UNIVERSITAT DE BARCELONA

Wireless Biodevices and Systems

In-body

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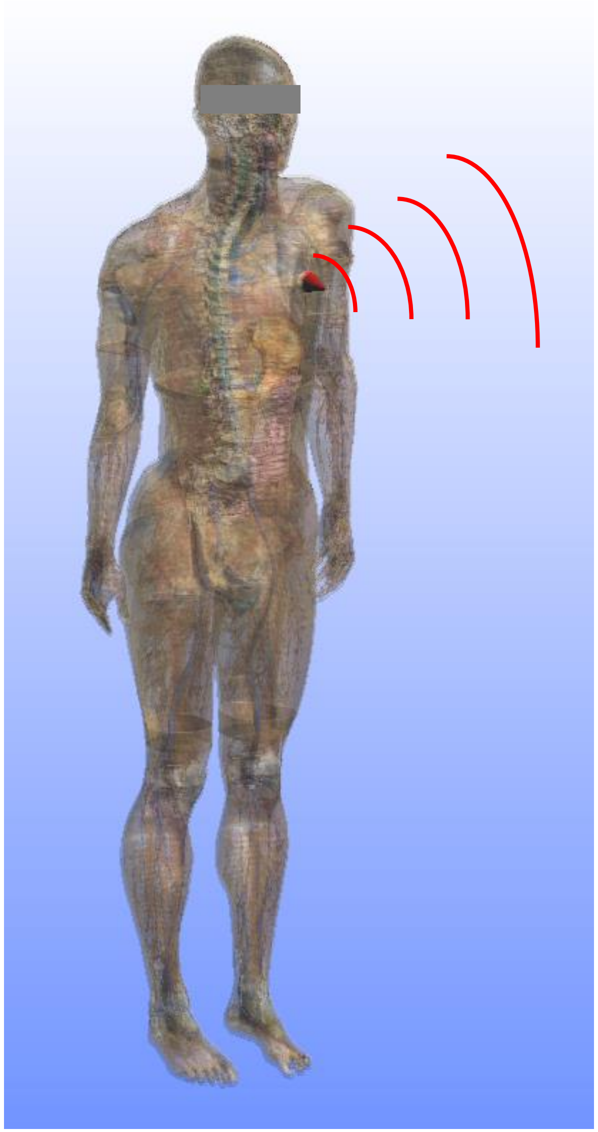
OUTLINE

- Introduction
- Challenges
- Modelling
- Measurements



Scenarios

Channel

In-body

A significant part of the channel is inside the body and implanted transceivers are used. This is called the in-body domain.

The purpose of using antennas for bio-implants can be either for telecommunication (telemetry) or for therapy. In the first case, data is transmitted in or out the human body. In the second case, antennas are used to provide energy, as in hyperthermia applications.

Introduction

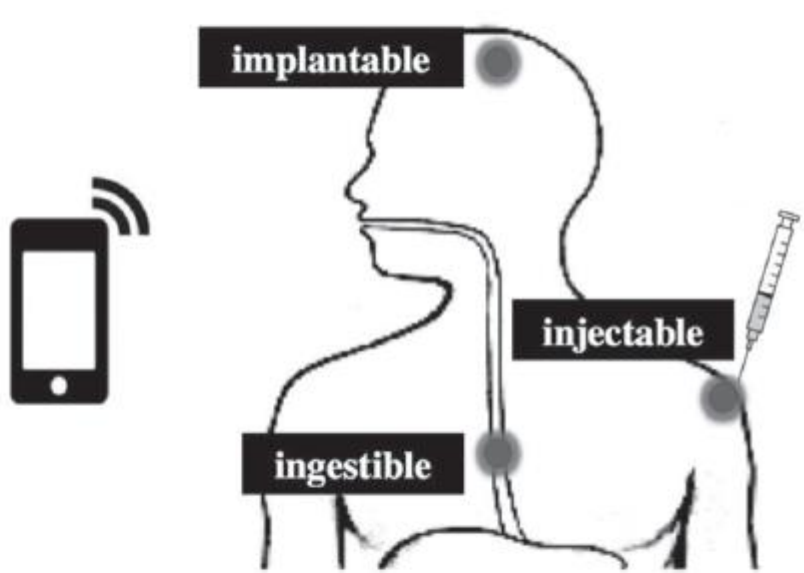
Scenarios

In-body

Implantable,

Ingestible

Injectables



A Review of In-Body Biotelemetry Devices: Implantables, Ingestibles, and Injectables

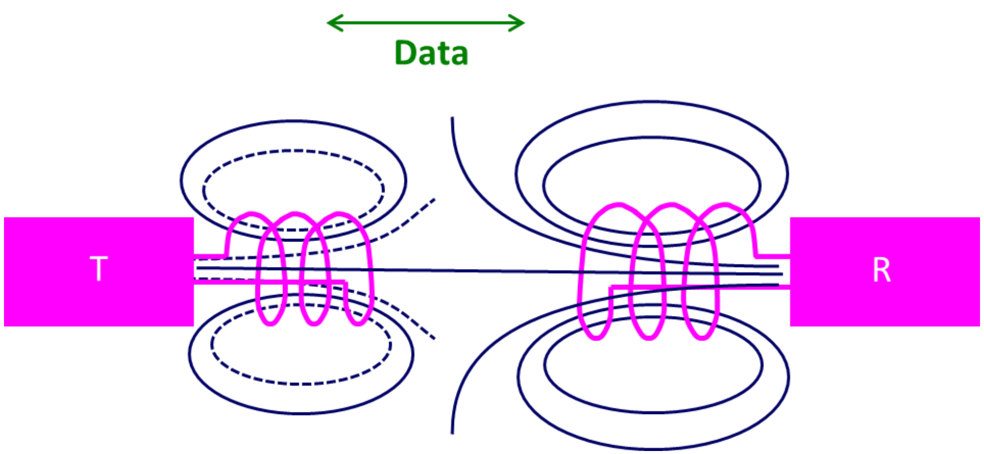
Asimina Kiourti, S. Nikita, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 64, NO. 7, JULY 2017*

Introduction

After an electronic implant has been placed inside the body, it could be a a need for communication with the implant.

The communication with implants is typically done over an inductive link.

Example: The inductive coupling between two coils, one external and one inside the pacemaker case, is used to transfer data to and from the implant.



Very short rang of distances, typically few tens of cm

Low bit rates

There are a number of advantages if the communication with the implant can be moved to a higher carrier frequency:

- Higher bit rates
- Propagating electromagnetic waves, longer communication distances

Medical Device Radiocommunications Service (MedRadio)

The Medical Device Radiocommunications Service (MedRadio) is in the 401 – 406, 413 – 419, 426 – 432, 438 – 444, and 451 – 457 MHz range. MedRadio spectrum is used for diagnostic and therapeutic purposes in implanted medical devices as well as devices worn on a body. For example, MedRadio devices include implanted cardiac pacemakers and defibrillators as well as neuromuscular stimulators that help restore sensation, mobility, and other functions to limbs and organs.

The Medical Device Radiocommunications Service (MedRadio) dates back to 1999 when the FCC established the Medical Implant Communication Service (MICS). At that time, the FCC set aside three megahertz of spectrum at 402 – 405 MHz for medical implant devices. In 2009, the FCC created the Medical Device Radiocommunications Service (MedRadio) in the 401 – 406 MHz range. The creation of the MedRadio Service incorporated the existing MICS spectrum at 402 – 405 MHz and added additional spectrum at 401 – 402 MHz and 405 – 406 MHz for a total of five megahertz of spectrum for implanted devices as well as devices worn on the actual body.

Two fields of application are indicated for this standard: communication between an implantable medical device and an exterior receiving station and communication between medical devices implanted within the same human body. The devices can use up to 300 kHz of bandwidth at a time for the complete session. Equivalently, separate transmitter and receiver bands, each with a bandwidth of 300 kHz, may be adopted as long as they are not used simultaneously. Assuming a full-duplex solution in which the system uses two separate frequencies for up- and downlink transmission, the two link bandwidths should not exceed 300 kHz.

http://www.fcc.gov/encyclopedia/medical-device-radiocommunications-service-medradio

Licensing

The Medical Device Radiocommunications Service (MedRadio) is licensed by rule. Licensed by rule means an individual license is not required to operate a MedRadio device.

Channels

The rules do not specify a channeling scheme for Medical Device Radiocommunications Service (MedRadio) devices. They may operate on any frequency in the MedRadio spectrum that does not exceed these authorized bandwidths:

401 – 401.85 MHz: 100 kHz
401.85 – 402 MHz: 150 kHz
402 – 405 MHz: 300 kHz
405 – 406 MHz: 100 kHz
413 - 419 MHz: 6 MHz
426 - 432 MHz: 6 MHz
438 - 444 MHz: 6 MHz
451 - 457 MHz: 6 MHz

Operating a Medical Device Radiocommunications Service (MedRadio) Device

Only authorized health care providers are eligible to operate Medical Device Radiocommunications Service (MedRadio) devices.

http://www.fcc.gov/encyclopedia/medical-device-radiocommunications-service-medradio

Introduction

The maximum transmit power is very low:
EIRP=25µw

In radio communication systems, equivalent isotropically radiated power (EIRP) or, alternatively, effective isotropically radiated power is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna.

The EIRP is often stated in terms of decibels over a reference power emitted by an isotropic radiator with an equivalent signal strength. The EIRP allows comparisons between different emitters regardless of type, size or form. From the EIRP, and with knowledge of a real antenna's gain, it is possible to calculate real power and field strength values.

$$EIRP = P_T - L_c + G_a$$

Industrial, Scientific, and Medical

The ISM bands were originally reserved internationally for noncommercial use of radio frequency (RF) electromagnetic fields. They are defined by the ITU-R, but individual countries' use of the bands differs due to variations in national radio regulations. The 902–928- and 2400.0–2483.5-MHz frequency bands are used in the United States and are defined by the FCC, whereas the European countries use the 433.1–434.8- and 868.0–868.6-MHz frequency bands, which are defined by the Electronic Communications Committee (ECC).

The ISM bands offer users the advantage of increased bandwidth, thus enabling video and voice transmissions.

Since government approval is not required, the ISM bands are nowadays being used by a wide variety of commercial standards. However, the ISM bands are not exclusive to biomedical telemetry equipment, meaning that transmission of sensitive medical data in these bands is susceptible to interference from other devices.

