Dosimetria numerica nei sistemi WPT in ambito automotive: metodi e modelli

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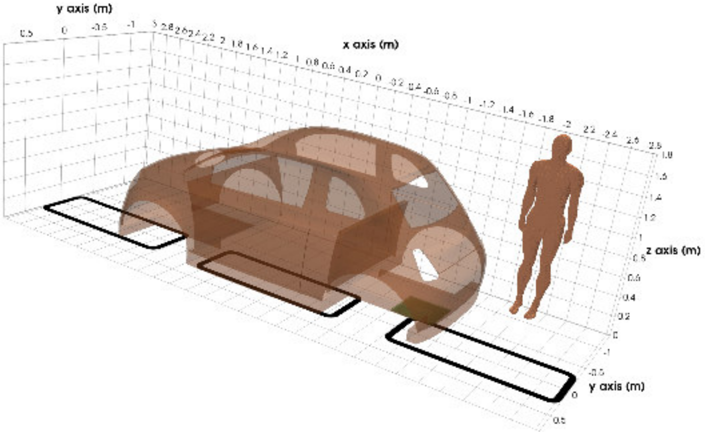
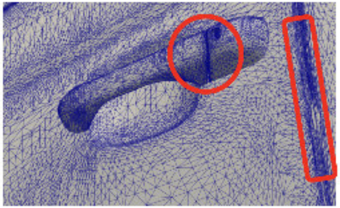
Key points of the field problem

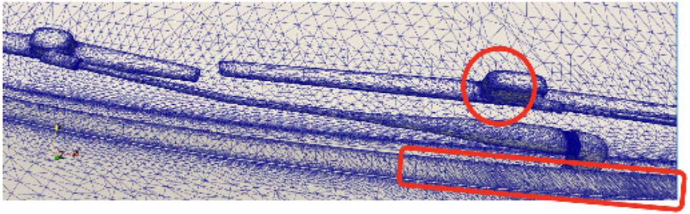
1. complex vehicle model
2. open/large domain
3. multi scale
4. conductive/ferromagnetic materials
5. stationary and dynamic conditions
6. standard frequency $85\ \mathrm{kHz}$



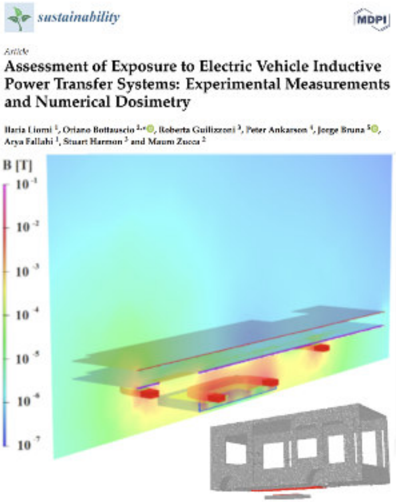
What vehicle model?

Commercial CAD models often include details that are unnecessary in electromagnetic simulations.





What vehicle model?

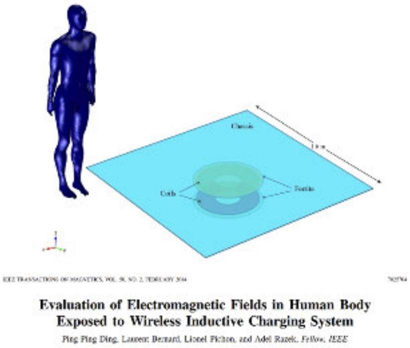


sustainability MDPI

Article

Assessment of Exposure to Electric Vehicle Inductive Power Transfer Systems: Experimental Measurements and Numerical Dosimetry

Ilaria Liorni [1], Oriano Bottauscio [2,*], Roberta Guilizzoni [3], Peter Ankarson [4], Jorge Bruna [5], Arya Fallahi [1], Stuart Harmon [3] and Mauro Zucca [2]



Evaluation of Electromagnetic Fields in Human Body Exposed to Wireless Inductive Charging System

Ping Ping Ding, Laurent Bernard, Lionel Pichon, and Adel Razek, *Fellow, IEEE*

What vehicle model?

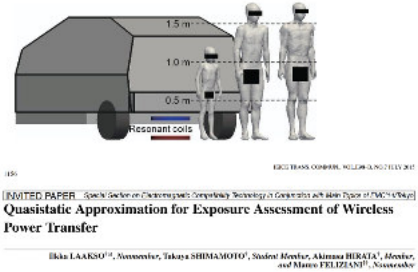

energies

MDPI

Article

Magnetic Field during Wireless Charging in an Electric Vehicle According to Standard SAE J2954

Tommaso Campi [1,*], Silvano Cruciani [1], Francesca Maradei [2] and Mauro Feliziani [1]



1156 IEICE TRANS. COMMUN., VOL.E98-B, NO.7 JULY 2015

INVITED PAPER

Quasistatic Approximation for Exposure Assessment of Wireless Power Transfer

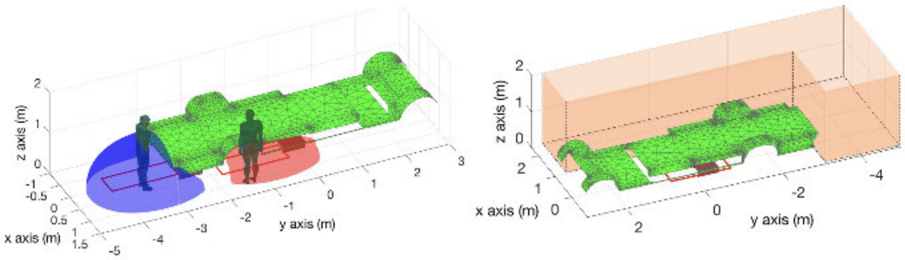
Ilkka LAAKSO[†a)], *Nonmember*, Takuya SHIMAMOTO[†], *Student Member*, Akimasa HIRATA[†], *Member*, *and* Mauro FELIZIANI[††], *Nonmember*

What vehicle model?

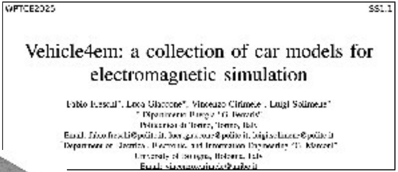
IEEE TRANSACTIONS ON MAGNETICS, VOL. 53, NO. 6, JUNE 2017

Human Exposure Assessment in Dynamic Inductive Power Transfer for Automotive Applications

Vincenzo Cirimele[1,2], Fabio Freschi[1], Luca Giaccone[1], Lionel Pichon[2], and Maurizio Repetto[1]

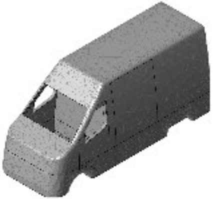


Vehicle4em



WPTCE2025 SS1.1

Vehicle4em: a collection of car models for electromagnetic simulation



SCAN ME

Freely available under MIT licence:

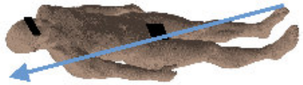
`https://github.com/cadema-PoliTO/vehicle4em`

$f = 85$ kHz, are we in the "Low frequency" renge?

Field theory - near field condition

Wavelength (λ) of electromagnetic field $>>$ maximum dimension of the problem (D)
$\Rightarrow$ electric field and the magnetic field can be analyzed independently.

