CST STUDIO SUITE®
Webinar Series

Analyzing HF & LF RadHaz Scenarios with 3D EM Simulation

Dr. Tilmann Wittig – CST

- Start time: 5pm CET, 11am ET, 8am PT
- Audio will be broadcast through your computer speakers or headphones (no need to teleconference)
- In case of audio broadcast failure please use dial-in numbers from your registration email
- There will be no audio until the scheduled start time.
- A recording will be made available, you will be notified by email
- More information: www.cst.com/webinars

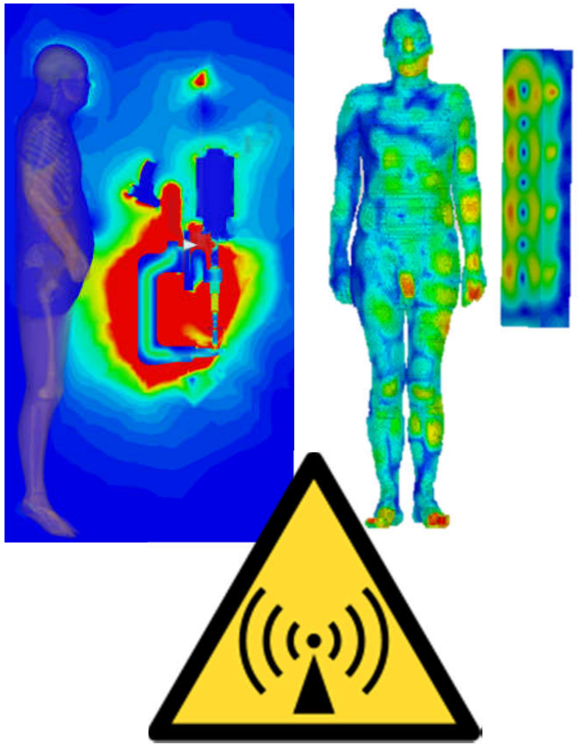
Introduction

Humans are exposed to electro-magnetic fields of different frequencies almost everywhere!

EM Fields typically fade quickly with distance from source

Fields may be hazardous in close vicinity to source

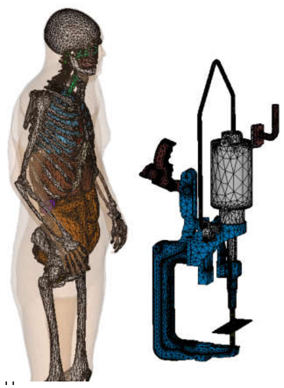
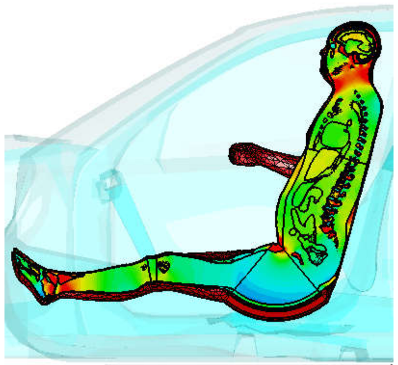
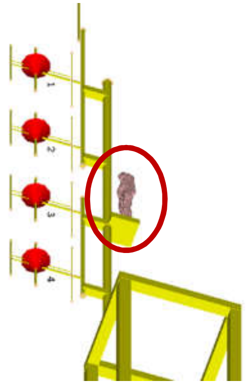
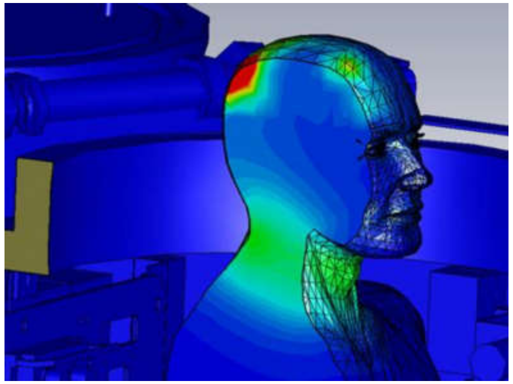
- Medical Imaging & Treatment
- Persons near machines of high power
- Persons near antennas



Source: Wikipedia

Outline

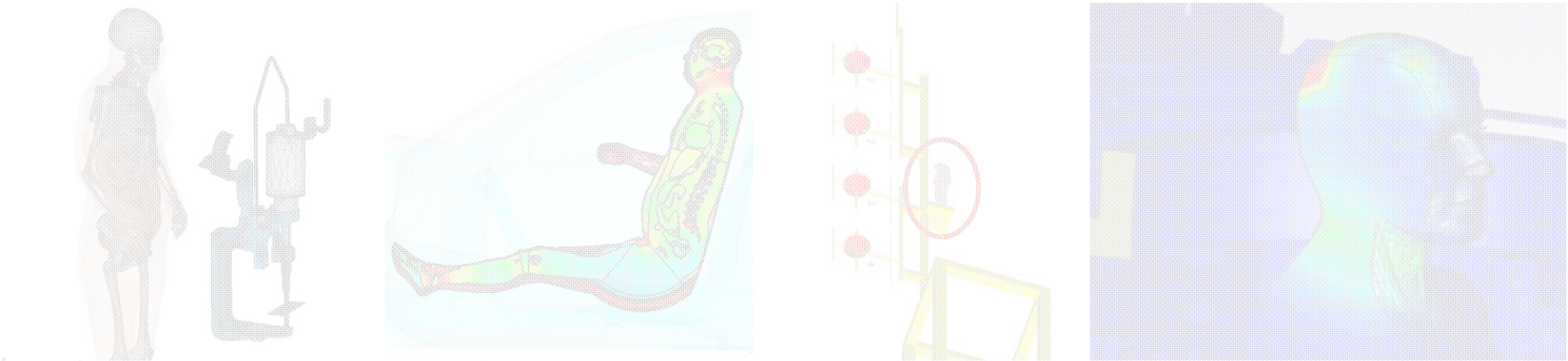
- Radiation Hazard Introduction
- Human Models for EM Simulation
- Applications:

- Summary

Outline

- Radiation Hazard Introduction
- Human Models for EM Simulation
- Applications:



- Summary

Types of Radiation

Ionizing Radiation

High energy radiation,
e.g. UV, X-Ray, Gamma
Damages DNA and cause cancer

Non-Ionizing Radiation

Much lower energy

Static Fields

Known effects on human organism only for very high field strength (e.g. MRI)

Low Frequency Fields

1 Hz – 100 kHz

Induced fields interfere with body-own fields

High Frequency Fields

100 kHz – 300 GHz

Heating of exposed tissues

Classification and assesment according to icnirp.org

Radiation Hazard Regulation

Various organizations are involved in standardization and regulation providing guidelines for measurement and simulation setup as well as defining limits

- International Commission on Non-Ionizing Radiation Protection (ICNIRP)
- IEC, IEEE, local standardization authorities
- Local legislation, e.g. *European Directive 2013-35 EU for "the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)"*

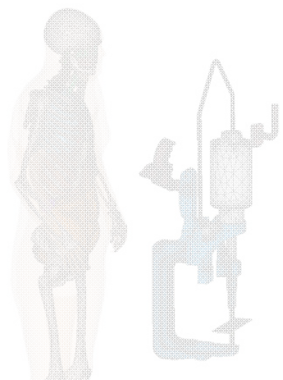
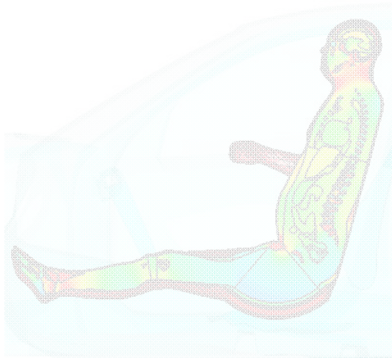
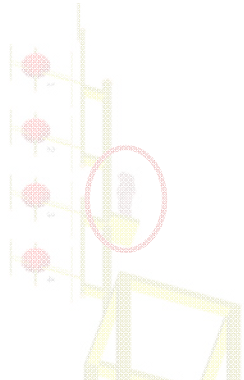
Radiation Hazard Standards

Most standards distinguish between

- Occupational and general public scenarios (occupational limits typically 2-4 times higher)
- Dosimetry values inside body (induced E-fields, SAR)
  - Represents the value of interest
  - Very hard to measure, but can be simulated!
- Unperturbed E- and H-field values in position of human
  - Much easier to measure or simulate
  - May be unreliable (human presence changes field distribution)
  - Are chosen very conservatively

Outline

- Radiation Hazard Introduction
- Human Models for EM Simulation
- Applications:

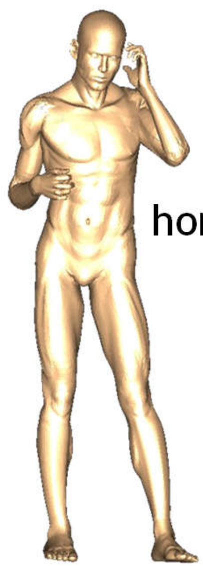





- Summary

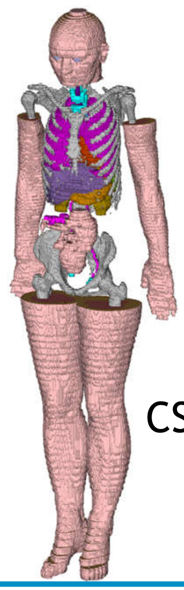
Human Simulation Models

The right choice of biological model is essential for the reliability of a medical simulation.