Introduction

Frequency range		Bandwidth	Center frequency	Availability
6.765 MHz	6.795 MHz	30 kHz	6.780 MHz	Subject to local acceptance
13.553 MHz	13.567 MHz	14 kHz	13.560 MHz	Worldwide
26.957 MHz	27.283 MHz	326 kHz	27.120 MHz	Worldwide
40.660 MHz	40.700 MHz	40 kHz	40.680 MHz	Worldwide
433.050 MHz	434.790 MHz	1.74 MHz	433.920 MHz	Region 1 only and subject to local acceptance (within the amateur radio 70 cm band)
902.000 MHz	928.000 MHz	26 MHz	915.000 MHz	Region 2 only (with some exceptions)
2.400 GHz	2.500 GHz	100 MHz	2.450 GHz	Worldwide
5.725 GHz	5.875 GHz	150 MHz	5.800 GHz	Worldwide
24.000 GHz	24.250 GHz	250 MHz	24.125 GHz	Worldwide
61.000 GHz	61.500 GHz	500 MHz	61.250 GHz	Subject to local acceptance
122.000 GHz	123.000 GHz	1 GHz	122.500 GHz	Subject to local acceptance
244.000 GHz	246.000 GHz	2 GHz	245.000 GHz	Subject to local acceptance

http://en.wikipedia.org/wiki/ISM_band

Introduction

The standard is defined by the **U.S. Federal Communications Commission** (FCC) and **European Telecommunications Standards Institute** (ETSI)

Standards

- FCC Rules and Regulations, “MICS Band Plan”, Part 95, Jan. 2003.

- 47 CFR 95.601-95.673 Subpart E, Federal Communications Commission, 1999.

- ETSI EN 301 839-1 "Electromagnetic compatibility and Radio spectrum Matters (ERM);Short Range Devices (SRD);Ultra Low Power Active Medical Implants(ULP-AMI) and Peripherals (ULP-AMI-P) operating in the frequency range 402 MHz to 405 MHz;Part 1: Technical characteristics and test methods.", European Telecommunications Standards Institute, 2009.

Challenges

Challenges

further miniaturization

sensor technology

power/harvesting

communication link

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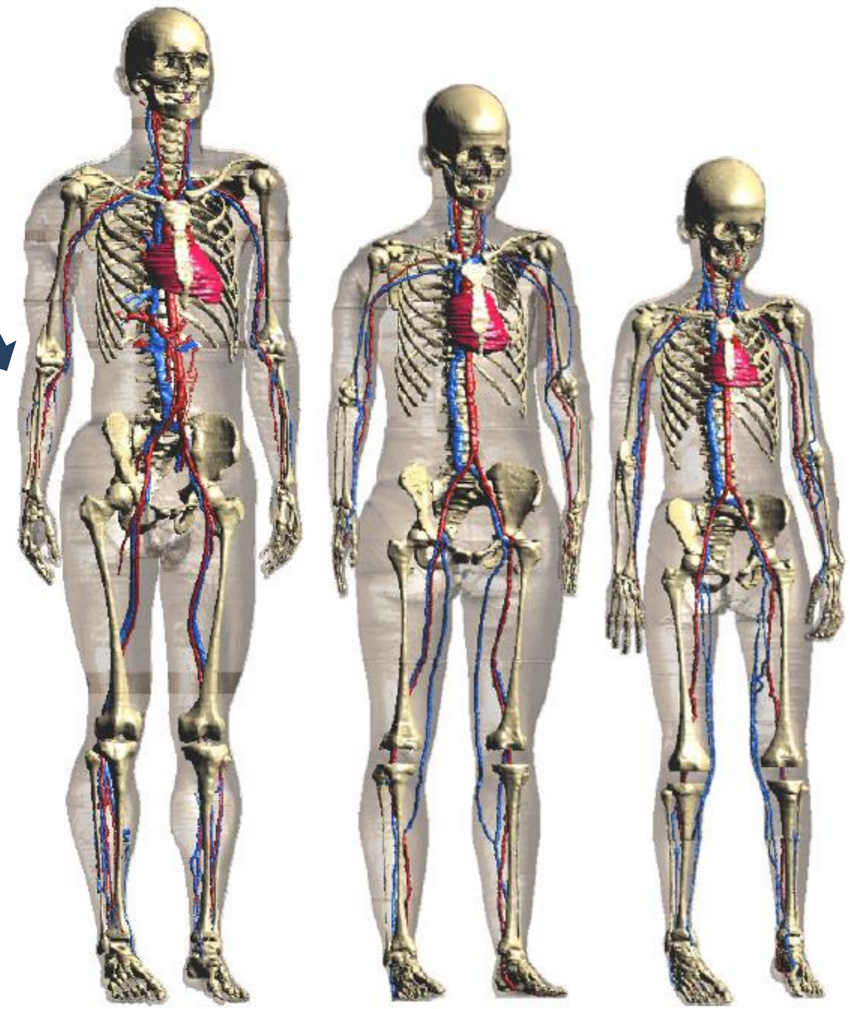
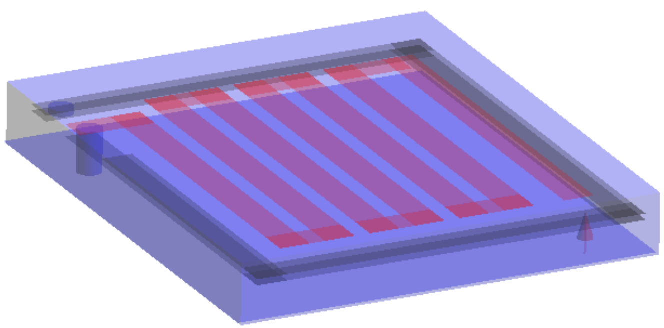


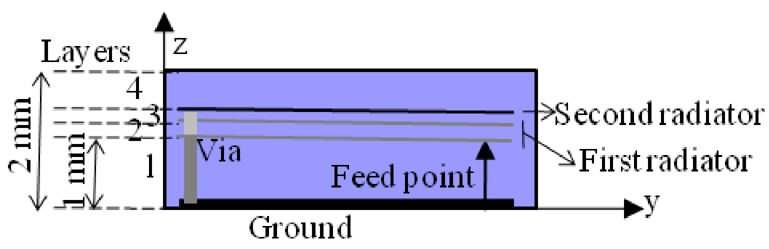
Christ, A., W. Kainz, E. G. Hahn, K. Honegger, M. Zefferer, E. Neufeld, W. Rascher, R. Janka, W. Bautz, J. Chen, B. Kiefer, P. Schmitt, H. P. Hollenbach, J. Shen, M. Oberle, D. Szczerba, A. Kam, J. W. Guag, and N. Kuster, "The virtual family-development of surface-based anatomical models of two adults and two children for dosimetric simulations," Phys. Med. Biol., Vol. 55, 23-38, 2010.

1- Miniaturization

Implants have to be small in order to facilitate the surgical procedure, while in the MedRadio band the free space wavelength is around 74 cm. This implies that implantable antennas must be heavily miniaturized, leading to the design of a small antenna with dimensions of some fractions of the free space wavelength (typically $\lambda/30$).

Implantable antennas are usually electrically small antennas. Decreasing the electrical size of an antenna will lead to a decrease of its electromagnetic performances and many studies focus on how to obtain a good compromise between geometry and radiation characteristics.





Challenges

2 -Small antennas in lossy media: communication link

The communication link is probably one of the major challenges. The implantable antenna should provide a signal that is strong enough to be picked up by the exterior device, regardless of any power limitations. It is important to highlight that accounting for patient safety a strict limit of −16 dBm (25 μW) has been set on the effective radiated power of implantable medical devices operating in the MedRadio band. The main quality criterion in the design of such antennas is the amount of power the antenna is able to transmit out of the host body.

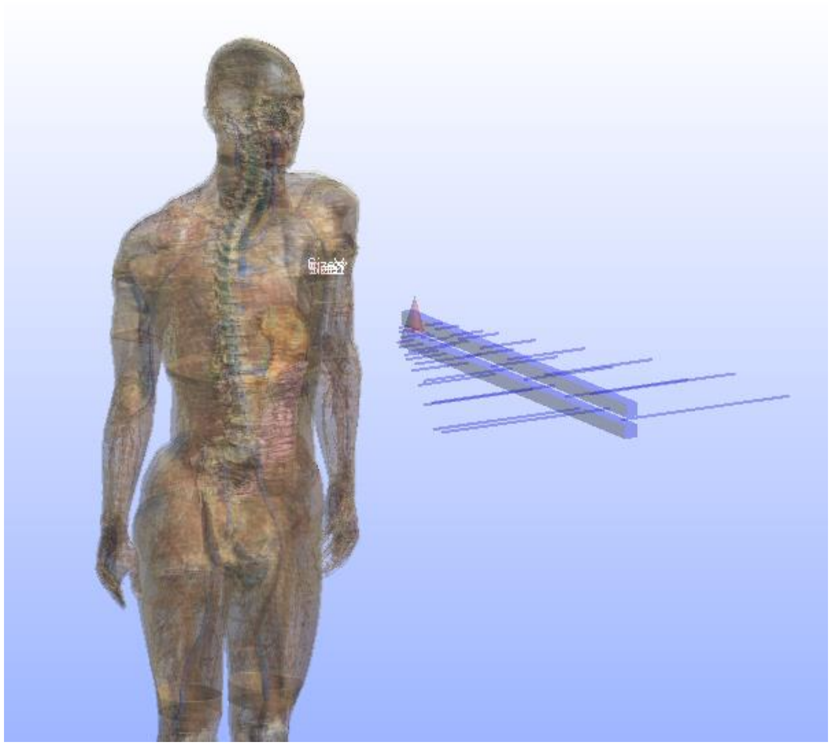
3 – Propagation inside the human body

For medical implants, to establish the communication link RF electromagnetic waves typically may need to traverse layers of alternating high and low dielectric property values. The large variance between different layers results in significant reflections, which reduce the strength of the signal. Moreover, asymmetrical radiation will be recorded within anatomical tissue models that are irregular and inhomogeneous.

4- Antenna encapsulation

Implantable antennas must be biocompatible in order to preserve patient safety and prevent rejection of the implant. Moreover prevention of undesirable short-circuits are especially crucial in the case of antennas that are intended for long-term implantation. Biocompatible insulation must embed the implantable device.