$D \approx 2\text{m}$



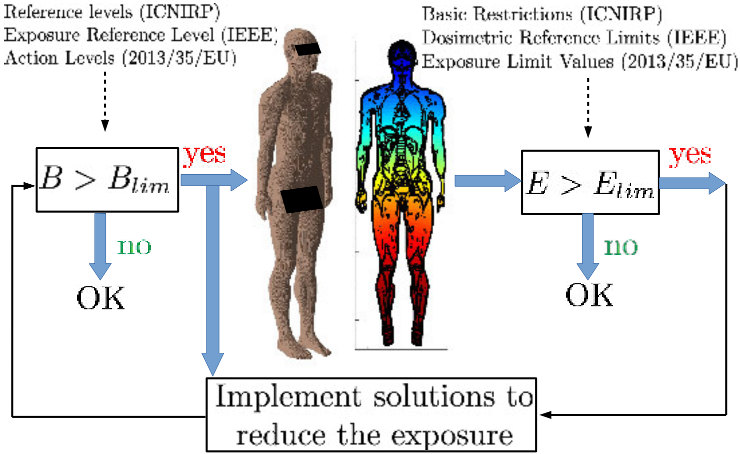
	$f = 50$ Hz $\lambda = 3000$ km	$f = 100$ kHz $\lambda = 3$ km	$f = 10$ MHz $\lambda = 30$ m
$\lambda >> D$?	✓	✓	$\approx$

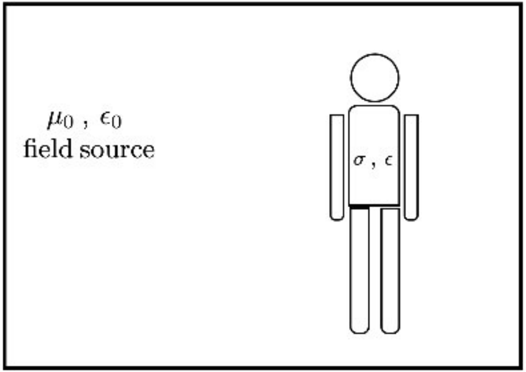
Applied bioelectricity

In the low frequency range stimulation of nervous system is predominant with respect to energy absorption causing superficial heating of tissues.

1 Hz $-$ 100 kHz: the standard low frequency range. Guidelines and standards often cover information up to 10 MHz to prevent stimulation of the nervous system.

1. assess the B-field against *reference levels*
2. assess the E-field against *basic restrictions*



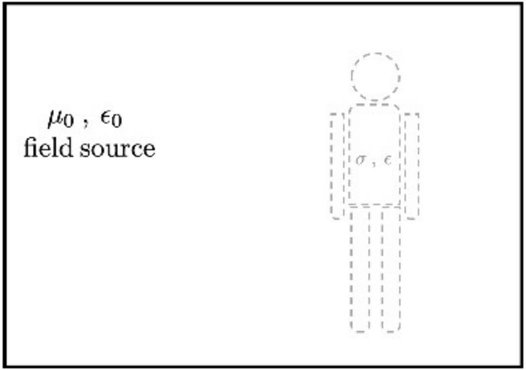


- conductivities of living tissues are very low (e.g. $0.2\ \mathrm{S/m}$)
- induced currents do not modify the source field

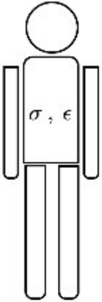
$\downarrow$

- It is possible split the full problem into two separate problems:
  1. simulation of the source
  2. numerical dosimetry

First step: simulation of the source without the human model



Second step: dosimetric problem considering only the human model



Formulation: SPFD

Scalar Potential Finite Difference

- Under the hypothesis of unperturbed external field, the only unknown becomes the electric scalar potential φ.
- it can be computed using the equation:

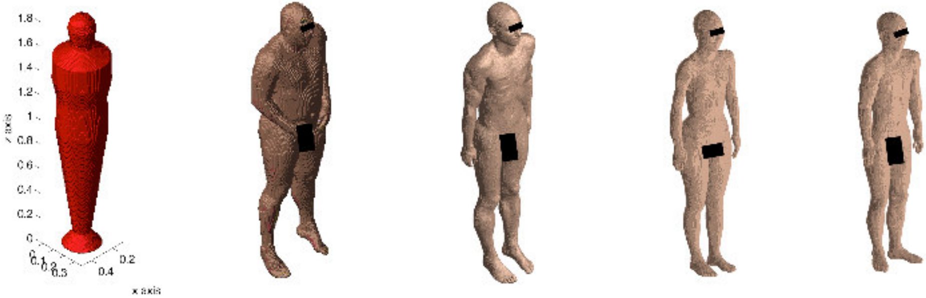
$$\nabla \cdot (\sigma \nabla \varphi) = -\nabla \cdot \left(\sigma \frac{\partial A}{\partial t} \right) \tag{1}$$

- once φ is computed, internal electric field and/or current density are computed as:

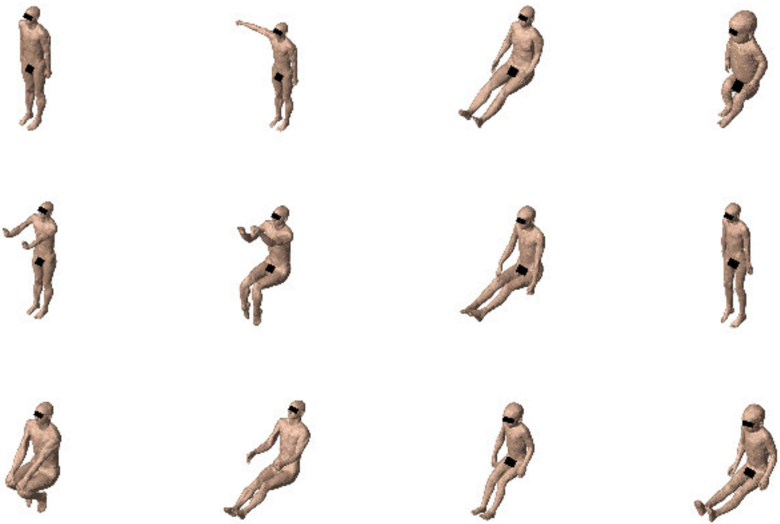
$$E = -\nabla \varphi - \frac{\partial A}{\partial t} \tag{2}$$

$$J = \sigma E \tag{3}$$

Human body models

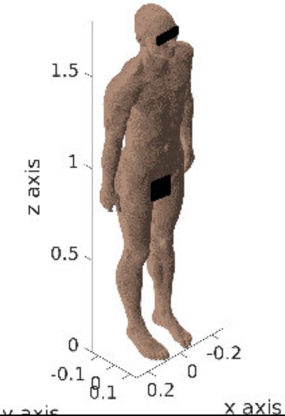


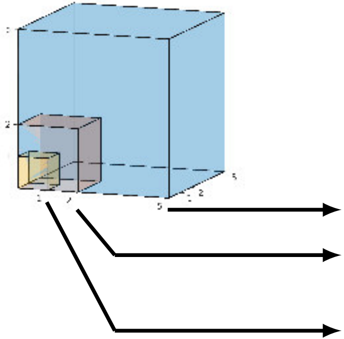
Human body models



How about the number of unknown?

$$\underset{(n \times n)}{\mathbf{K}} \quad \underset{(n \times 1)}{\varphi} \quad = \quad \underset{(n \times 1)}{\mathbf{b}}$$