Anatomical details:



homogeneous models



CST Voxel Family

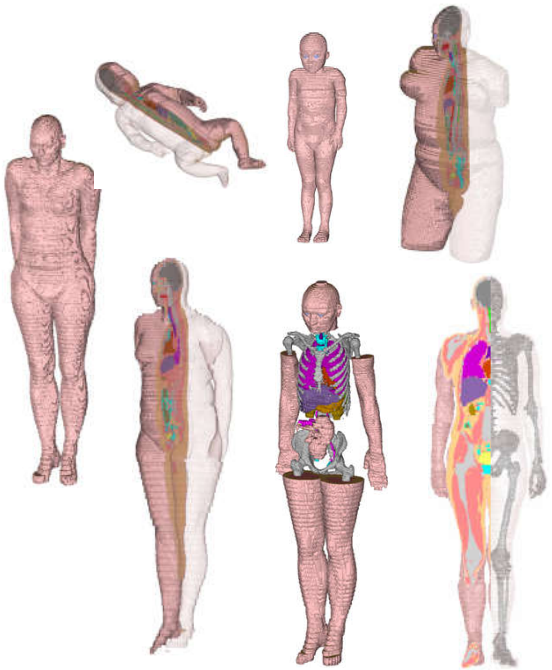
heterogeneous CAD models

Material properties:

- Frequency dependent EM properties (Cole-Cole)
- Temperature dependent EM properties
- Temperature dependent thermal properties

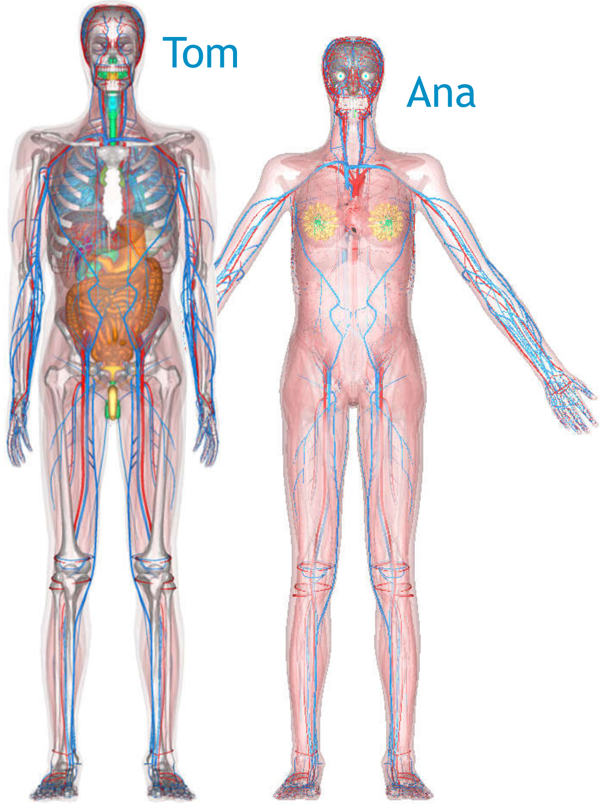
CST Biological Model Library

The CST Voxel Family



Tom

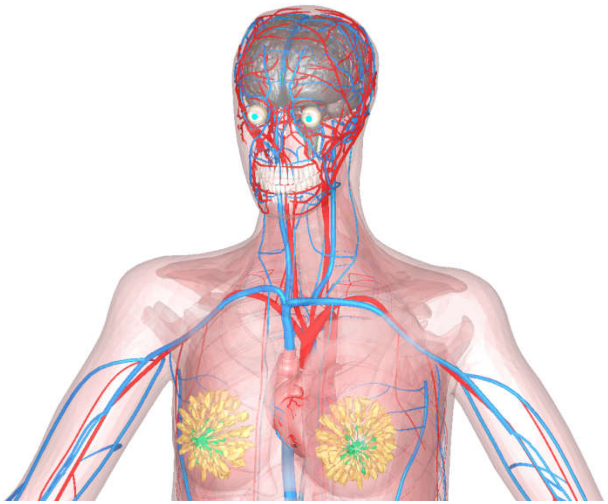
Ana



Nelly

(Female Visible Human)

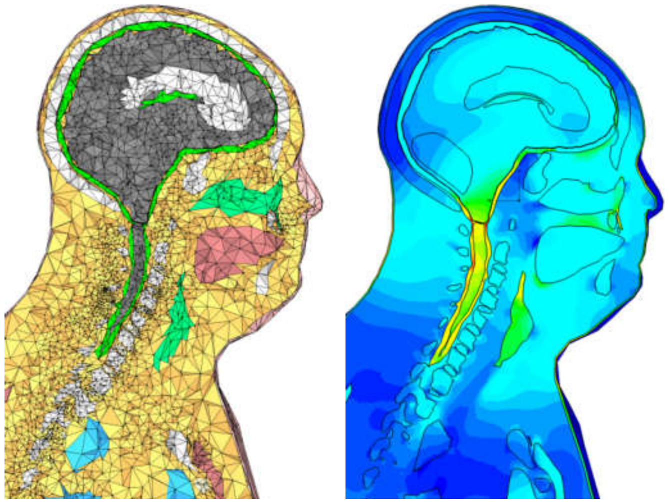
CST Biological Model Library



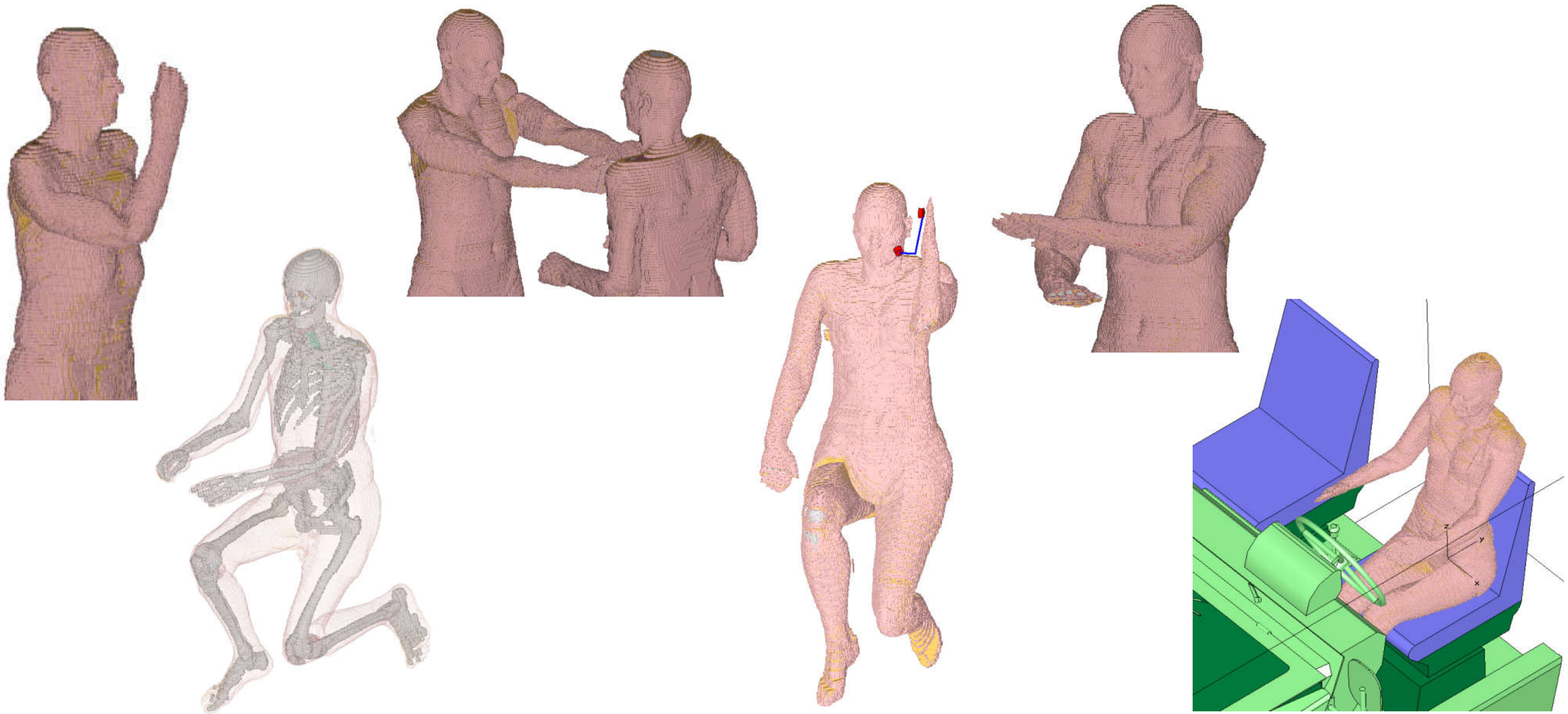
CAD based models:

- TET meshing possible
- Voxelling in custom-resolution

F-solver for LF, high Q



Voxel Model Posing



CST Simulation Technologies

Static Fields

Es Ms Js

Low Frequency Fields

1 Hz – 100 kHz

LF F

High Frequency Fields

100 kHz – 300 GHz

T F

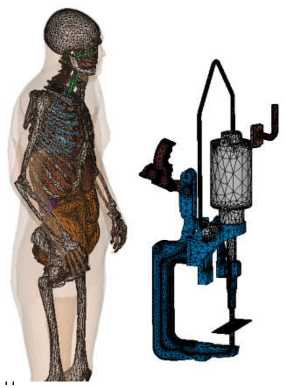
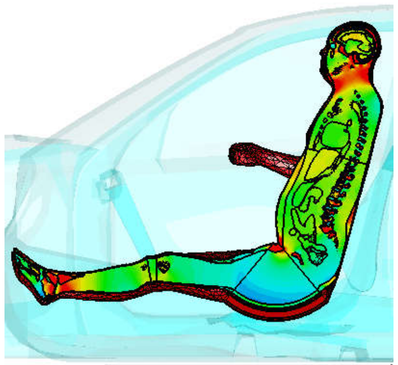
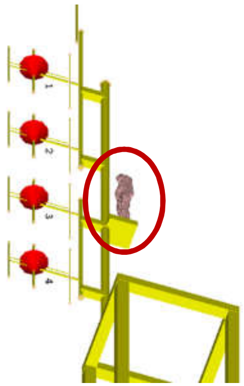
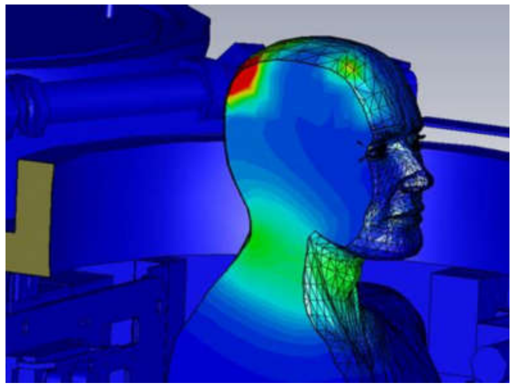
System Simulation
Antenna Matching
Field Source Coupling