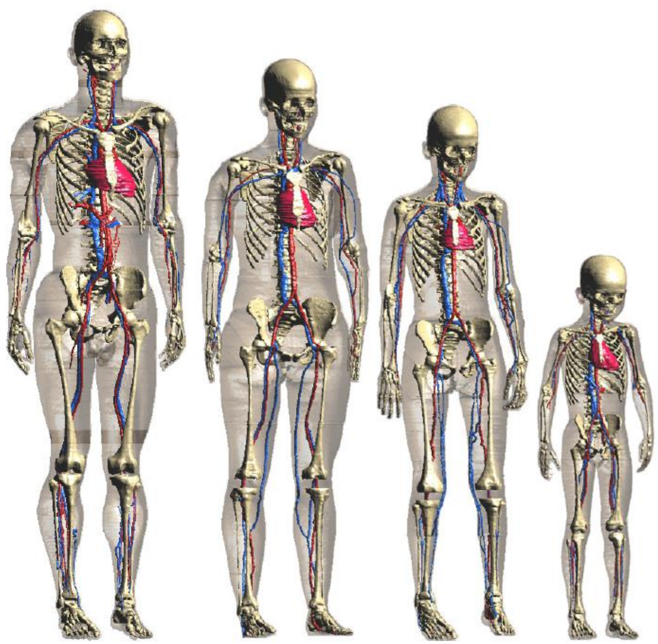
Nevertheless, the shape and dimensions of the capsule can have an important effect on the radiating characteristics of an implanted antenna. This is also a main topic that should be analyzed to improve the performance on the antennas and enhance the communication link as much as possible.



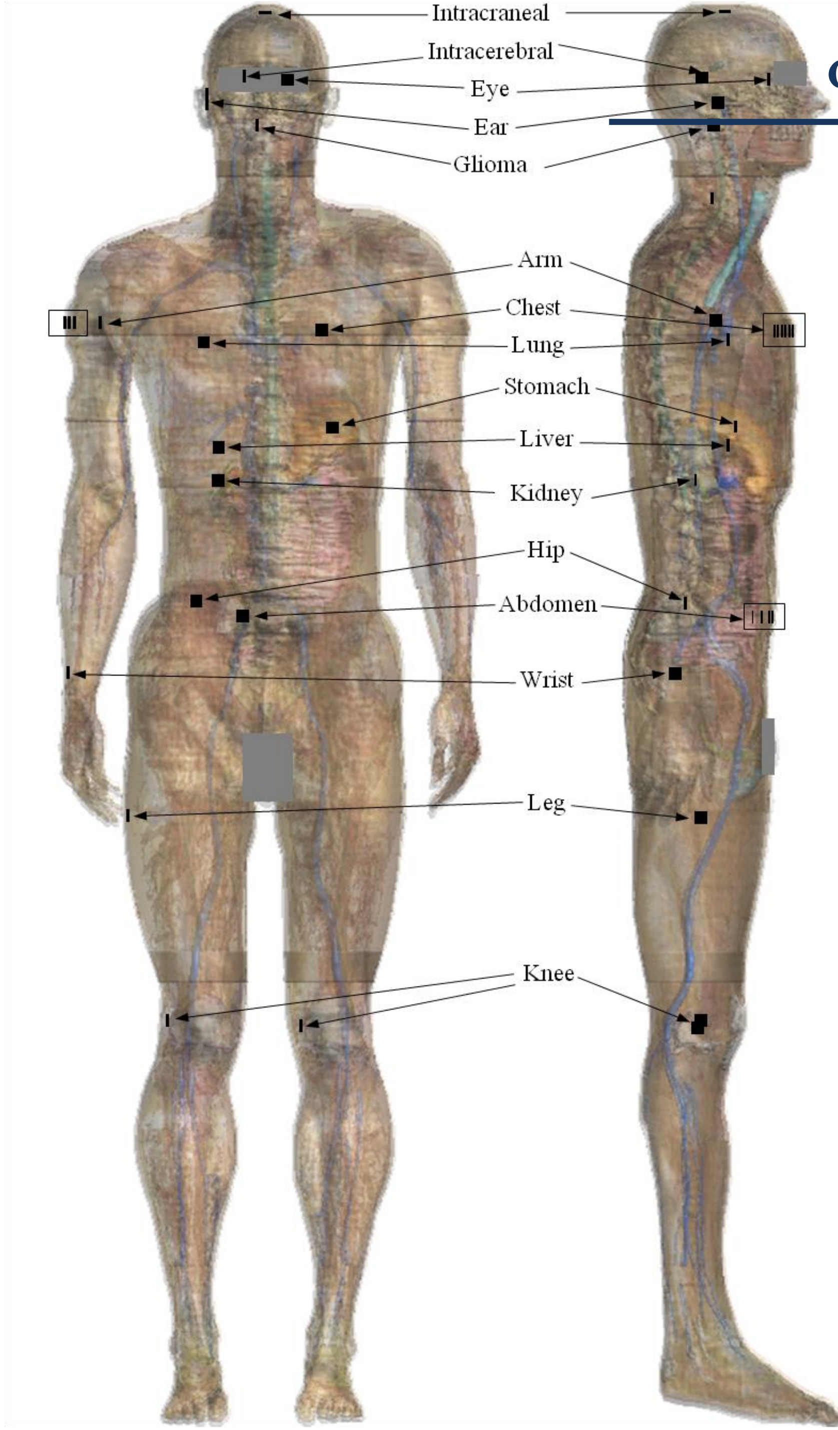
5- Antenna detuning

Detuning effects have already been identified as a major challenge for the design of implantable antennas. The anatomical distribution as well as the different electrical properties and dimensions of the various tissues may affect the performance of the devices. Moreover, these anatomical characteristics vary from individual to individual. An antenna optimized for one location and person may not be adequately tuned for another location or person .

In general, the design of the antennas takes into consideration specific single tissues and they are tested using tissue-equivalent liquids, mimicking gels and animals.

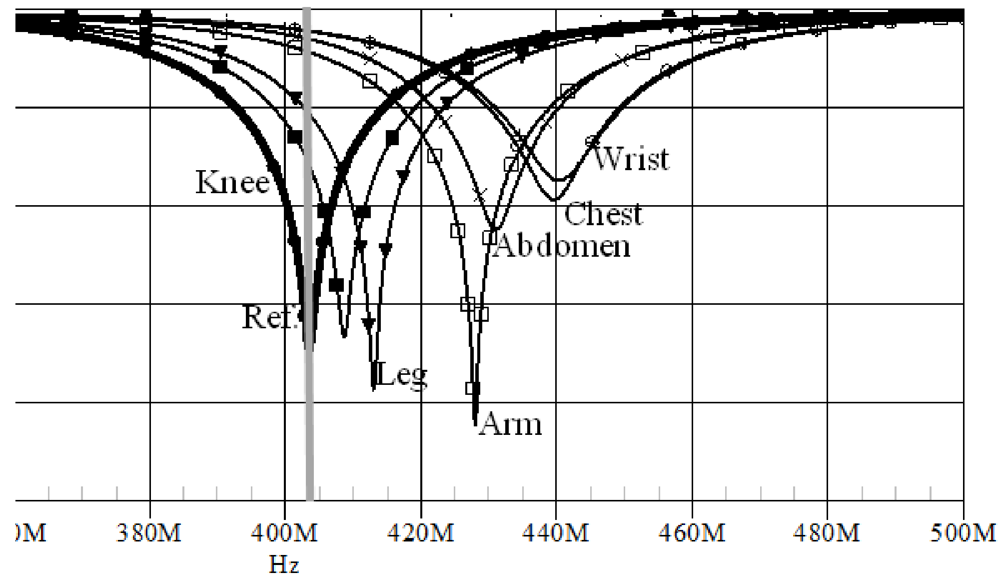


Christ, A., et al., "The virtual family-development of surface-based anatomical models of two adults and two children for dosimetric simulations," Phys. Med. Biol., Vol. 55, 23-38, 2010.