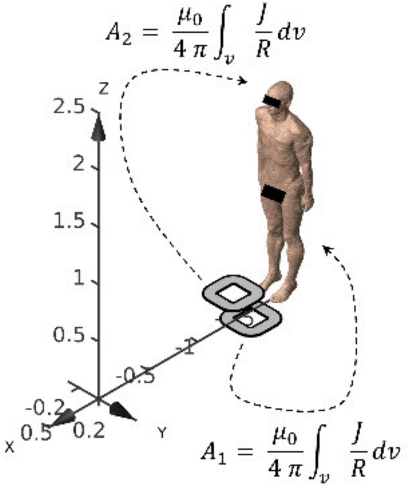




$5 \text{ mm}\ ,\ n \approx 600k$

$2 \text{ mm}\ ,\ n \approx 9M$

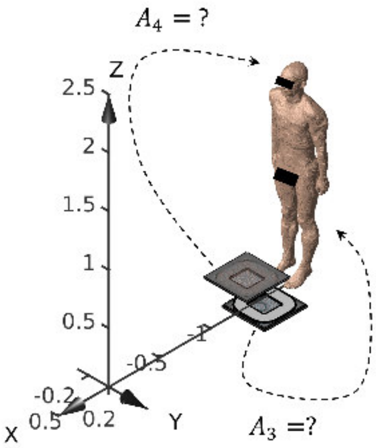
$1 \text{ mm}\ ,\ n \approx 70M$



Example 1: WPT system made of two coils (transmitter and receiver)

- the problem is linear
- superposition can be exploited
- considering the example of two coils, the magnetic vector potential is computed separately for each coil
- the best way to simulate this kind of source is an integral technique that does not need to discretize the air

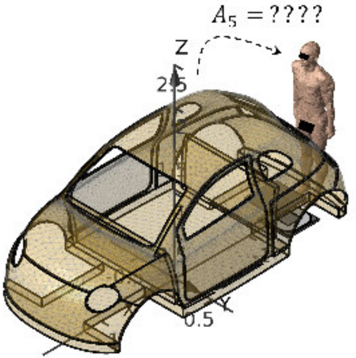
How do we compute the right hand side?



Example 2: WPT system made of two coils + Aluminum + Ferrite.

- the problem is still linear
- superposition can be still exploited
- we need to add the contribution of the metallic material (Aluminum + Ferrite).
- sometimes the best formulation to solve this problem does not provide the magnetic vector potential

How do we compute the right hand side?

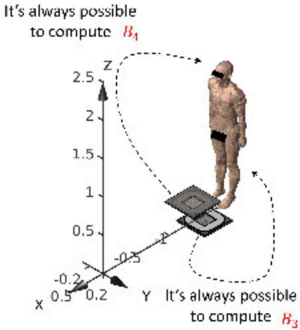


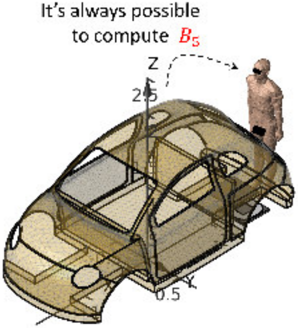
Example 3: WPT system made of two coils + Aluminum + Ferrite + car body.

- the problem is still linear
- superposition can be still exploited
- we need to add the contribution of the cab body.
- again, sometimes the best formulation to solve this problem does not provide the magnetic vector potential

How do we compute the right hand side?

It is wort nothing that the computation of the magnetic flux density is always possible with all formulations and software.





Formulation used: F. Freschi, L. Giaccone, and M. Repetto, "Algebraic formulation of nonlinear surface impedance boundary condition coupled with BEM for unstructured meshes," Eng. An. Bound. Elem., vol. 88, pp. 104-114, 2018.

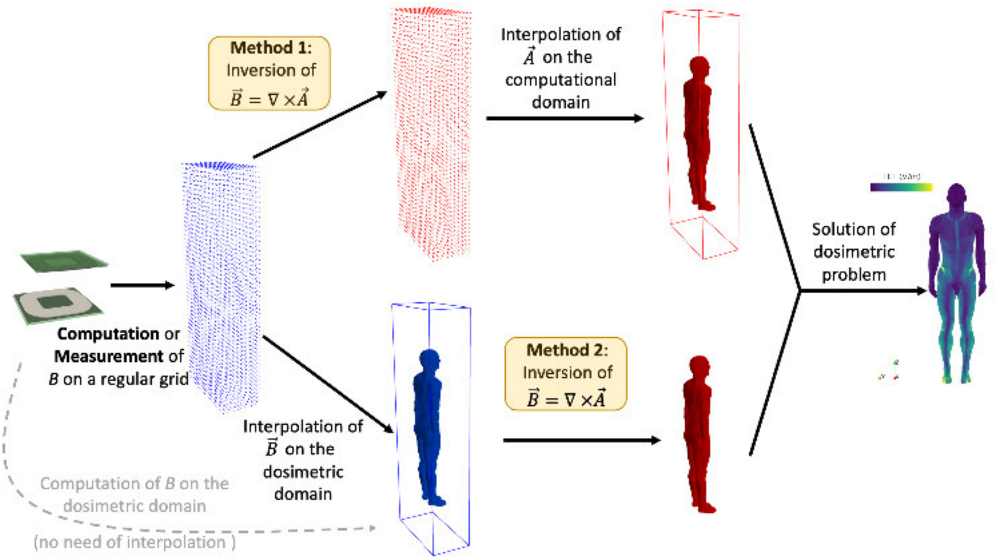
Is it possible to compute $\vec{A}$ from $\vec{B}$?

[1] Laakso, I., De Santis, V., Cruciani, S., Campi, T. and Feliziani, M. (2017) Modelling of induced electric fields based on incompletely known magnetic fields. Physics in Medicine and Biology, 62 (16).

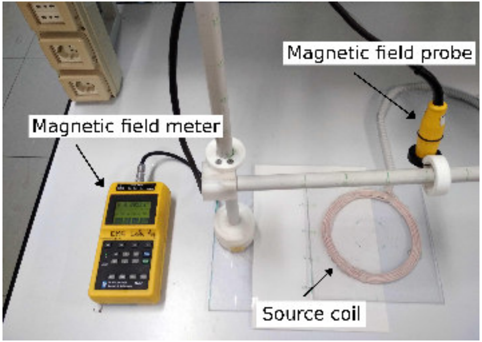
[2] Freschi, F., Giaccone, L., Cirimele, V., and Canova, A. (2018). Numerical assessment of low-frequency dosimetry from sampled magnetic fields. Physics in Medicine and Biology, 63(1).

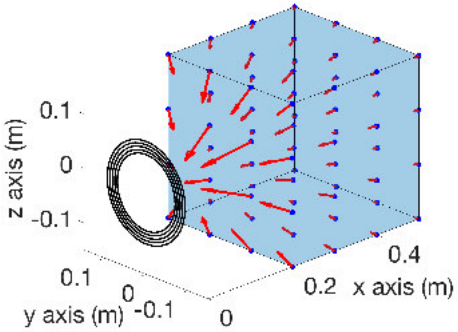
[3] Conchin Gubernati, A., Freschi, F., Giaccone, L., Campi, T., De Santis, V., and Laakso, I. (2019). Comparison of numerical techniques for the evaluation of human exposure from measurement data. IEEE Transactions on Magnetics, 55(6).

Is it possible to compute $\vec{A}$ from $\vec{B}$?