Bioheat Simulation

THs THt

Outline

- Radiation Hazard Introduction
- Human Models for EM Simulation
- Applications:

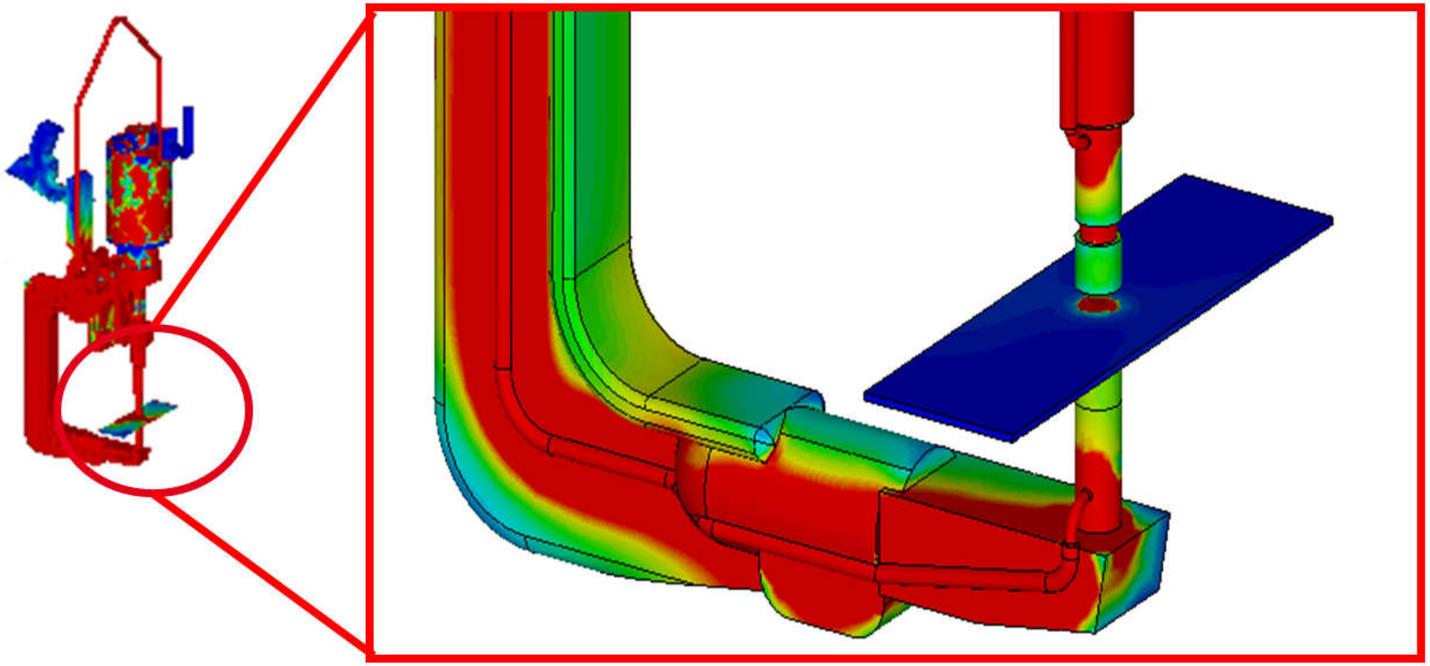





- Summary

Human Body Exposure to a 50 Hz Welding Gun

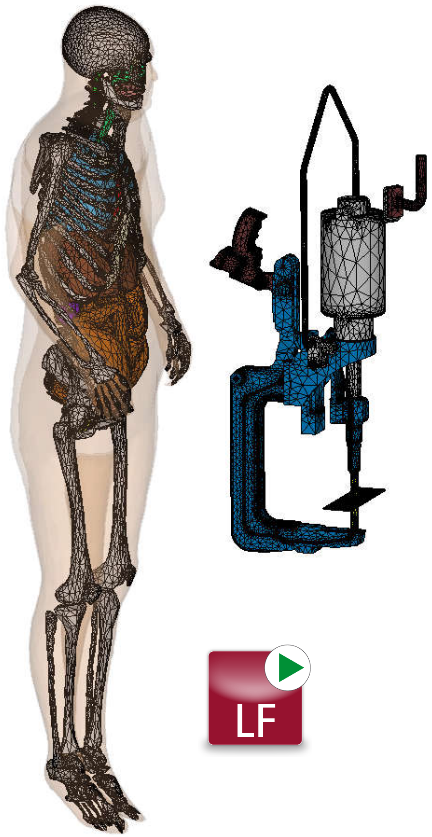
Welding Gun Model

Welding gun operating at 50 Hz when 3.1 kA current used



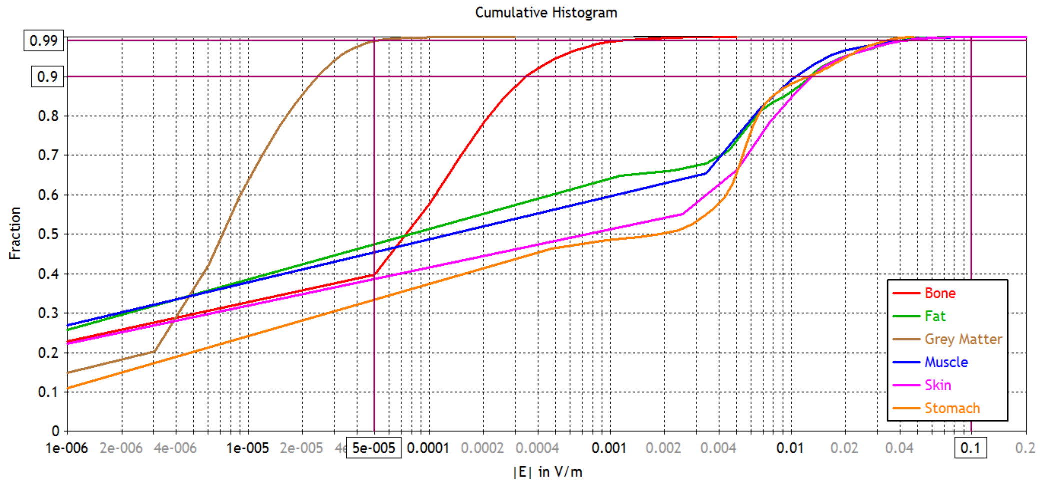
Low Frequency Radhaz

- Welding gun test case for new guide of good practice for European Directive 2013-35 EU-Electromagnetic Fields
- Worker is at specific distance from gun
- Of interest: field exposure e.g. at 50 Hz when 3.1 kA current used
- Solver used: Magnetoquasistatic solver with curved tetrahedral mesh
- Statistics: 575.000 TETs, required RAM is 10 Gb and simulation time 25 minutes



Low Frequency Radhaz

- Result: predicted E-field in body is below limit of 0.08 V/m at 50 Hz.
- Cumulative histograms show 99th percentile distribution of induced electric field averaged over 2x2x2 mm³ in various organs



Human exposure basic restriction at 50 Hz (ICNIRP)

- Occupational exposure: 0.08 V/m
- General public exposure: 0.02 V/m

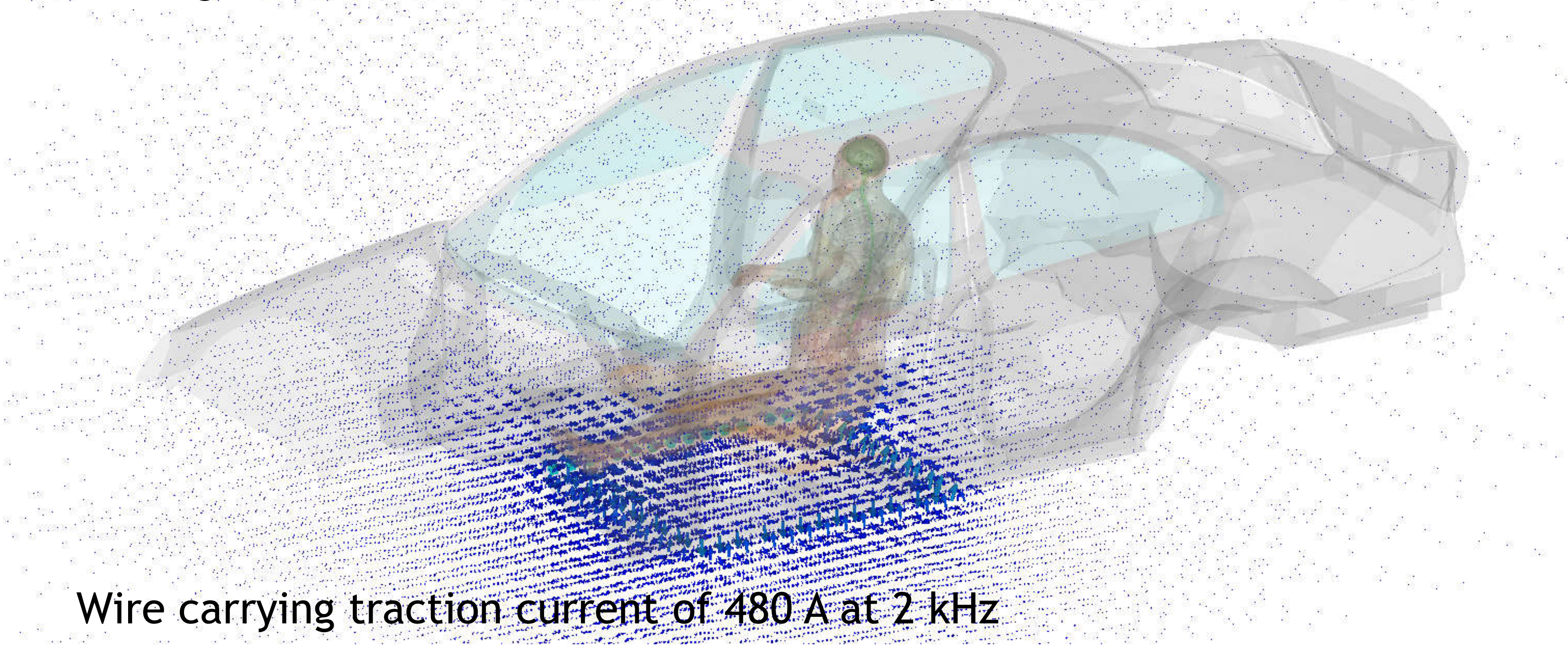
Welding gun is compliant for occupational usage (but not for general public usage)