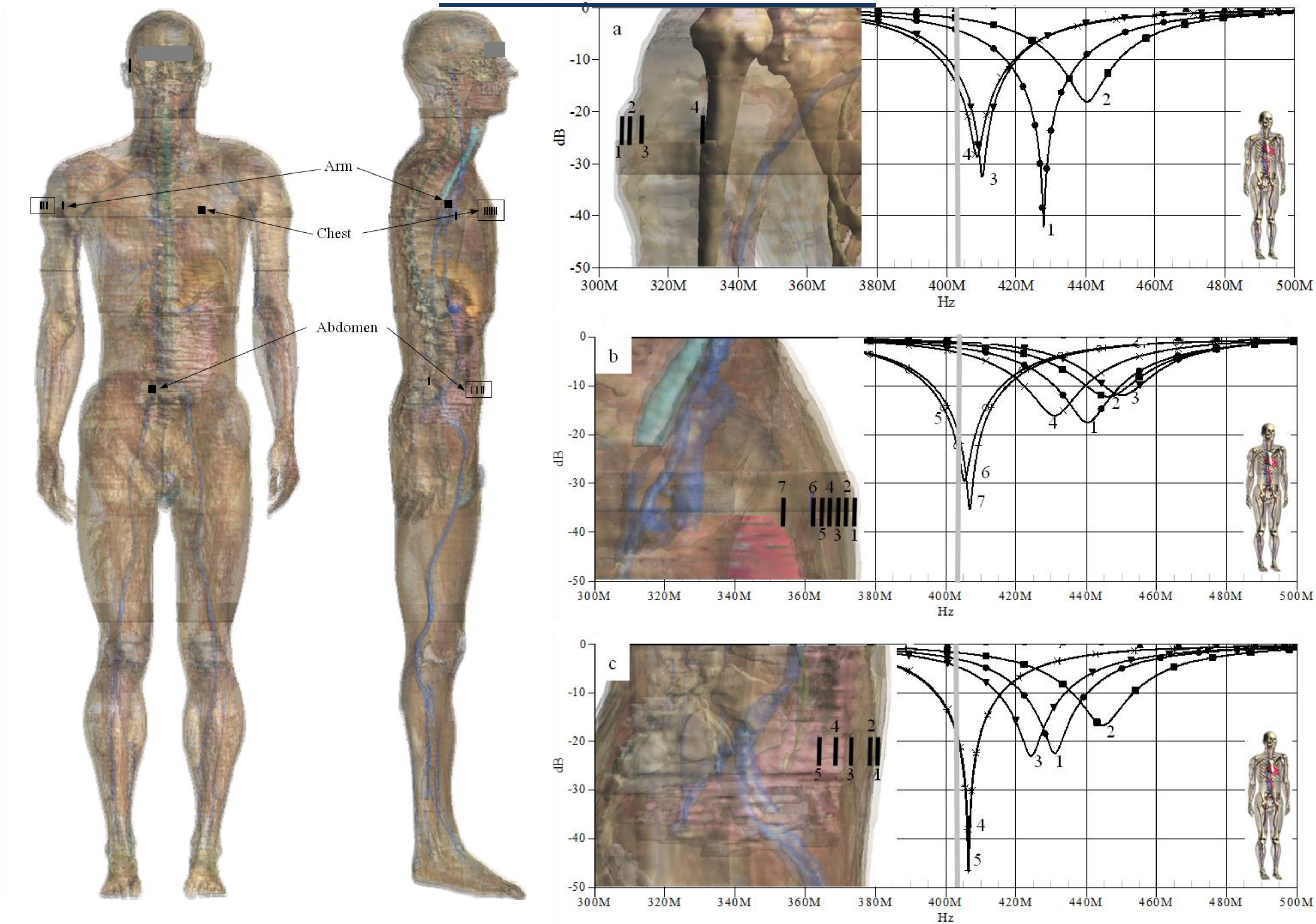


Challenges

Example



Challenges

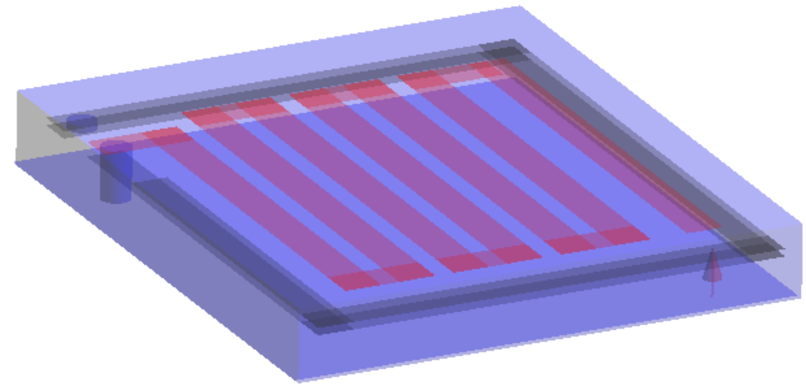


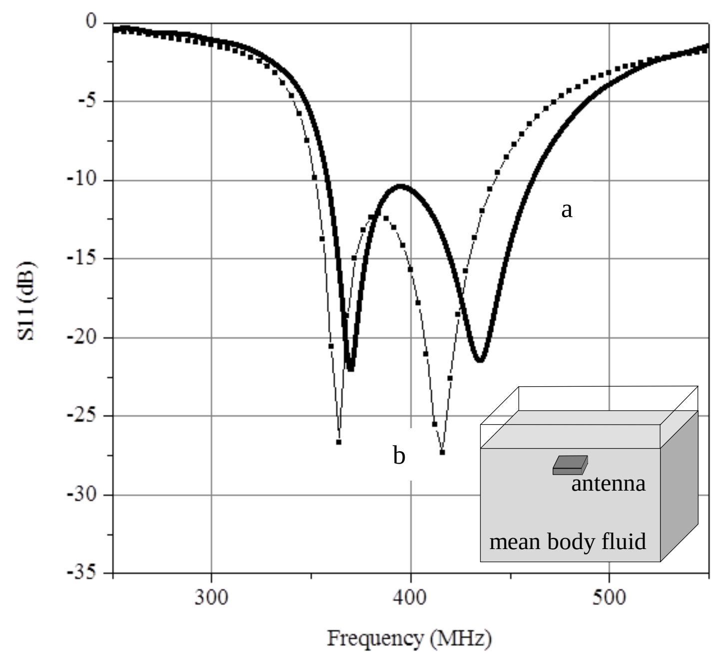
Arm
Chest
Abdomen
a
b
c
dB
Hz
0
-10
-20
-30
-40
-50
300M
320M
340M
360M
380M
400M
420M
440M
460M
480M
500M

7 – Physical testing

An implanted laboratory setting is required to produce relevant results/measurements. The use of representative human body phantoms allows for testing.

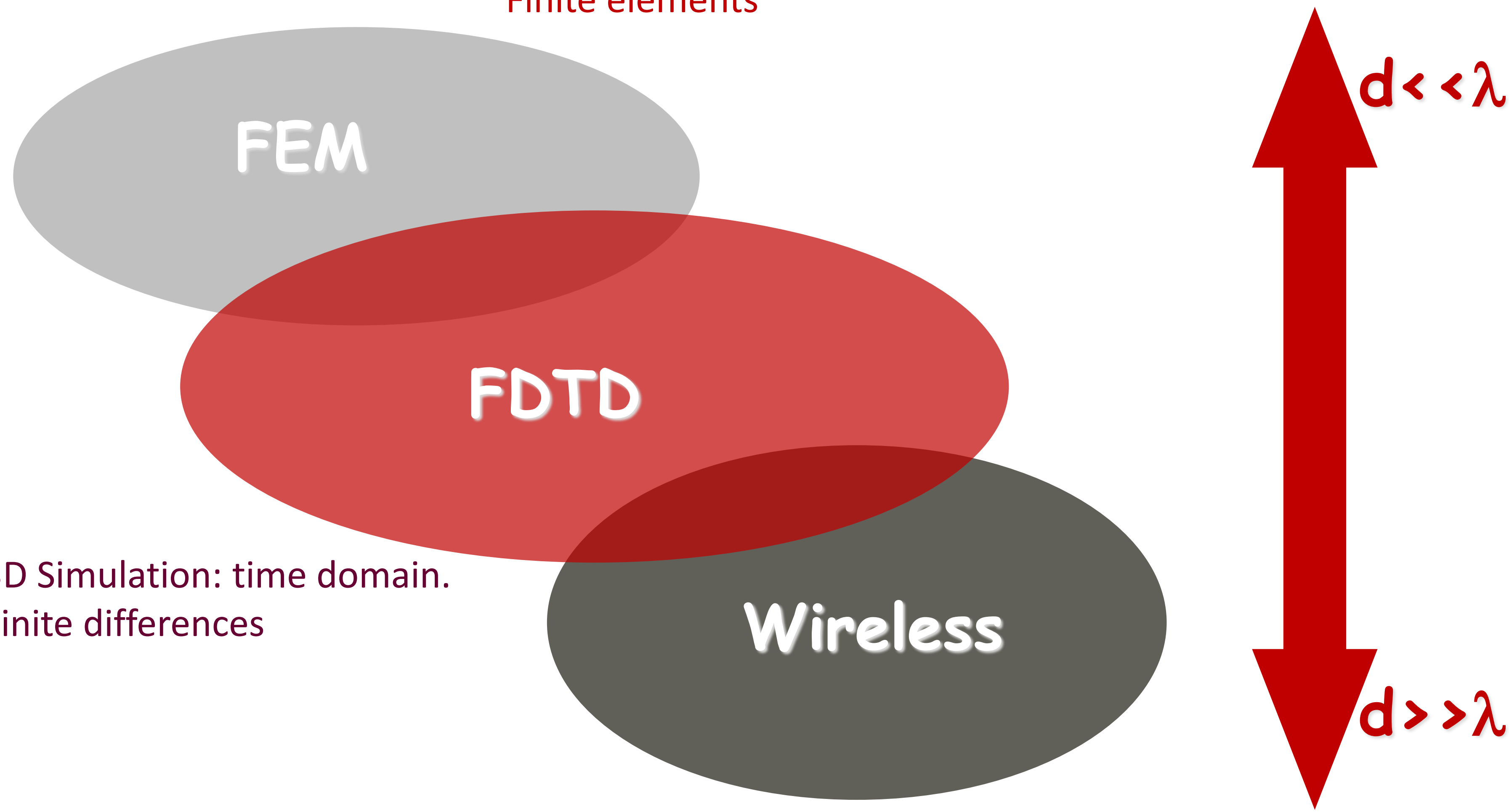
A general procedure for a proper qualitative characterization of the antenna is not standardized.





Modelling

3D Simulation: frequency domain
Finite elements



3D Simulation: time domain.
Finite differences

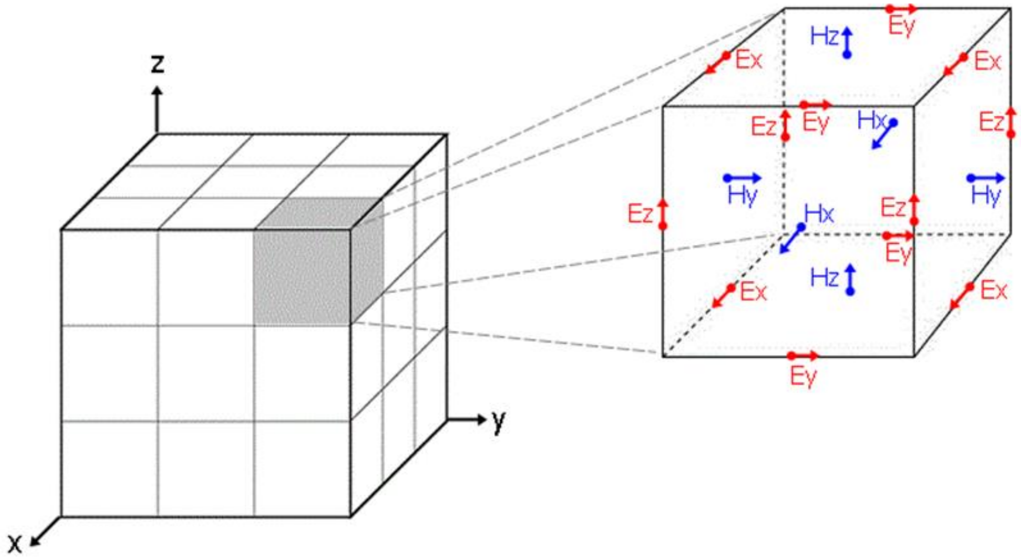
3D Simulation: geometric propagation
Ray tracing

Numerical methods

The finite-difference time-domain (FDTD) method is probably the most widely used computational method for bioelectromagnetic dosimetry because of its versatility and computational efficiency.