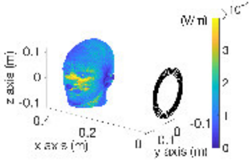


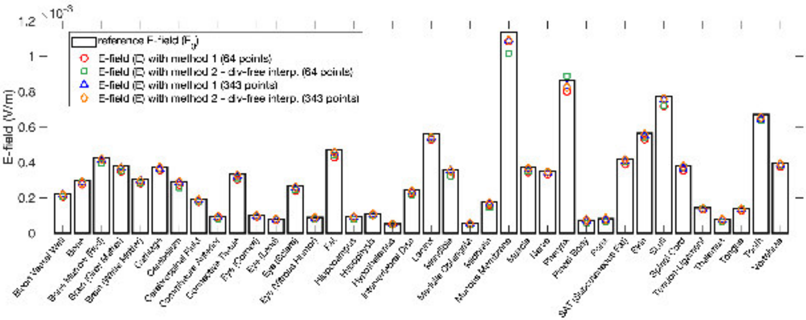
Method 1 vs Method 2





Method 1 vs Method 2

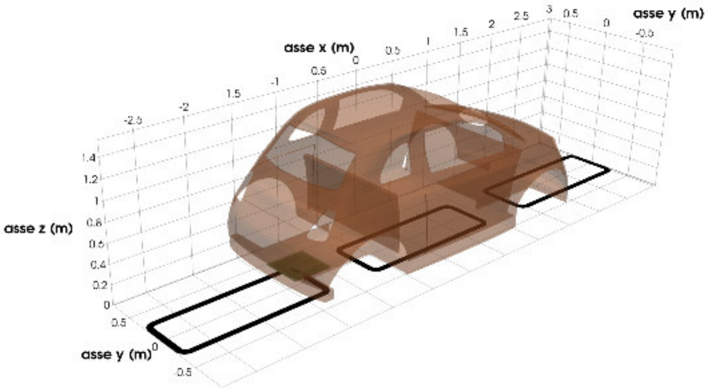




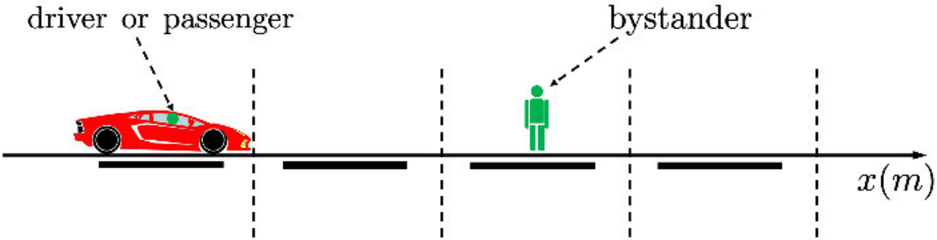
Case study: dynamic WPT system

Charge while driving

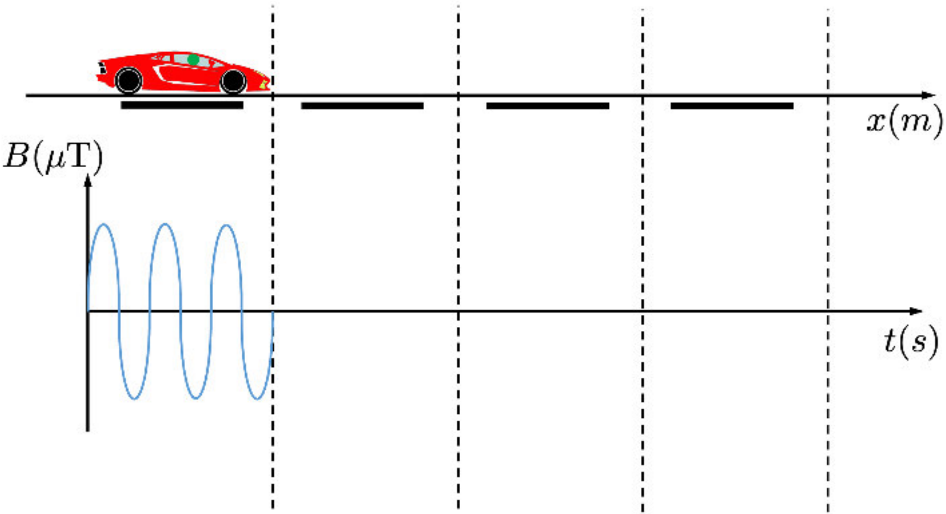
- frequency 85 kHz
- (max) power 7.7 kW
- 50 transmitters:
  - 1.5 m length, 0.5 m wide, 0.5 m gap
  - 26 A
  - 10 number of turns
- 1 receiver
  - based on standard SAE J2954
  - rear position
  - 13 A
  - 10 turns



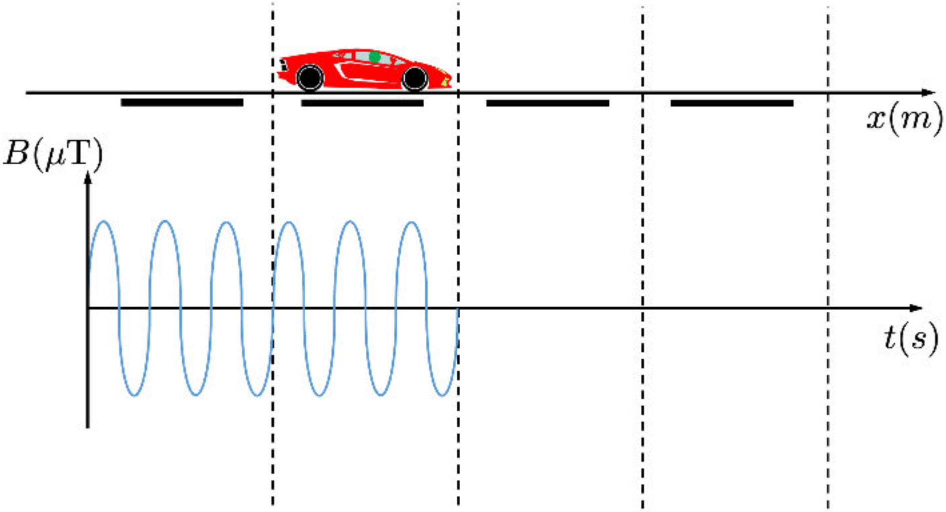
Driver, passenger and bystander: are they exposed to the same field?



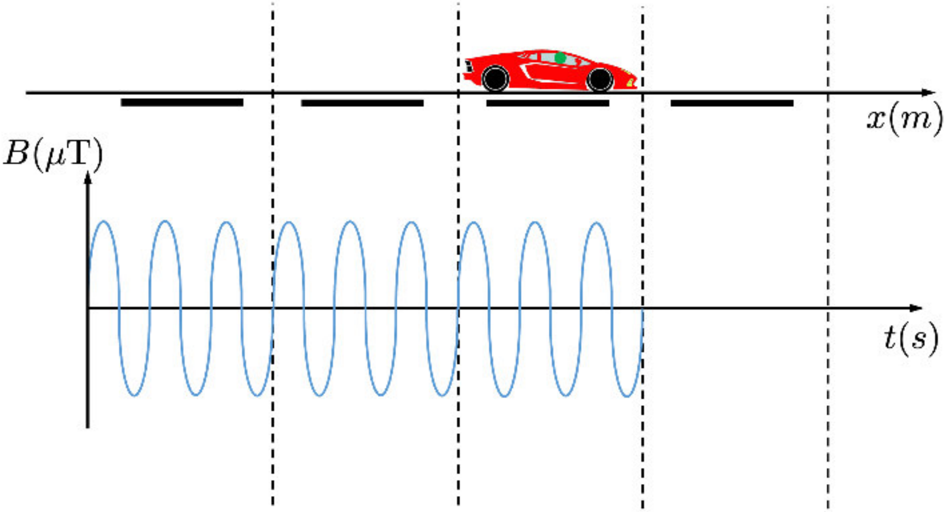
$B-$field “observed” by the driver/passenger during motion