E-Mobility: Driver Safety in Presence of High Traction Currents

Model of Electric Car

Car chassis modelled as transparent impedance sheet

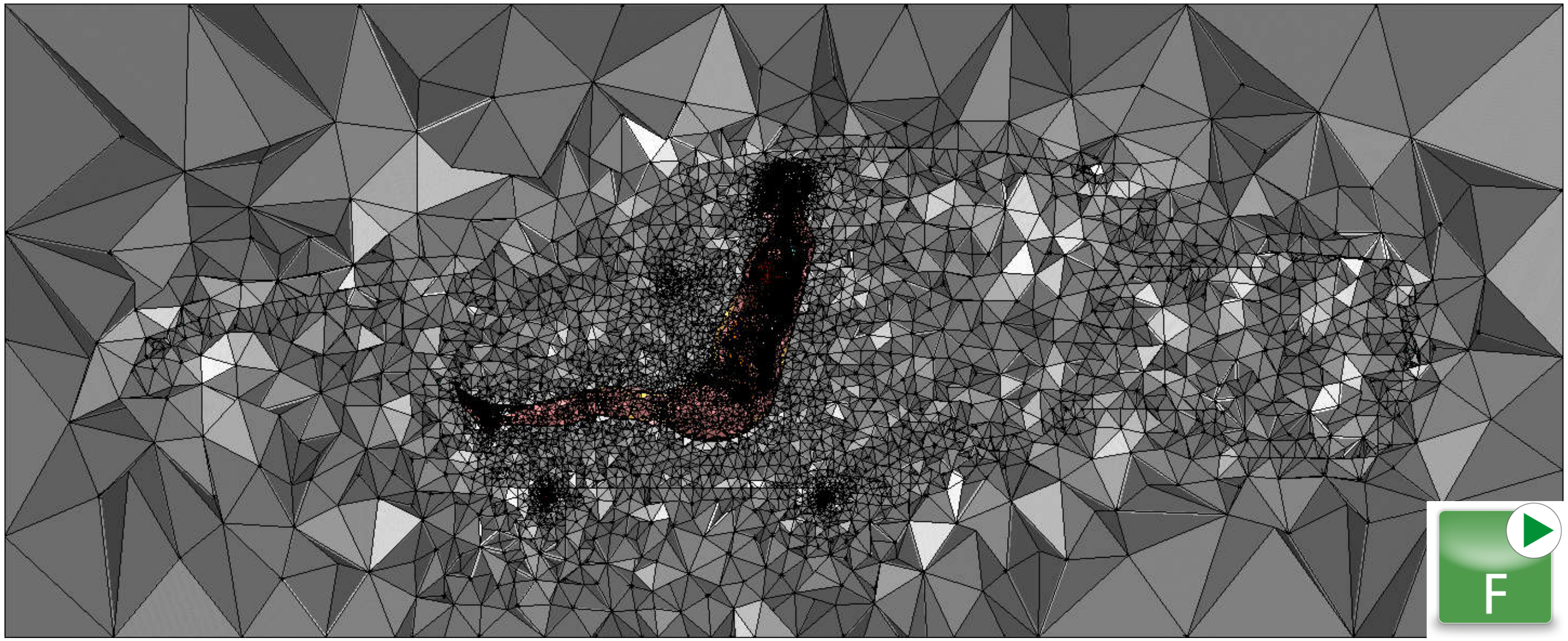
Heterogeneous CAD based human Model Nelly



Wire carrying traction current of 480 A at 2 kHz

Simulation Properties

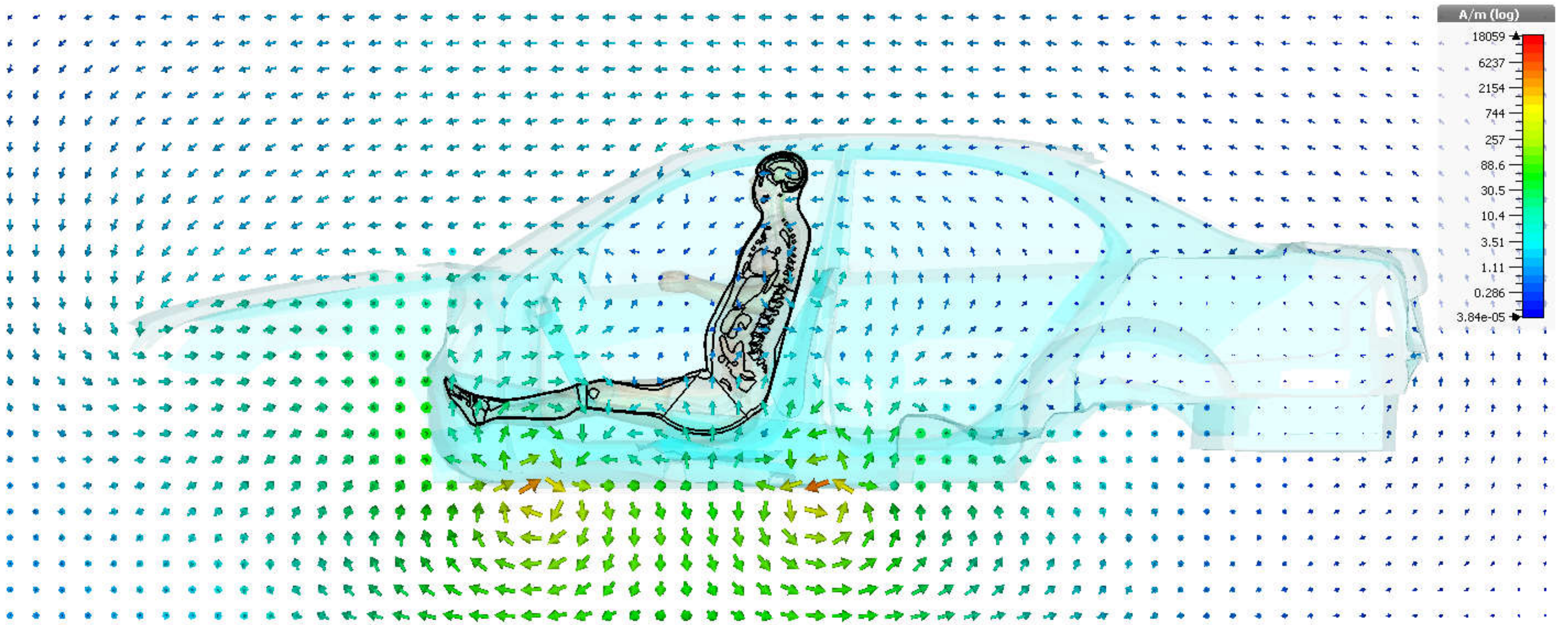
1.93 Million TETs after 7 automatic adaption passes



3h 15 min total simulation time

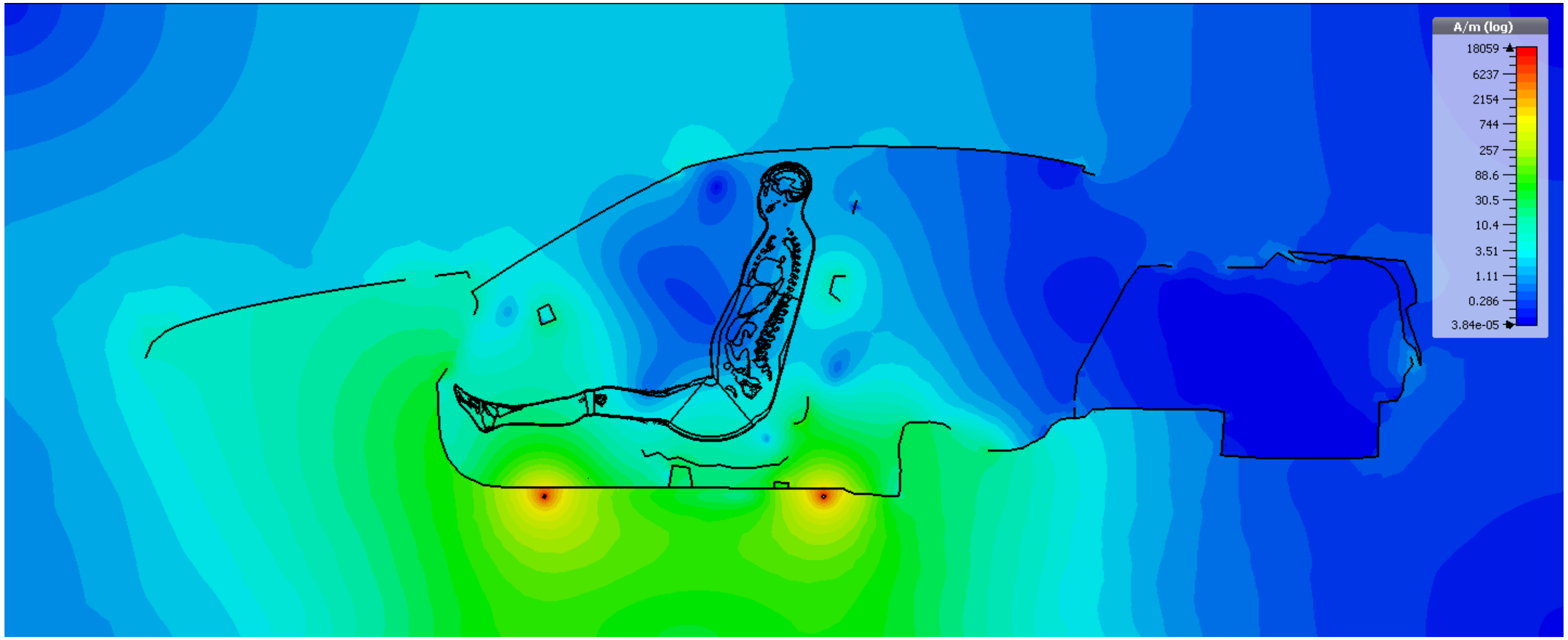
Results at 2 kHz

Magnetic Field at 2 kHz (vector plot)