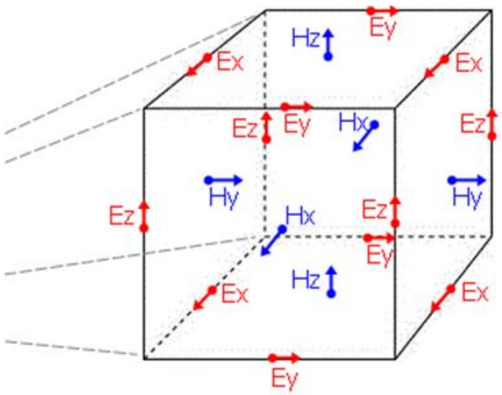
The FDTD method solves differential equations in partial derivatives approaching the differential operators by operators over finite differences. This allows the resolution of the Maxwell equations in the temporal domain. The way to define the finite differences is to convert the target volume into small cuboid cells with significantly smaller dimensions than the radiation wavelength.

The electric fields are defined at the center of the edges of the cubes, while the magnetic fields are taken to be at the center of the faces. Thus, cells with three electric fields and three magnetic fields can be obtained, and the Maxwell equations in finite difference equations can be solved for each cell.



The Finite-Difference Time-Domain method (FDTD) proposed by Yee in 1966 is a direct solution of Maxwell's curl equations in the time domain. The electric and magnetic field components are allocated in space on a staggered mesh of a Cartesian coordinate system.

$$\frac{E_x|^{n+1}_{i,j,k} - E_x|^{n}_{i,j,k}}{\Delta t} = \frac{1}{\epsilon_{i,j,k}} \left(\frac{H_z|^{n+1/2}_{i,j+1/2,k} - H_z|^{n+1/2}_{i,j-1/2,k}}{\Delta y} - \frac{H_y|^{n+1/2}_{i,j,k+1/2} - H_y|^{n+1/2}_{i,j,k-1/2}}{\Delta z} - \sigma_{i,j,k} E_x|^{n+1/2}_{i,j,k} \right).$$



FDTD cell

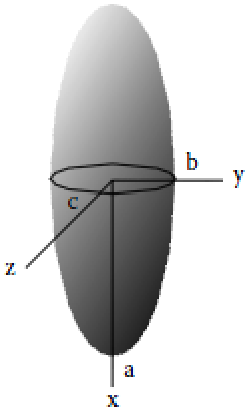
Maxwell's curl equations are discretized using a 2nd order finite-difference approximation both in space and in time in a mesh that is equidistant.

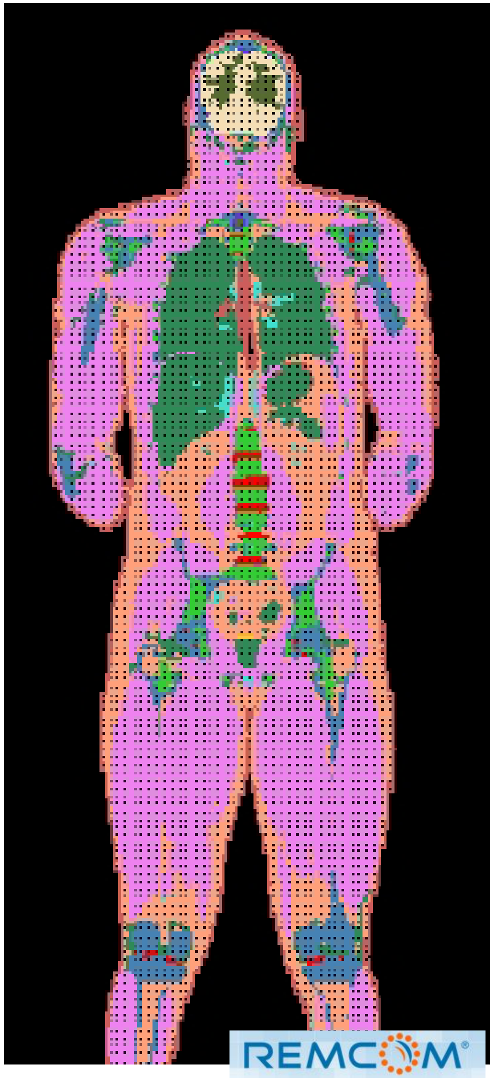
It can efficiently model the heterogeneity of the human body with high resolution, can model anisotropy and frequency-dependent properties as needed, and can easily model a wide variety of sources coupled to the body over an extremely wide range of frequencies, from 60 Hz to 16 GHz, and also for broadband applications.

Human models.

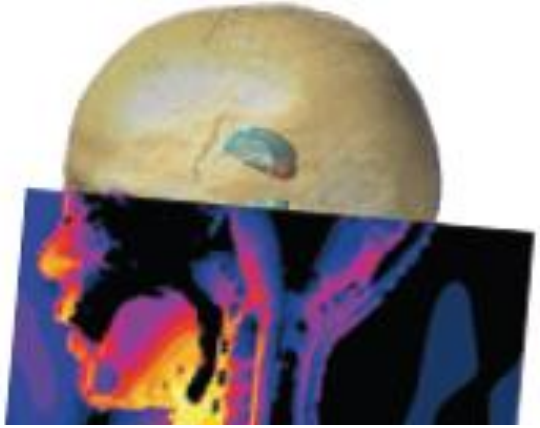
Models have progressed from spheroidal models to MRI-based models of the body. Poser models are also available.

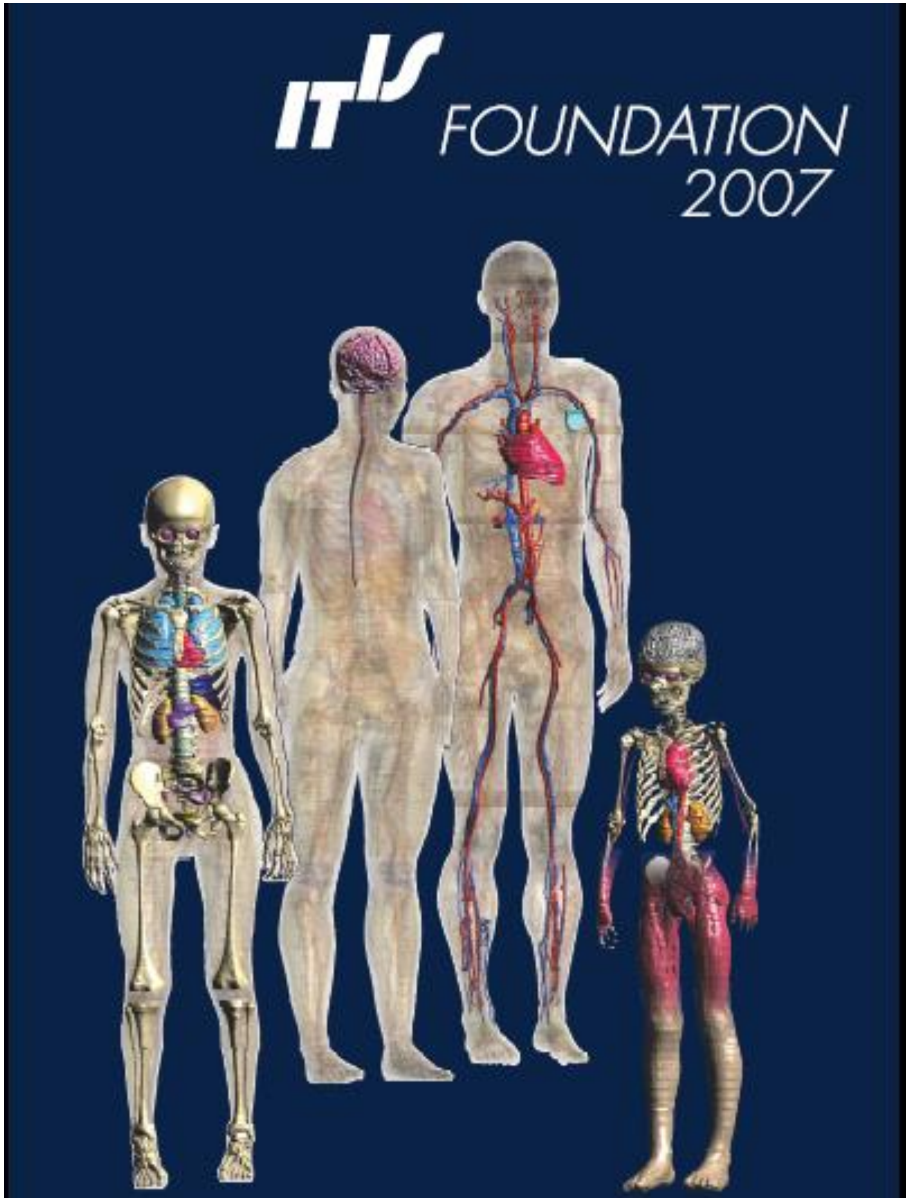
MRI scans provide an initial database for voxel-based models. The images are interpreted as gray-scale images by which the several tissues can be seen. Image segmentation is necessary to convert these density mappings into mappings of tissue type.





The "Virtual Family" dataset consists on four anatomical computer models of an adult male, an adult female and two children.