$B-$field "observed" by the driver/passenger during motion



$B-$field "observed" by the driver/passenger during motion



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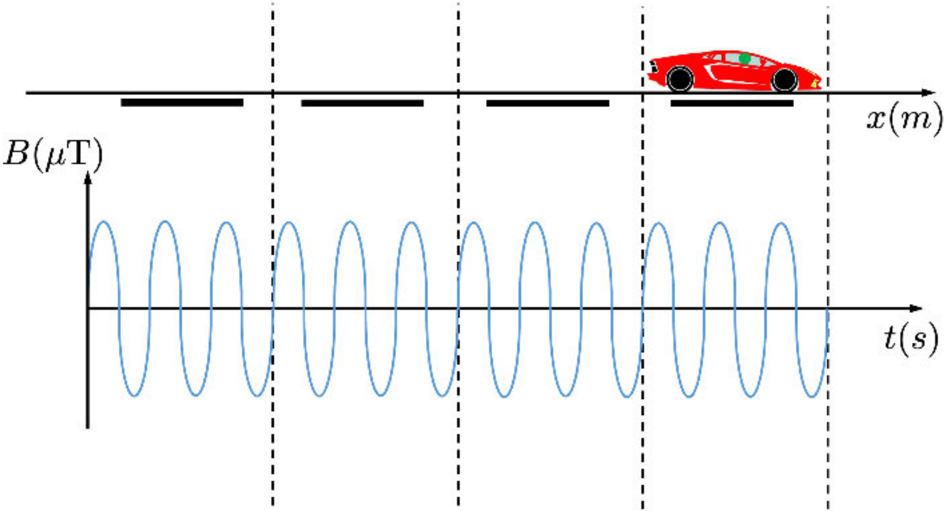
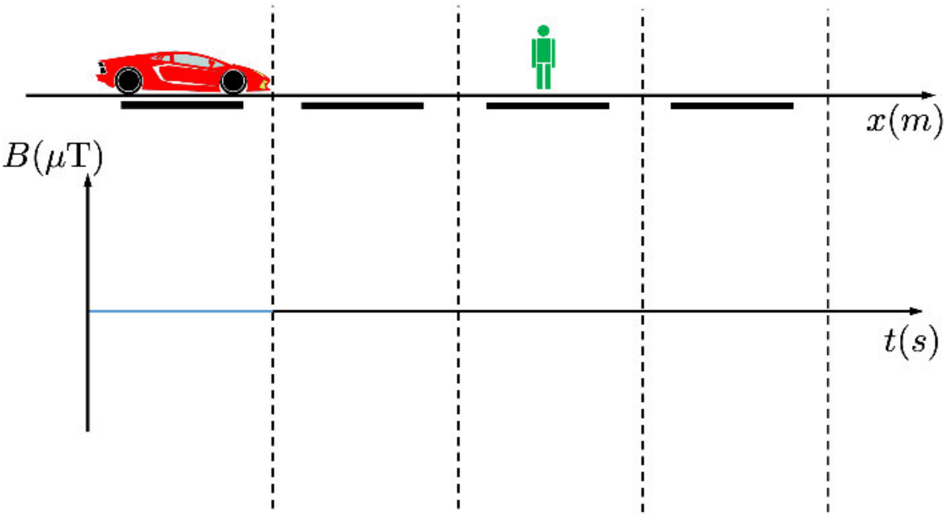
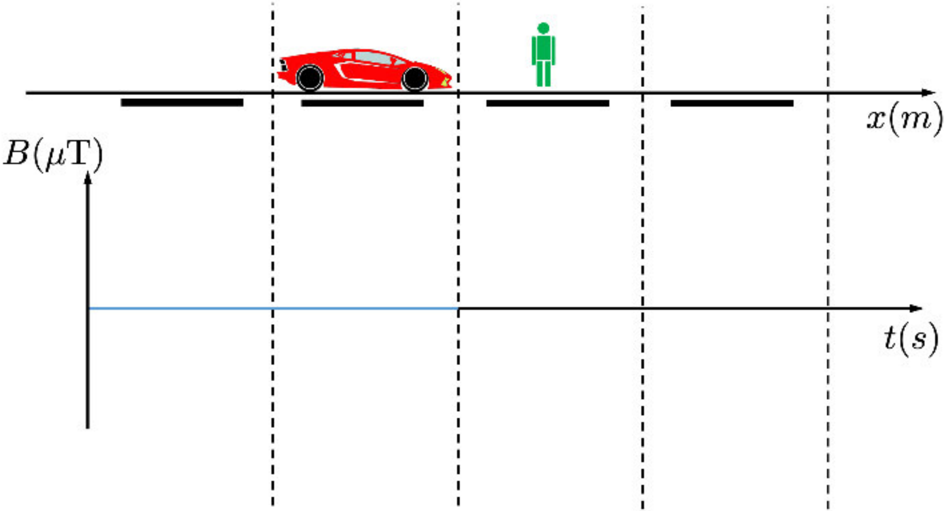


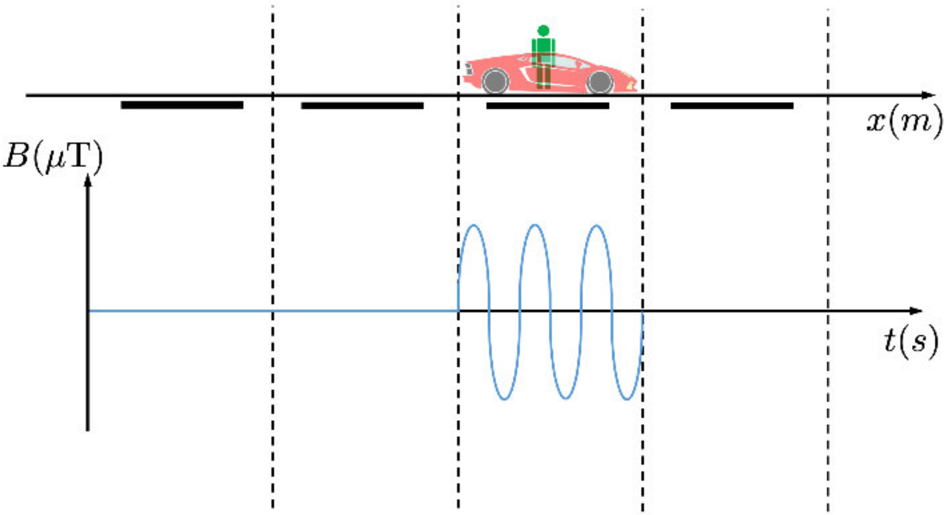
$B-$field "observed" by a bystander during motion



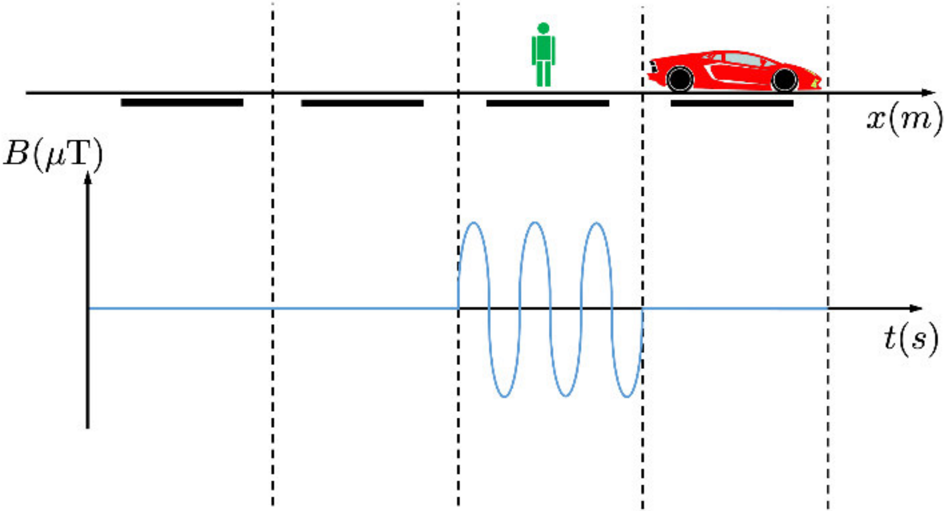
$B-$field "observed" by a bystander during motion



$B-$field "observed" by a bystander during motion

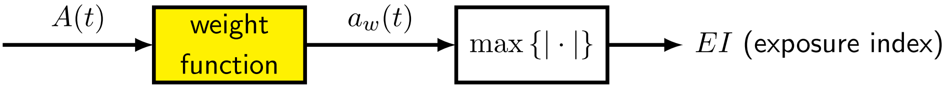


$B-$field "observed" by a bystander during motion



How can we analyze a pulsed $B-$field?