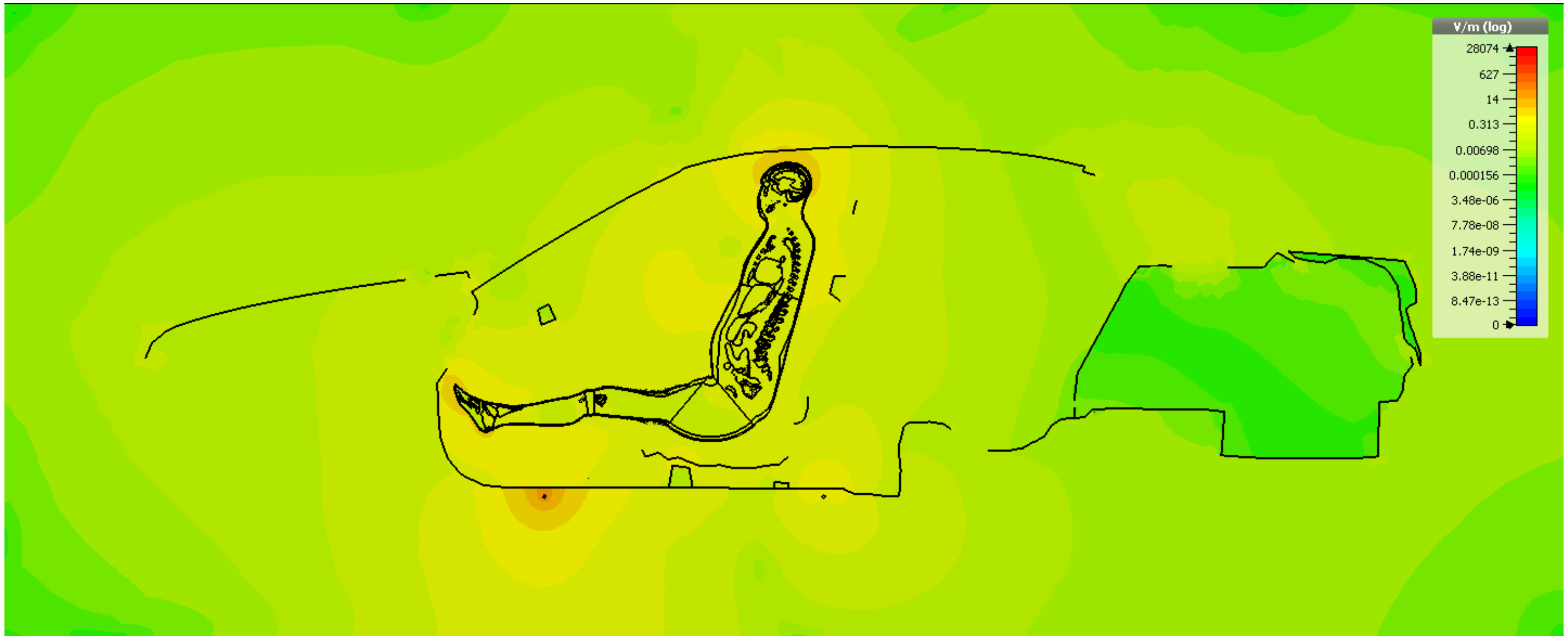
Results at 2 kHz

Magnetic Field at 2 kHz (absolute value)

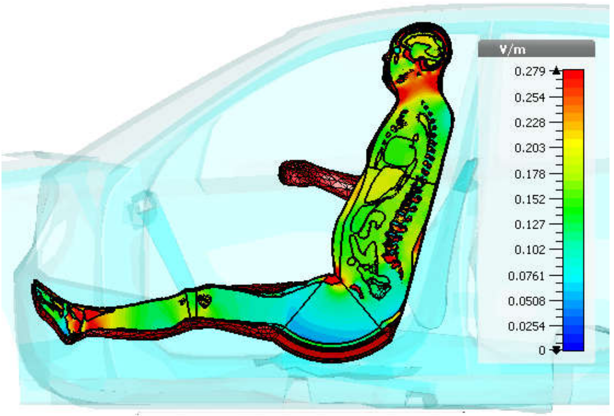


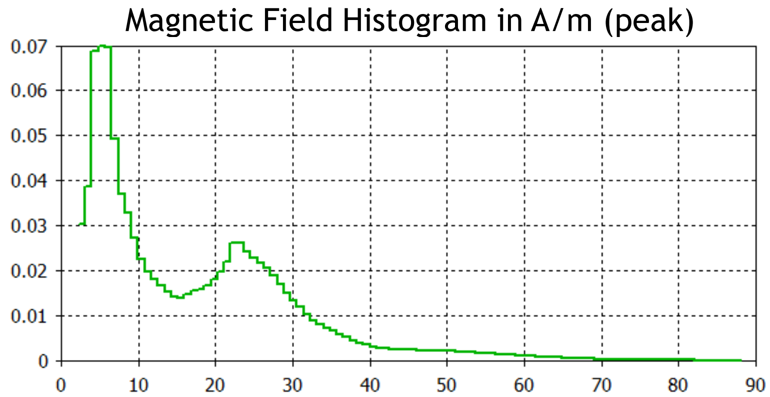
Results at 2 kHz

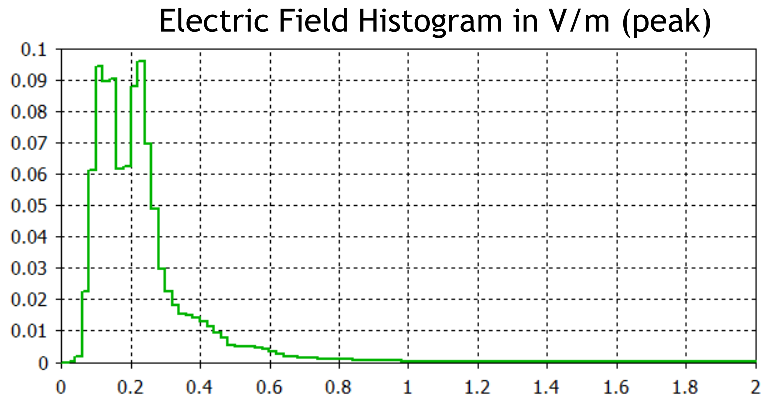
Electric Field at 2 kHz (absolute value)



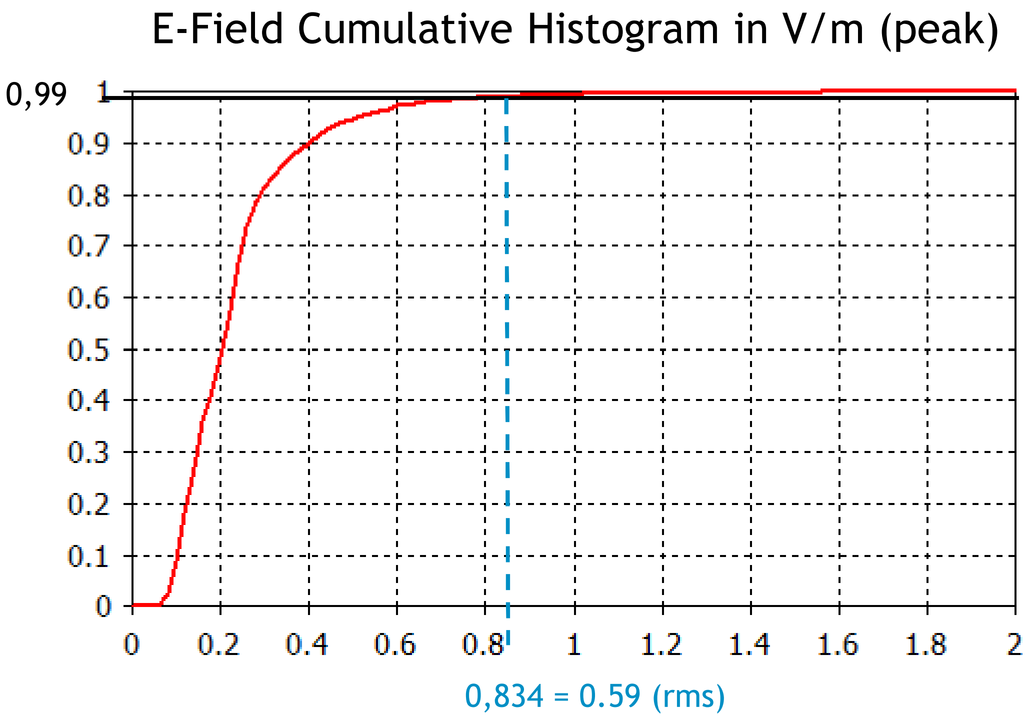
Histogram Field Distribution







Compliance of Traction Current



Human exposure basic restriction at 2 kHz (ICNIRP)

- Occupational exposure: 0.8 V/m
- General public exposure: 0.4 V/m

99th percentile is 0.59 V/m (rms), above general public expose limit. But: peak current applies only few seconds, average needs to be considered!