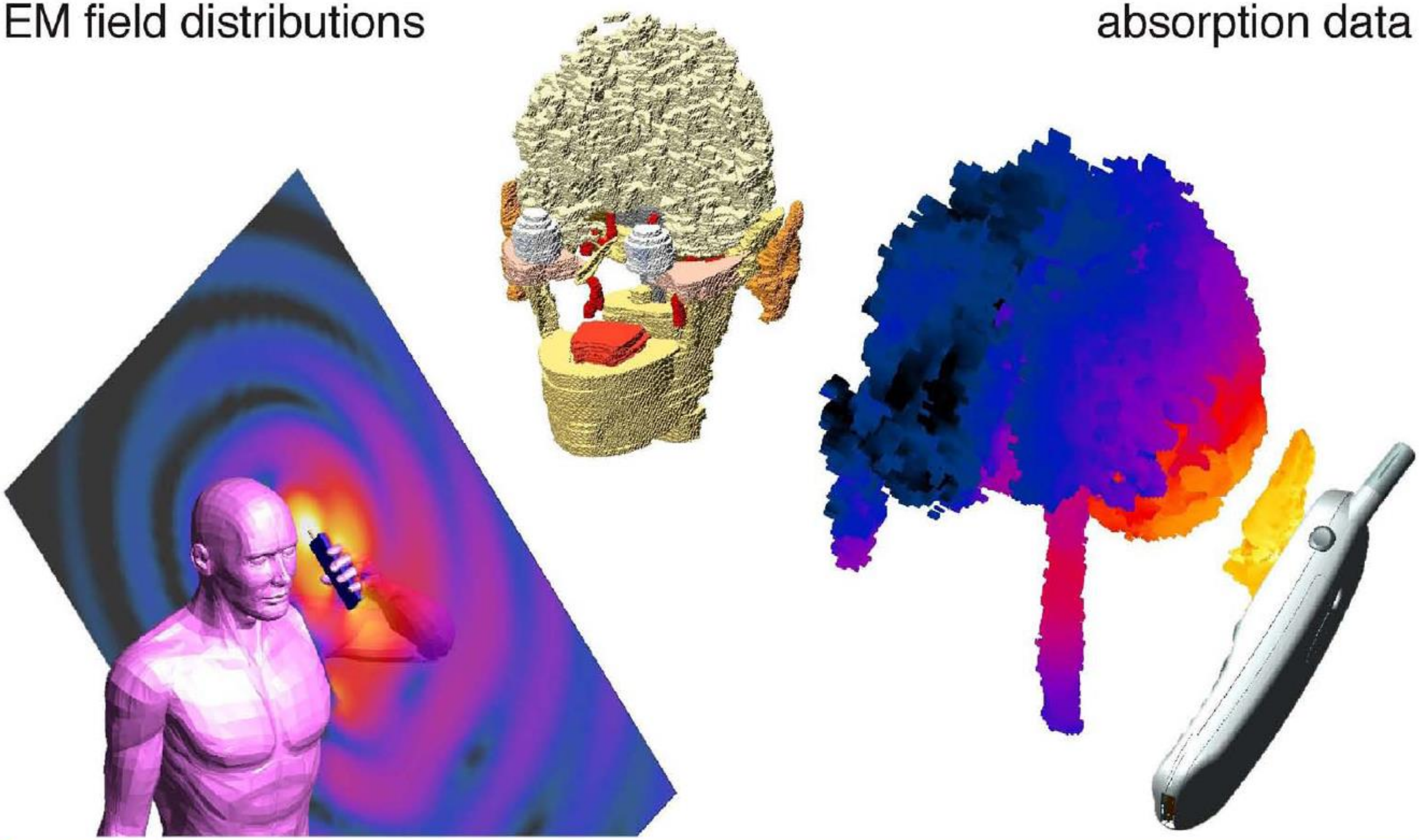


SEMCAD X: Applications

General Dosimetry: Anatomical Phantoms Database

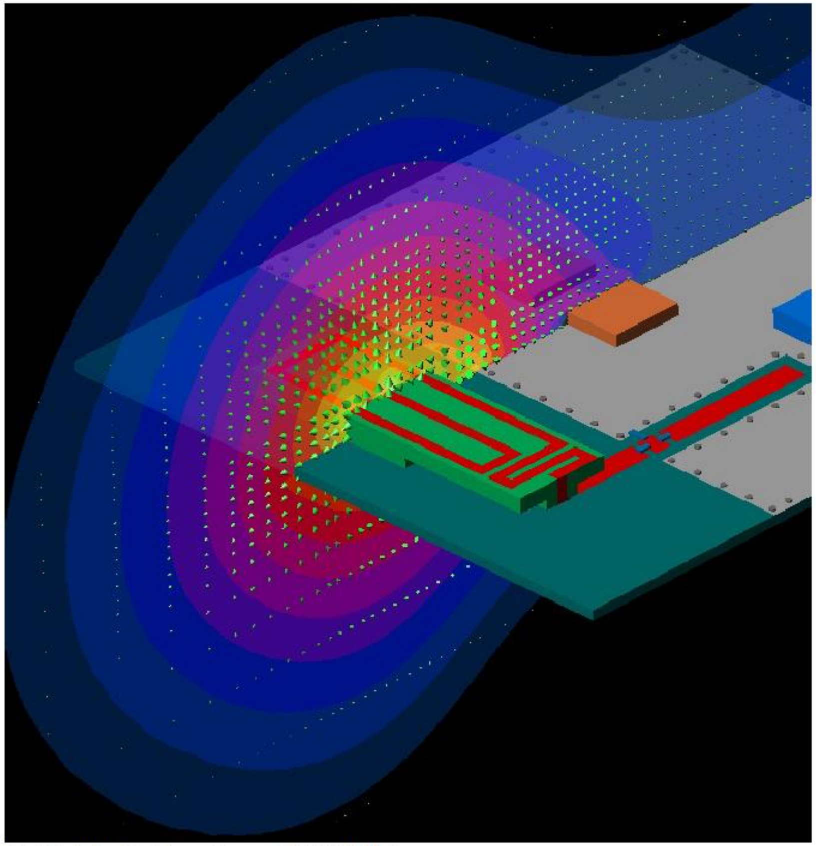
EM field distributions

absorption data

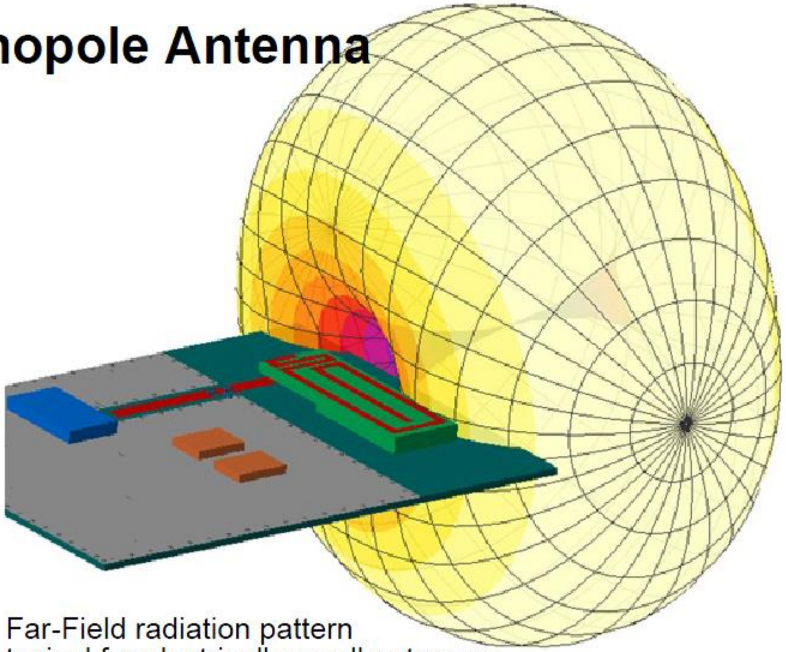


SEMCAD X: Applications

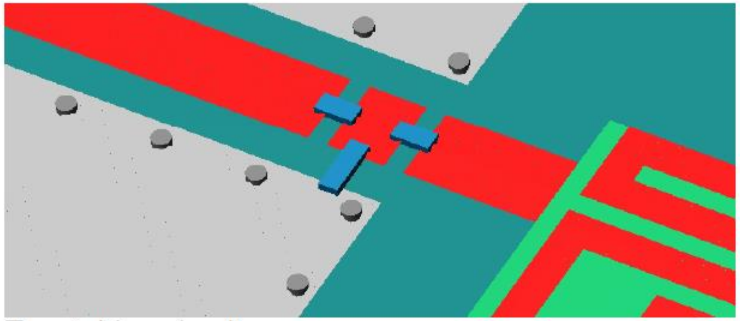
Antenna Applications: Folded Monopole Antenna



E-Field distribution at 900MHz



Far-Field radiation pattern
typical for electrically small antennas



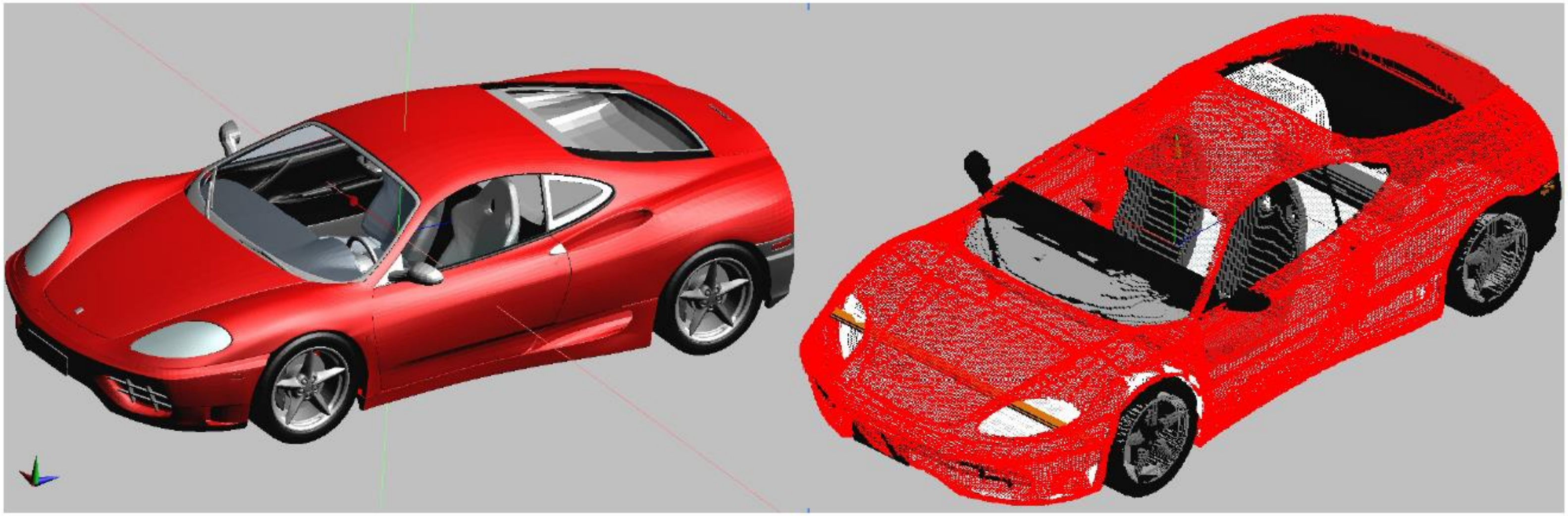
T-matching circuit

Antenna Applications: Automobile Simulations

The superior features of **SEMCAD X** now even allow the simulation of a detailed car model with a person speaking on a mobile phone in the car.