Weighted peak method



Mathematical definitions

$$EI = \max\left\{\left|\sum_i WF_i \cdot A_i \cos\left(2\pi f_i t + \theta_i + \varphi_i\right)\right|\right\}$$

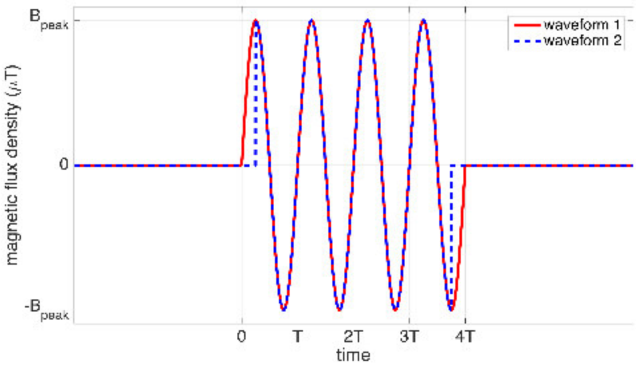
- A_i and θ_i are magnitude and phase of a waveform that can be either an external or an induced field
- WF_i and φ_i are magnitude and phase of a weight function

Requirement:

The exposure is compliant if $EI < 1$

How can we analyze a pulsed $B-$field?

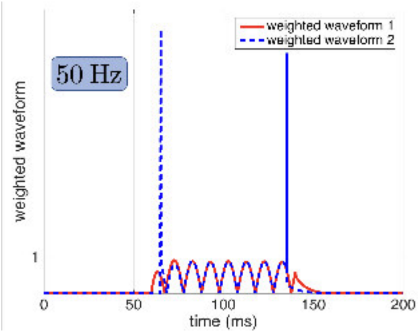
1. exposure is pulsed but can be considered as steady state[1]

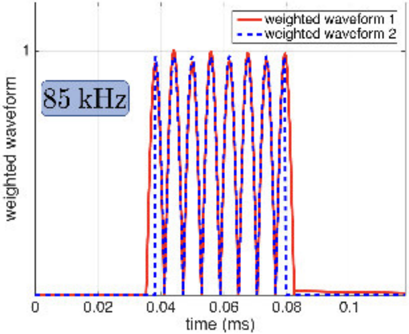


[1] V. Cirimele, F. Freschi, L. Giaccone, L. Pichon, and M. Repetto, "Human exposure assessment in dynamic inductive power transfer for automotive applications," IEEE Transactions on Magnetics, vol. 53, 2017.

Effect of the fundamental frequency of the burst

1. exposure is pulsed but can be considered as steady state[2]



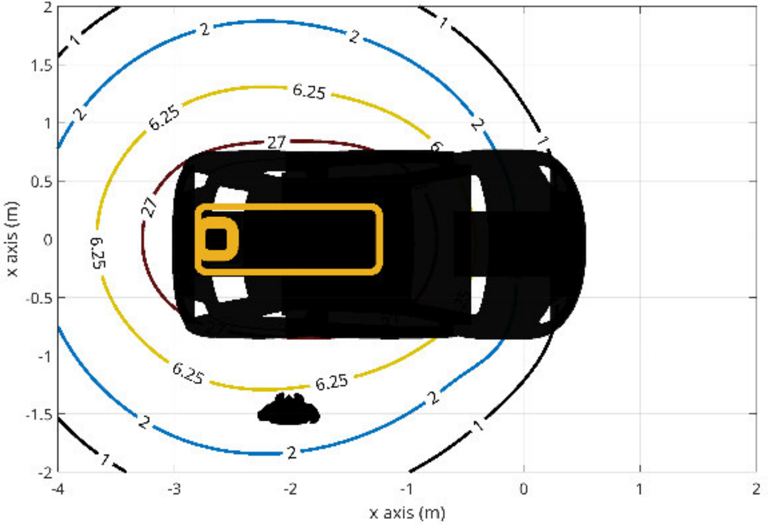


[2] V. Cirimele, F. Freschi, L. Giaccone, L. Pichon, and M. Repetto, "Human exposure assessment in dynamic inductive power transfer for automotive applications," IEEE Transactions on Magnetics, vol. 53, 2017.

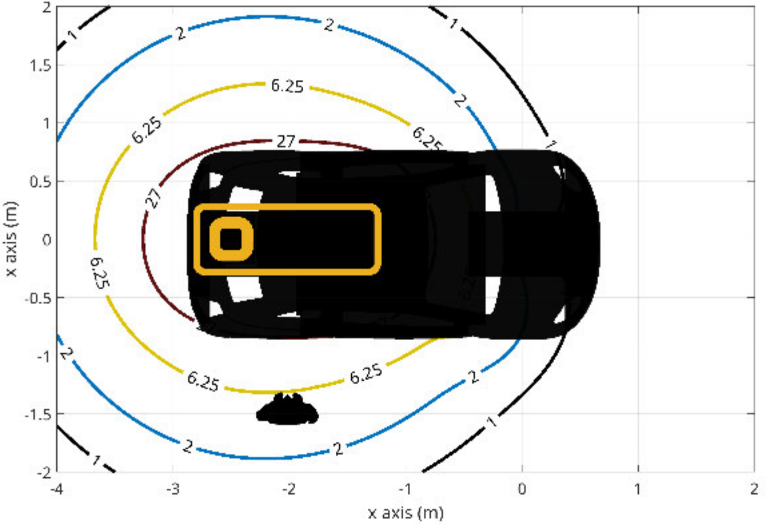
Final approach for DWPT systems

1. It is possible to study a Dynamic-WPT with all methods suitable for a Stationary-WPT.
2. Due to the motion of the vehicle the worst case conditions have to be defined.