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

RadHaz of Worker on Telecommunication Tower

Courtesy of Vanni Lopresto,

vanni.lopresto@enea.it

Two Telecommunication Towers

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Tower A

- FM-VHF stations
  - 99.6 MHz, 103.9 MHz
  - 635.5 W (rms) each
- UMTS-BTS
  - band I (2150 MHz) - 10.6 W (rms)
  - band VIII (950 MHz) - 31.9 W (rms)

Tower B

- DVB-T station (690 MHz)
- FM-VHF station (91 MHz)

Worker Exposure Scenarios

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

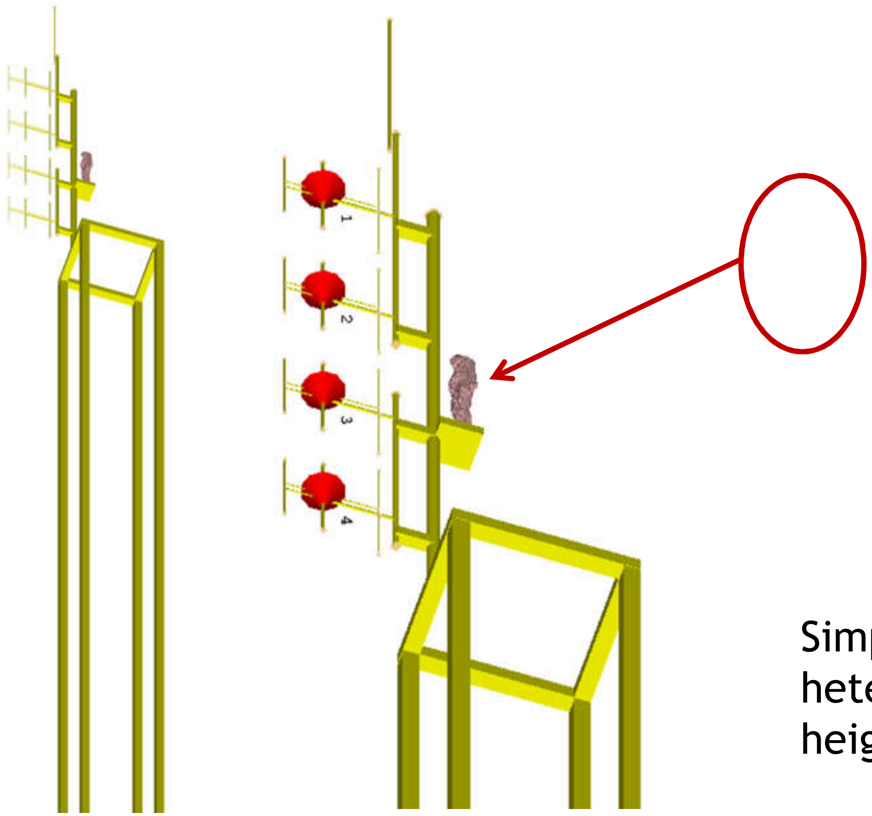
Evaluation of Directive 2013-35-EU for technical personnel operating on Tower A

1. Exposure to FM-VHF antennas on upper platform (height 35 m)
3. Exposure to UMTS-BTS antennas on lower platform (height 28 m)

2. Exposure to the far fields radiated by antennas on Tower B

1) FM Near-Field Exposure

Italian National Agency for New Technologies, Energy and Sustainable Economic Development



FM near-field simulations

2 x Workstations, Xeon multiprocessor (256 GB RAM, 4 GPU)

Simulation Requirements:

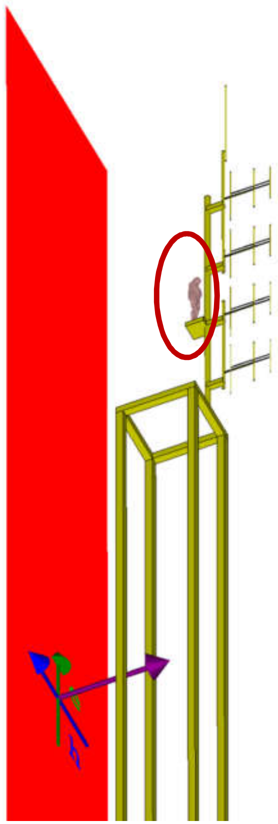
96 Million mesh cells,

38 GB (4.5 hrs)

Simplified tower model, detailled antenna, heterogeneous human model (voxel), full height of 42 m considered in simulation!

2) FM & DVB-T Far-Field Exposure

Italian National Agency for New Technologies, Energy and Sustainable Economic Development



Plane-wave simulations

2 x Workstations, Xeon multiprocessor (256 GB RAM, 4 GPU)

Total memory needed for simulation:

@ 91 MHz: 96 Million mesh cells, 35 GB (1.5 hrs)

@ 690 MHz: 180 Million mesh cells, 64 GB (2 hrs)

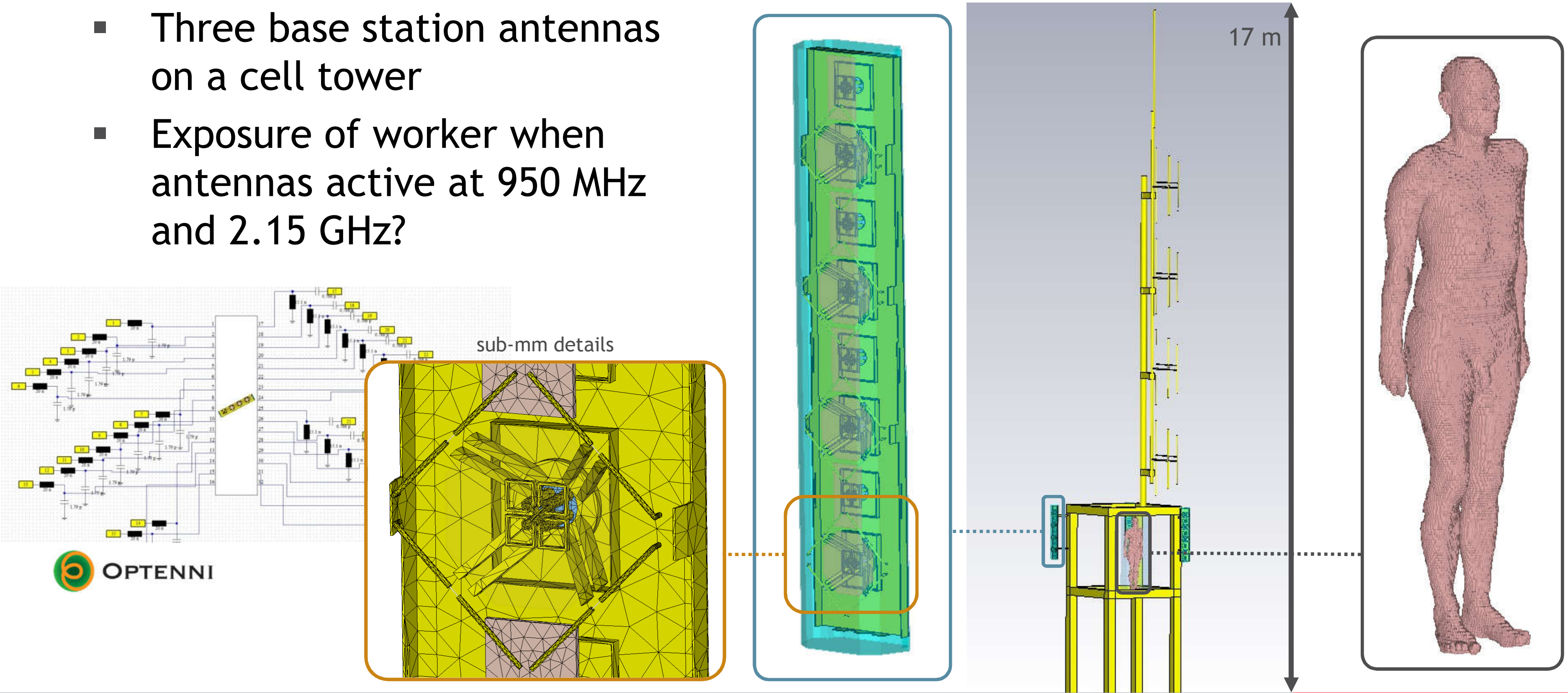
Radiated fields from tower B

Full tower height of 42 m considered in simulation!

3) UMTS Near-Field Exposure

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

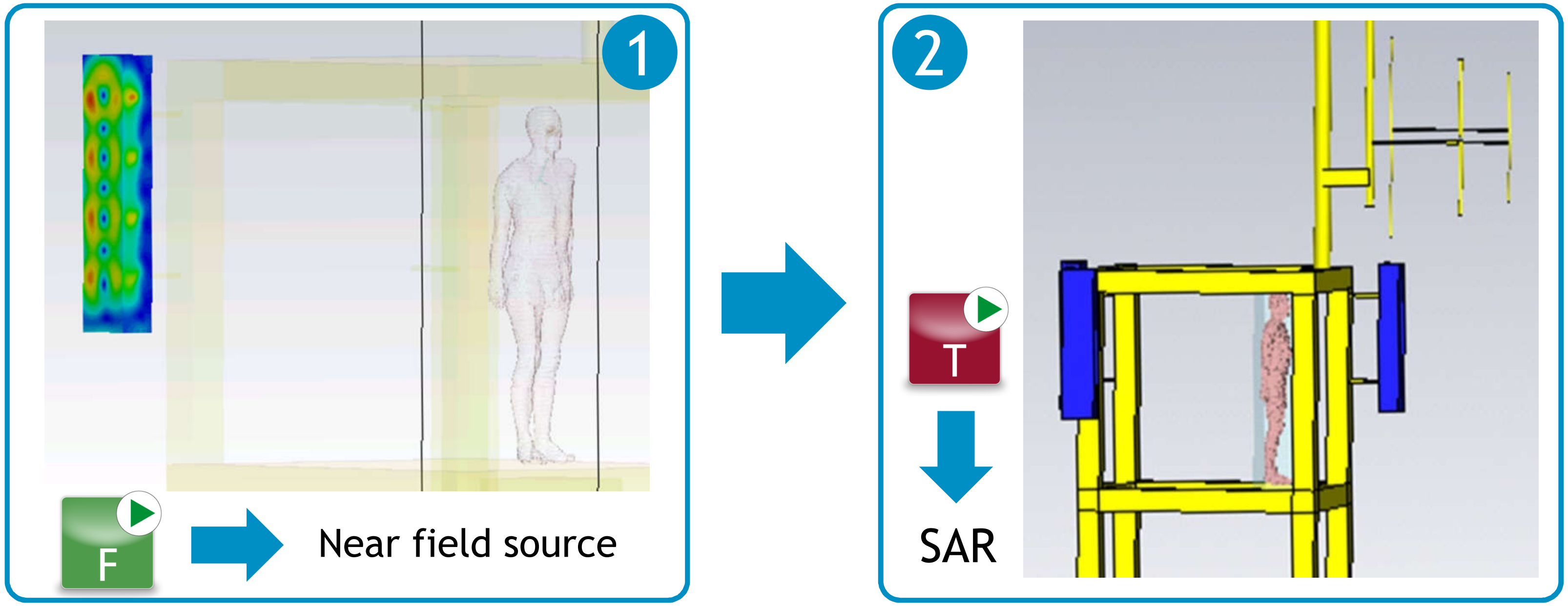
- Three base station antennas on a cell tower
- Exposure of worker when antennas active at 950 MHz and 2.15 GHz?