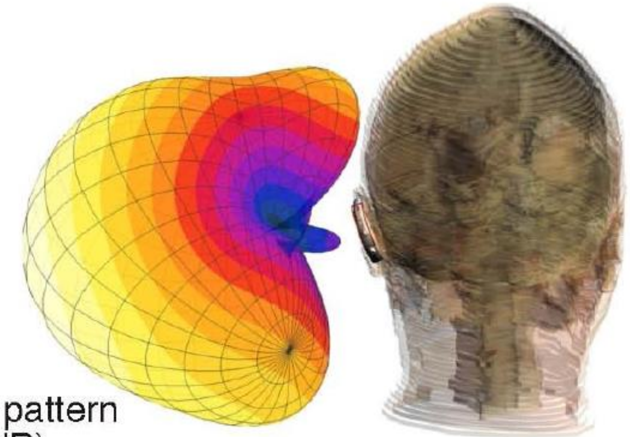
Typical challenges to be solved:

- spans a large computational domain (5m x3.5 m x2.5m) compared to the wavelength
- requires a fine grid resolution to resolve the detailed antenna structure
- contains largely non-conformal PEC and dielectric structures

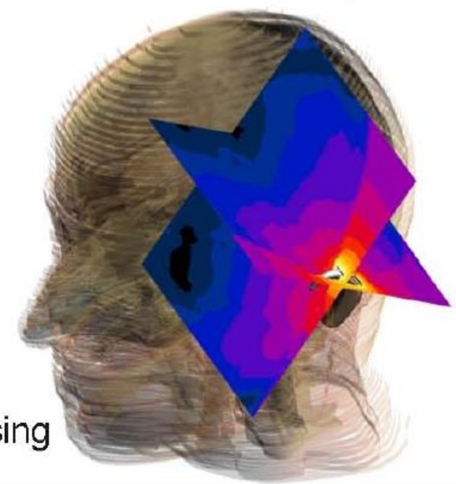


SEMCAD X: Applications

Medical Applications: Body Mounted Devices e.g. Hearing Aid



radiation pattern
E_total (dB)

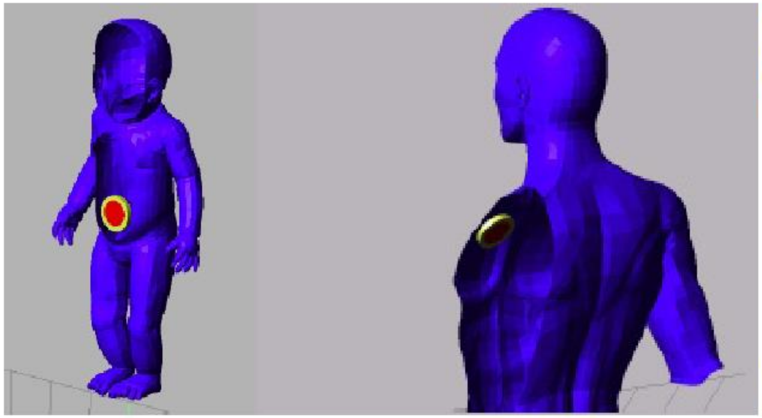


- BTE placed at EF-1 head model
- min cell = 0.15 mm
- about 12 mil. cells

E-field (dB)
in two planes crossing
head and BTE

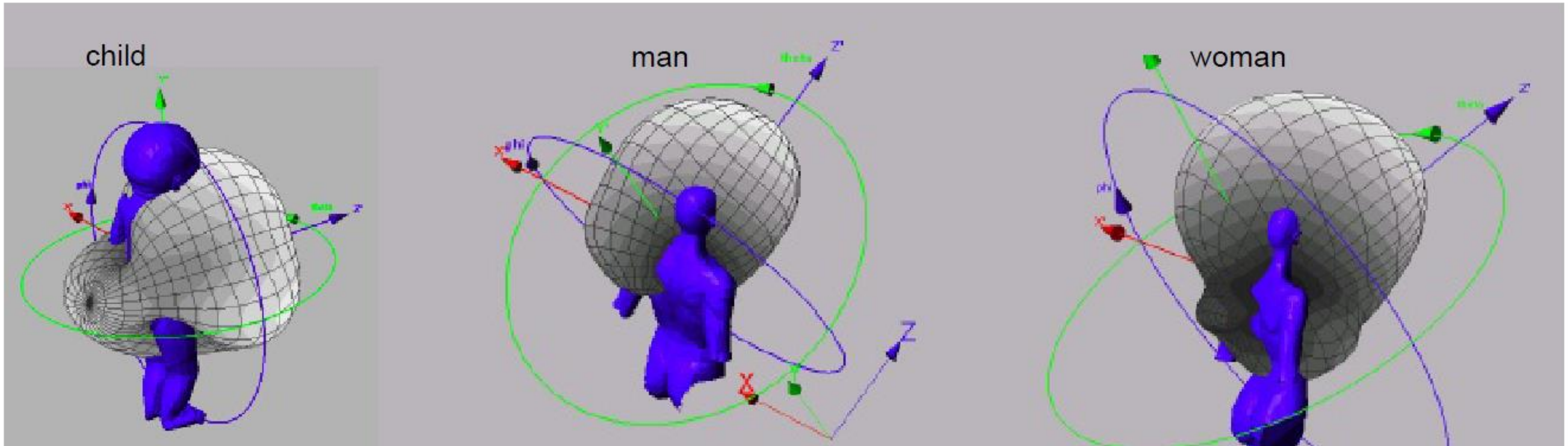
SEMCAD X: Applications

Medical Applications: Body Mounted Devices e.g. Pacemaker



Within the same study simulations were run to investigate the effect the patient had on the performance of the device once it was implanted. A variety of phantom models were used to investigate this effect.

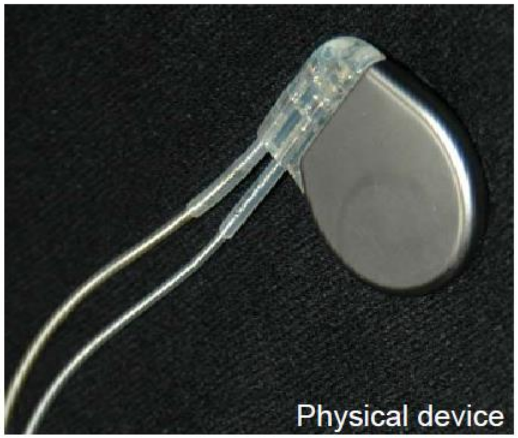
Placement of implant in baby and man phantom models