Magnetic flux density vs motion



Magnetic flux density vs motion



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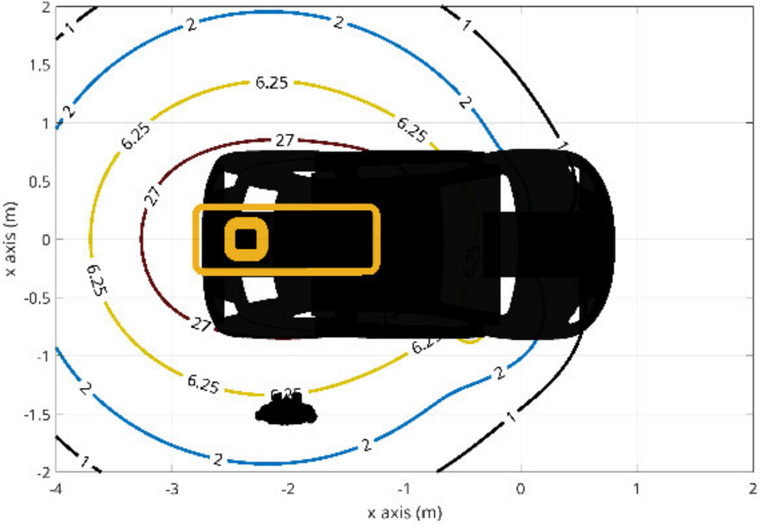
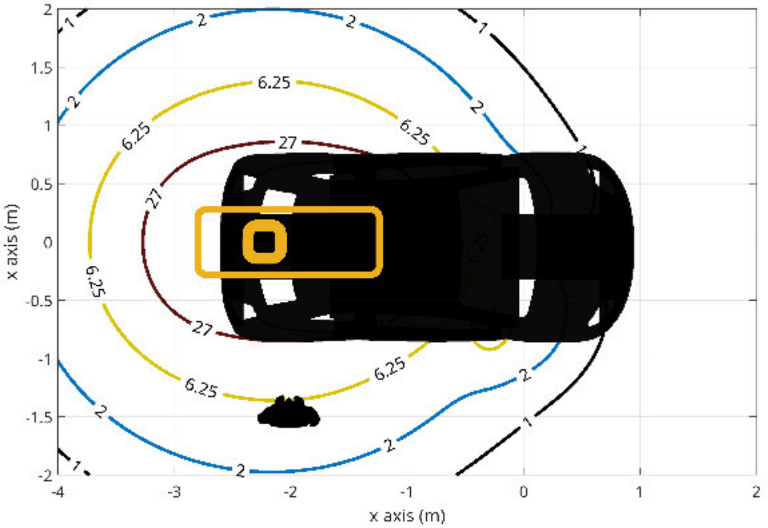
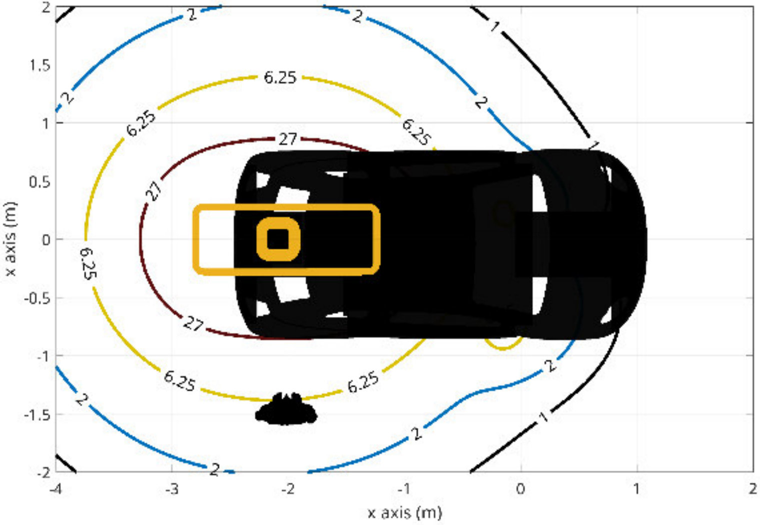


Magnetic flux density vs motion



Magnetic flux density vs motion



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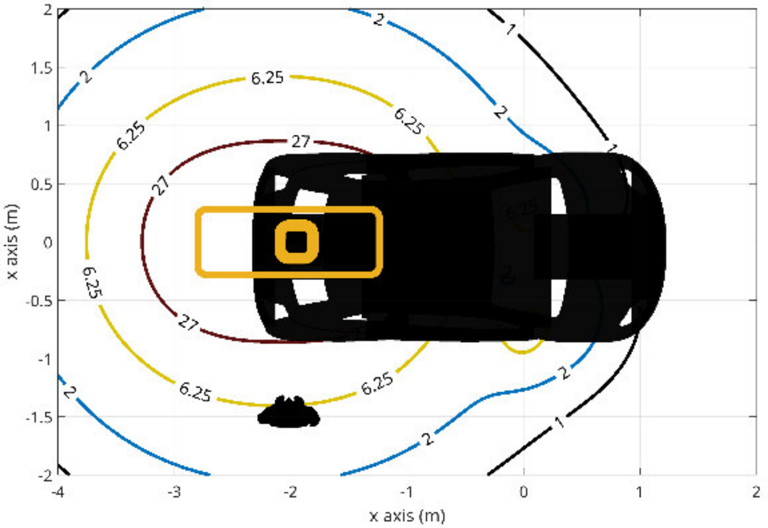
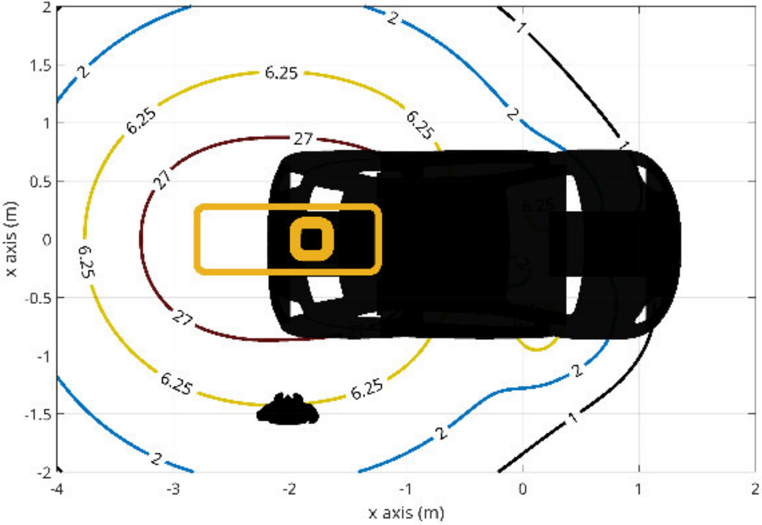


Magnetic flux density vs motion



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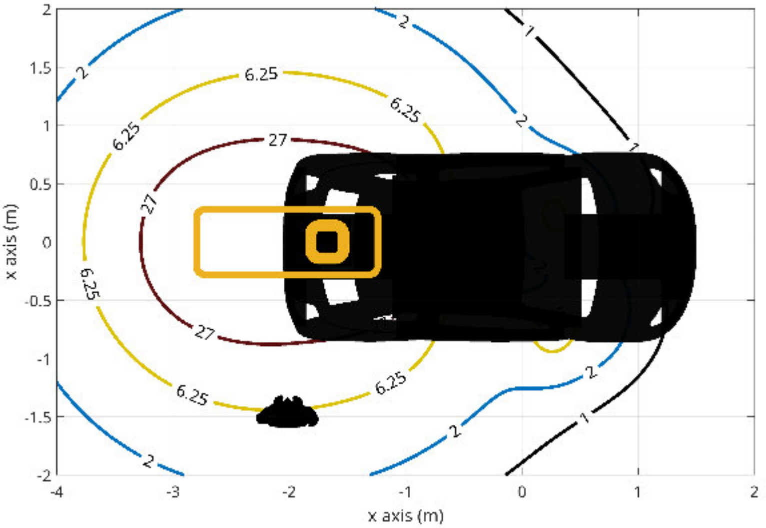