3) UMTS Simulation Setup

ENEA
Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Simulation in two stages using field source coupling…

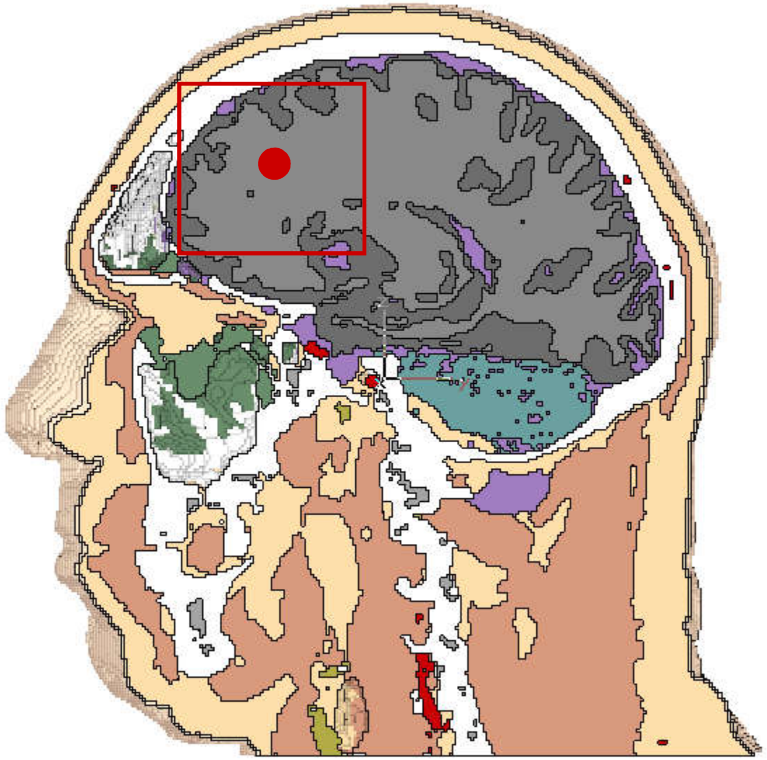


950 MHz: 272 e6 mesh cells, 98 GB (3 hrs), 2150 MHz: 546 e6 mesh cells, 200 GB (8 hrs)

Specific Absorbtion Rate (SAR)

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

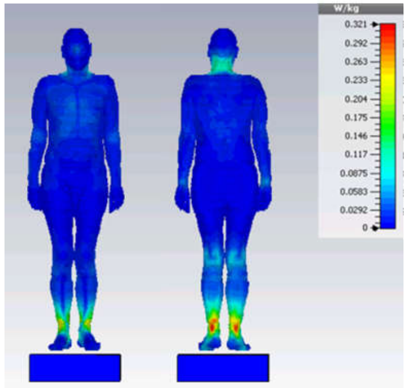
- Point SAR: Local SAR without mass or volume averaging
- Total SAR: Total power loss in a lossy structure divided by its total mass
- Mass Averaged SAR (typically 1g or 10g), often different limits for head, trunk and limbs.

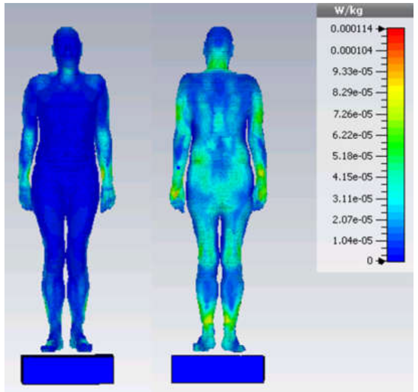


Specific Absorbtion Rate (10g SAR)

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

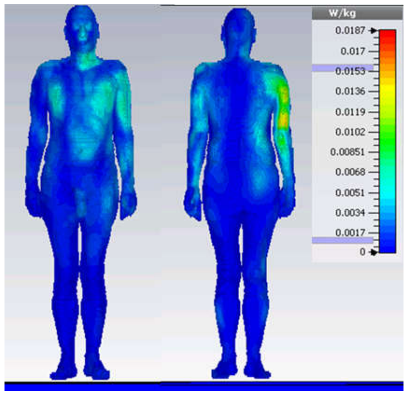
103.9 MHz

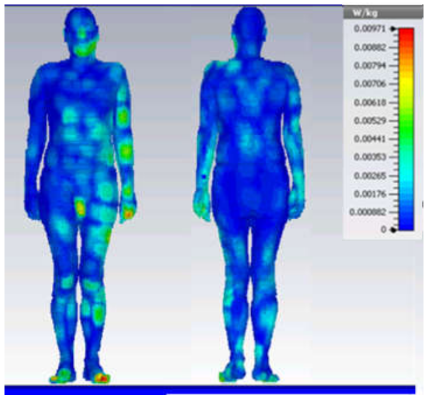




690 MHz

950 MHz





2150 MHz

Results of all Exposures

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Station	Frequency (MHz)	SAR_{WB} (W/kg)	SAR_{10g} (W/kg)	Maximum / secondary peaks
FM-VHF (Tower B)	91	8.00×10^{-4}	6.80×10^{-3}	ankles / neck
FM-VHF (Tower A)	99.6	1.37×10^{-2}	2.39×10^{-1}	ankles / neck
FM-VHF (Tower A)	103.9	1.56×10^{-2}	3.21×10^{-1}	ankles / neck
DVB-T (Tower B)	690	9.30×10^{-6}	5.00×10^{-4}	wrists / ankles
UMTS Band VIII (Tower A)	950	9.00×10^{-4}	1.87×10^{-2}	right forearm / neck
UMTS Band I (Tower A)	2150	5.00×10^{-4}	9.70×10^{-3}	feet / left hand / genitals

Compliance of Combined SAR

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Combined normalized SAR: $$\sum_{i=1}^{N} \frac{SAR_i}{SAR_{ELV}} \leq 1$$

Indexes of Compliance (IOC) according to Directive 2013-35-EU:

ELV	SAR (W/kg)	IOC
Whole-body	0.4	7.88×10^{-2}
Head & Trunk	10	5.85×10^{-2}
Limbs	20	2.98×10^{-2}

RadHaz Evaluation of Military Vehicles

Courtesy of Andy Sayers and Adam Silvester,
andy.sayers@phasorinnovation.com

"Near-Field RADHAZ Assessment in Complex Environments" EMC Soc. Workshop 2015

Radhaz Evaluation of Vehicle

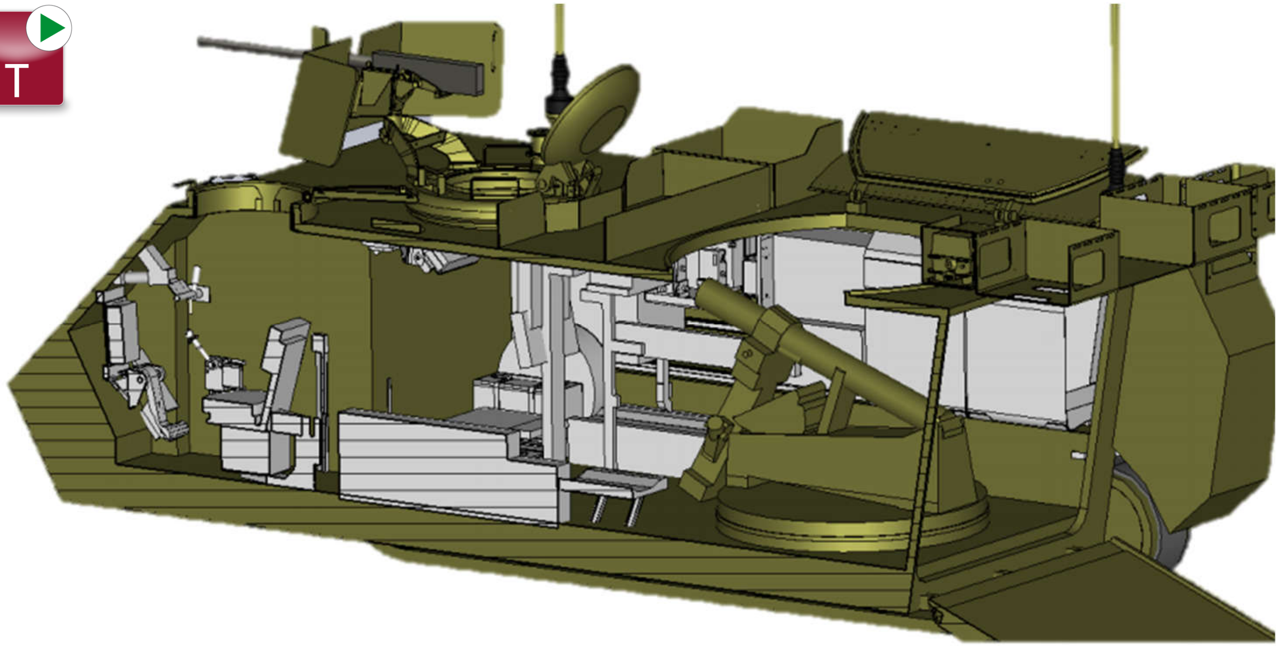
Phasor Innovation

- Vehicle with multiple communication systems
- Interested in exposure of personnel in close proximity to antennas

Radhaz Evaluation of Vehicle

Phasor Innovation

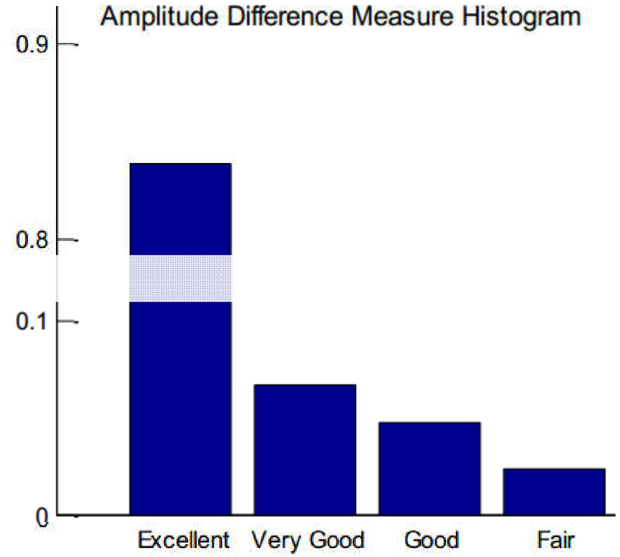
- CAD model imported with “sufficient detail for $f \leq$ UHF”
- No meshing problems with time domain solver