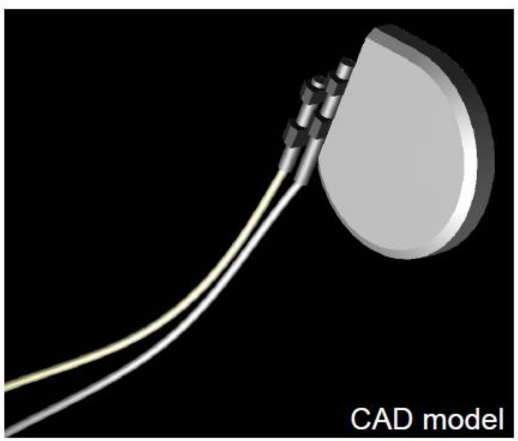


Far-Field and gain results of the implanted pacemaker and circumference antenna

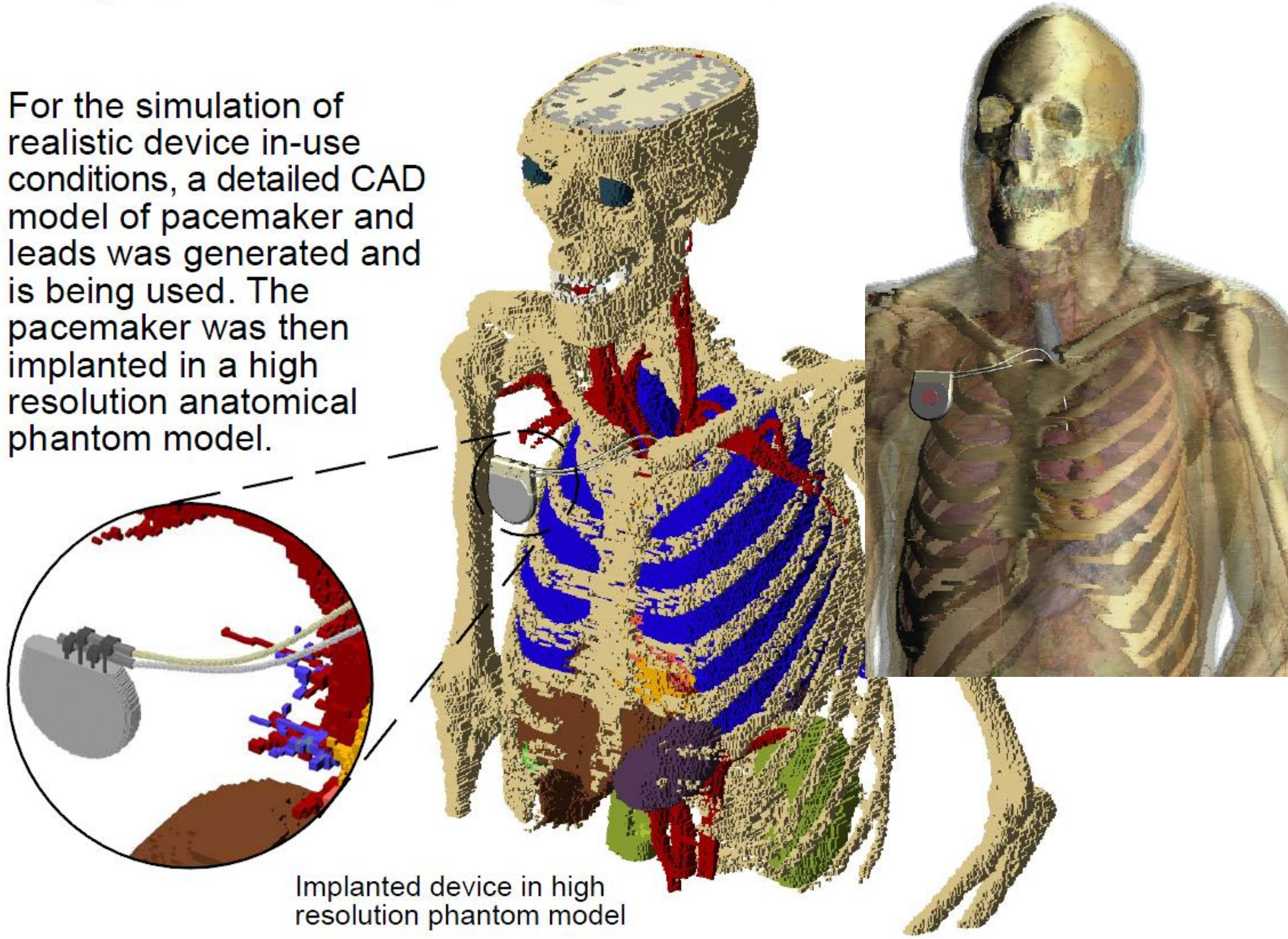
SEMCAD X: Applications

Medical Applications: Body Mounted Devices e.g. Pacemaker


Physical device

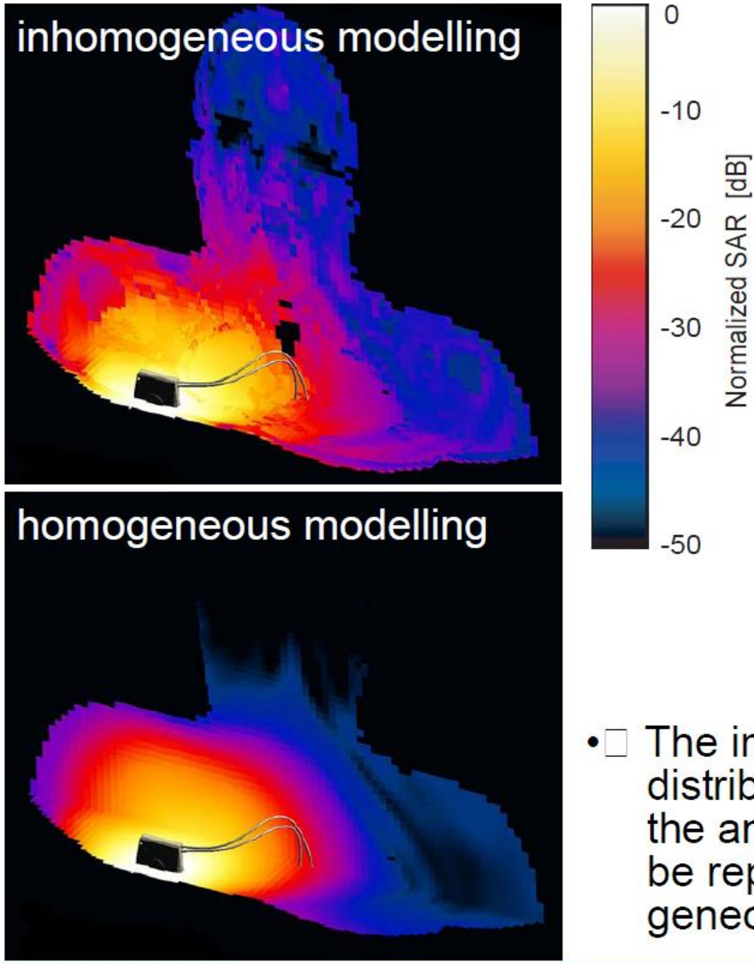

CAD model

For the simulation of realistic device in-use conditions, a detailed CAD model of pacemaker and leads was generated and is being used. The pacemaker was then implanted in a high resolution anatomical phantom model.


Implanted device in high resolution phantom model

SEMCAD X: Applications

SAR/E-Field Distribution in/on the body

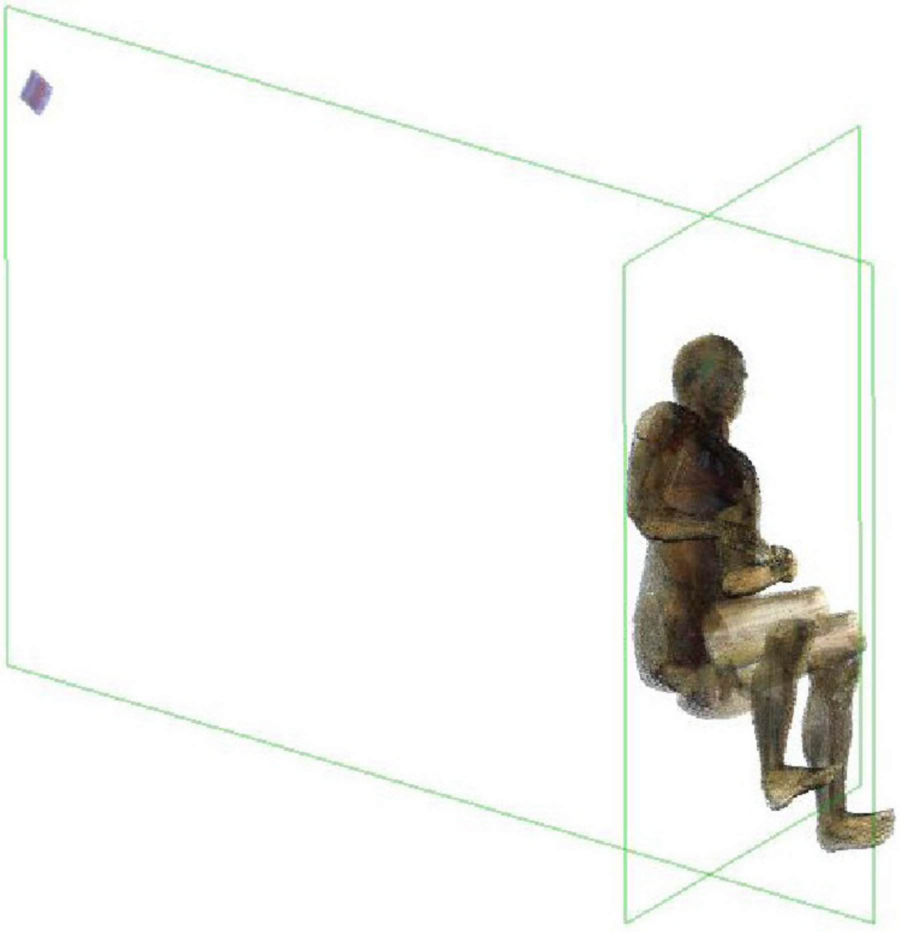


- The impact of the tissue distribution on local SAR and the antenna matching cannot be reproduced by homo-geneous modeling.

SEMCAD X: Applications

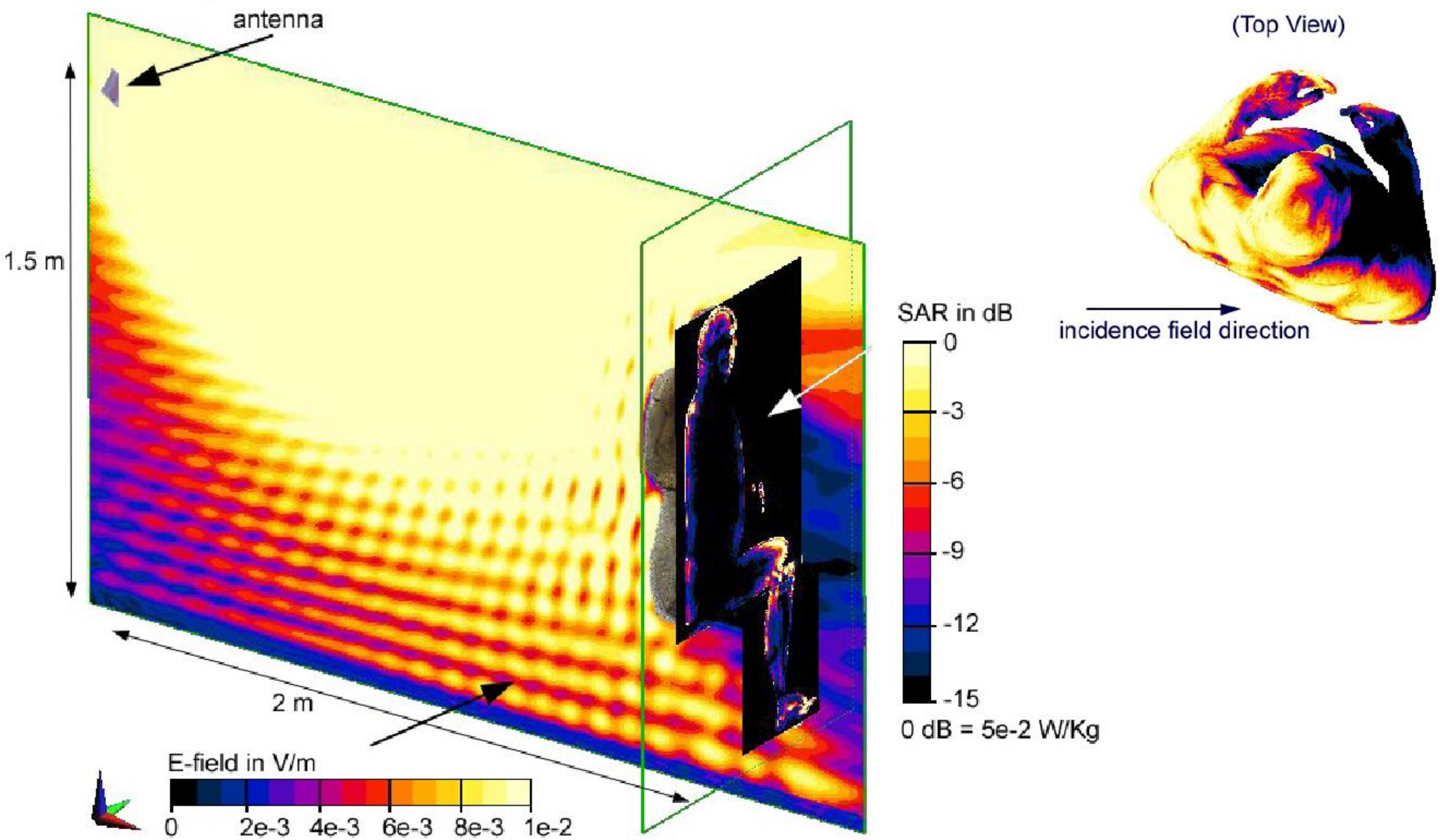
WLAN Antenna: Exposure within a room at 2.45 GHz

- Simulation of WLAN antenna placed within a room (1.5x 1.5x 2 m)
- Full-body high resolution anatomic phantom placed in the room
- The antenna is driven at 2.45 GHz; SAR data is recorded
- Due to the electrically large size of the computational the simulations must be performed using a 64-bit computer with 8 GB RAM
- The resulting computational contains 180 million cells



SEMCAD X: Applications

WLAN Antenna: Exposure within a room at 2.45 GHz



 s p e a g

Measurements

Phantom analysis