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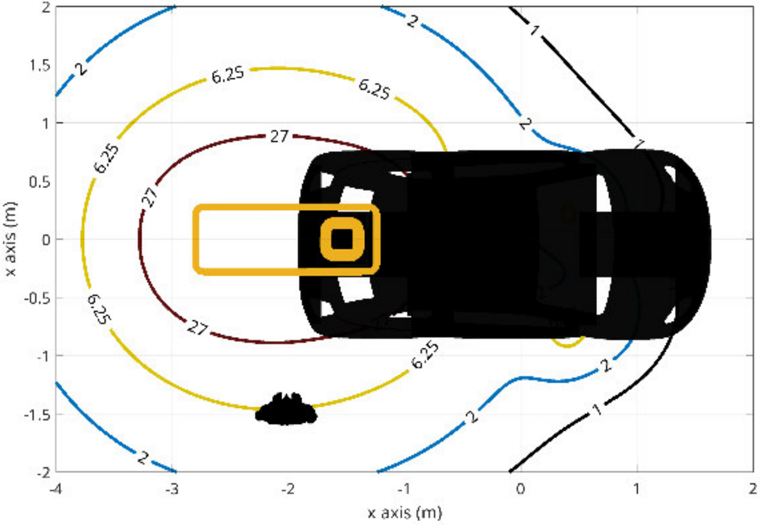
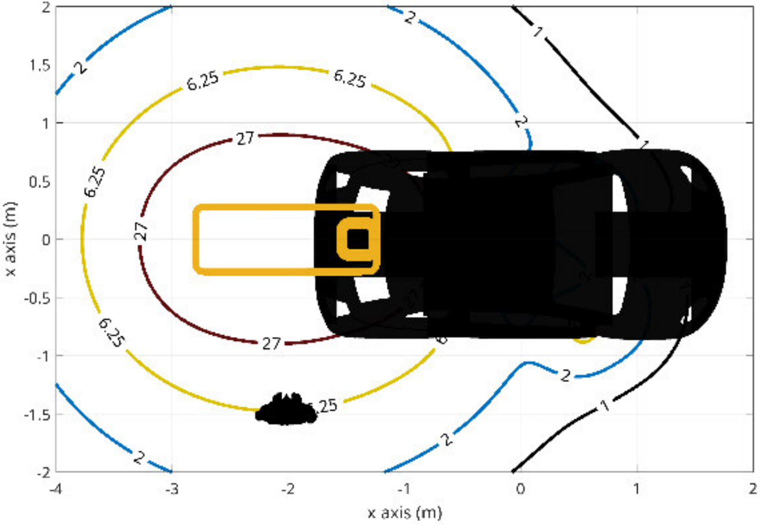
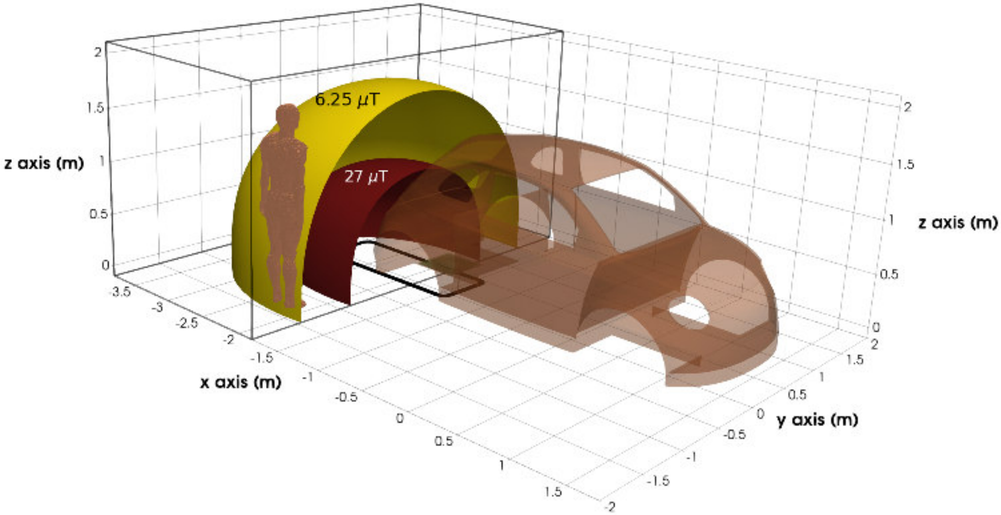


Magnetic flux density vs motion

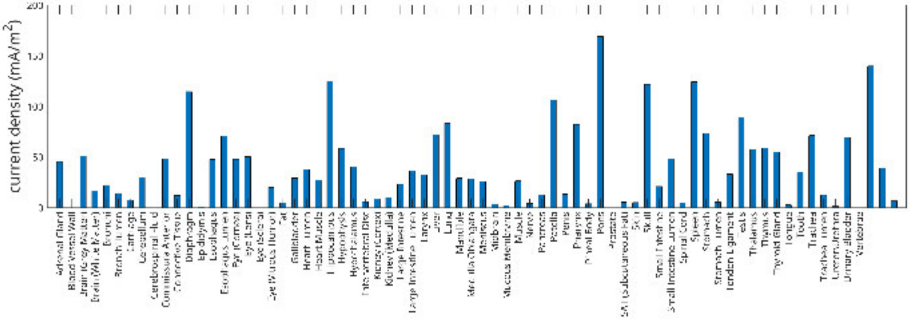


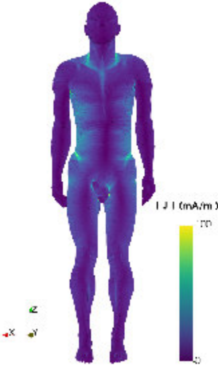
Case study



6.25 μT
27 μT
z axis (m)
x axis (m)
y axis (m)
z axis (m)
2
1.5
1
0.5
0
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2
1.5
1
0.5
0

Induced current density



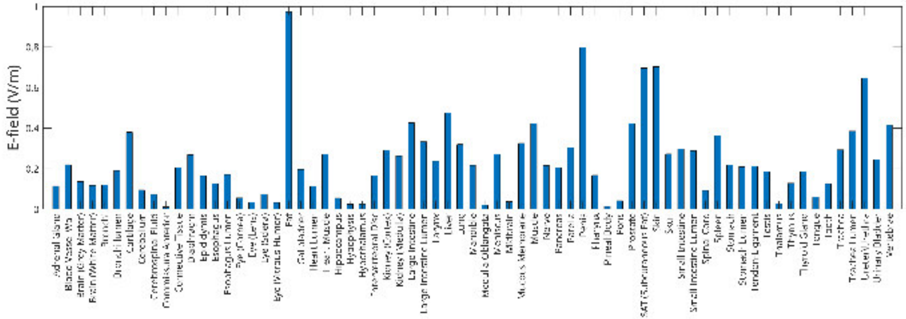


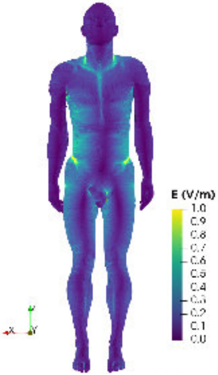
Max exposure in FAT-tissue

about $169\ \mathrm{mA/m^2}$, very close to $170\ \mathrm{mA/m^2}$

(ICNIRP guidelines 1998)

Induced electric field





Max exposure in FAT-tissue

about $1\ \mathrm{V/m}$, well below the the basic restriction of $11.5\ \mathrm{V/m}$

(ICNIRP guidelines 2010)

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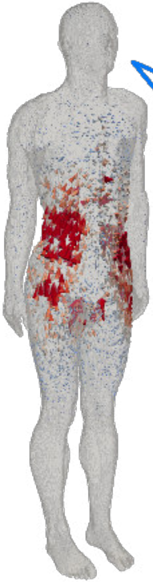

Thank you for the attention ...

... to my safety

Any questions?