Measurement and Simulation

Phasor Innovation

- Measured and simulated all antennas (2 – 500 MHz) at > 100 locations
- Simulations performed according to IEEE Standard 1597.1

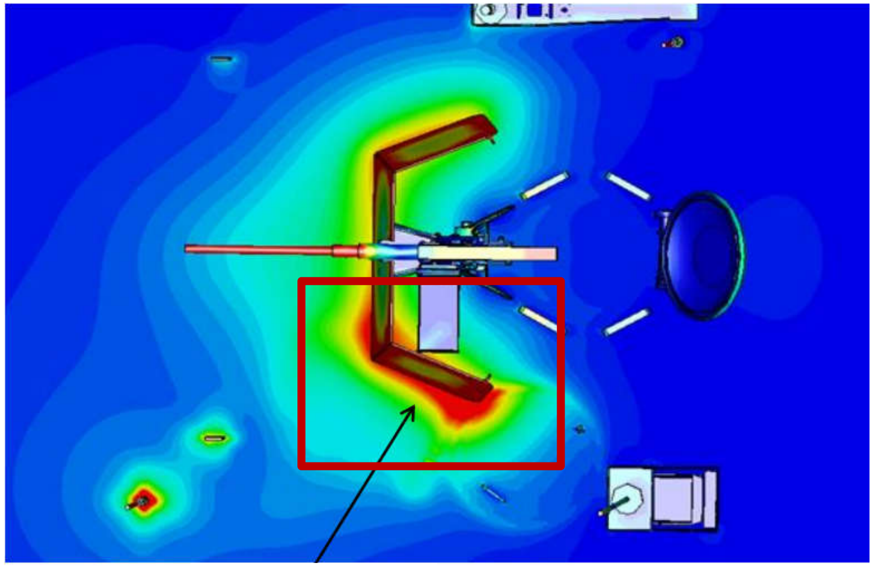


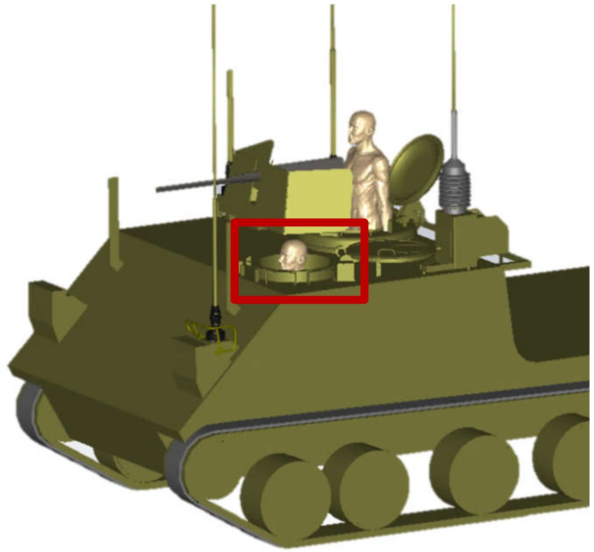
Excellent agreement ⇨ confidence in simulation

Example:Logistics Vehicle

Phasor Innovation

Antenna simulation shows resonance around gun shield



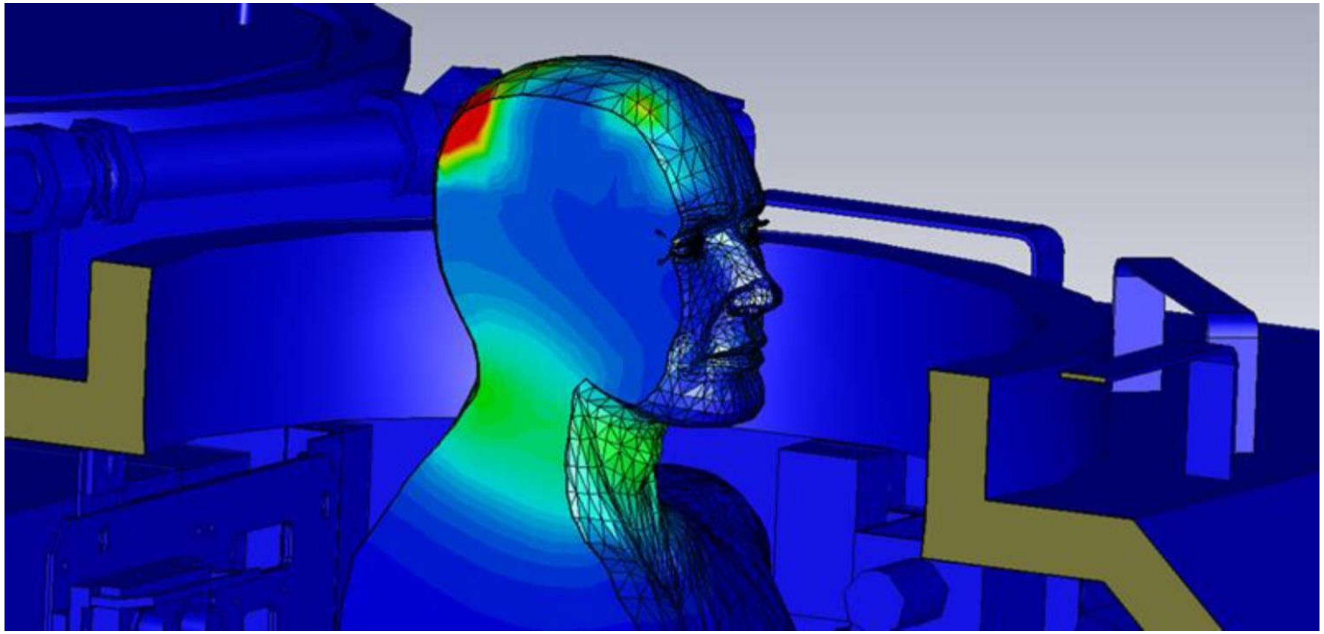


E-Fields exceed occupational limits for the driver

Radhaz Exposure in Vehicles

Phasor Innovation

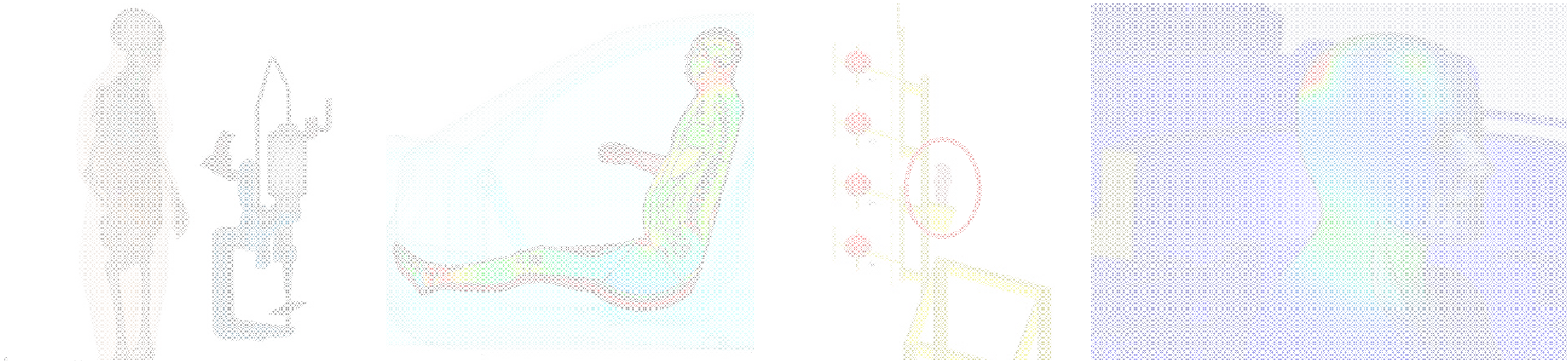
Additional SAR simulation (not part of standard RADHAZ assessment)



Local SAR peak is below the occupational SAR limit, so the driver is safe.

Outline

- Radiation Hazard Introduction
- Human Models for EM Simulation
- Applications:



- Summary

Summary

- Legal requirements make RadHaz compliance increasingly important

- Measurement campaigns are costly, and do not always give the full picture of field behaviour in a complex environment
- Thus simulation is a critically important tool to complement measurement

- Simulation can be challenging due to large frequency range and required complex body models and environments

CST STUDIO SUITE® Complete Technology provides the solutions needed for this multiscale, multiphysics problem

EU Directive

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

Table A1

Health effects ELVs for exposure to electromagnetic fields from 100 kHz to 6 GHz

Health effects ELVs	SAR values averaged over any six-minute period
ELVs related to whole body heat stress expressed as averaged SAR in the body	0,4 Wkg^{-1}
ELVs related to localised heat stress in head and trunk expressed as localised SAR in the body	10 Wkg^{-1}
ELVs related to localised heat stress in the limbs expressed as localised SAR in the limbs	20 Wkg^{-1}

Table B1

ALs for exposure to electric and magnetic fields from 100 kHz to 300 GHz

Frequency range	Electric field strength ALs(E) $[Vm^{-1}]$ (RMS)	Magnetic flux density ALs(B) [μT] (RMS)	Power density ALs(S) $[Wm^{-2}]$
100 kHz ≤ f < 1 MHz	$6,1 \times 10^2$	$2,0 \times 10^6/f$	—
1≤ f < 10 MHz	$6,1 \times 10^8/f$	$2,0 \times 10^6/f$	—
10 ≤ f < 400 MHz	61	0,2	—
400 MHz ≤ f < 2 GHz	$3 \times 10^{-3} f^{½}$	$1,0 \times 10^{-5} f^{½}$	—
2 ≤ f < 6 GHz	$1,4 \times 10^2$	$4,5 \times 10^{-1}$	—
6 ≤ f ≤ 300 GHz	$1,4 \times 10^2$	$4,5 \times 10^{-1}$	50

Directive 2013-35-EU

Non-binding practical guides early in 2016

Transposition into laws by July 1, 2016