive handling of SAR calculation and evaluation

