



**Sviluppo di strumenti e metodi per la valutazione e la gestione del rischio derivante da esposizione a campi elettromagnetici per la tutela dei lavoratori portatori di dispositivi medici indossabili ed impiantabili.**

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# Wireless (*Inductive*) Power Transfer per applicazioni automobilistiche

**A. Canova, F. Freschi, L. Giaccone**

Dipartimento Energia - Politecnico di Torino

V. Cirimele

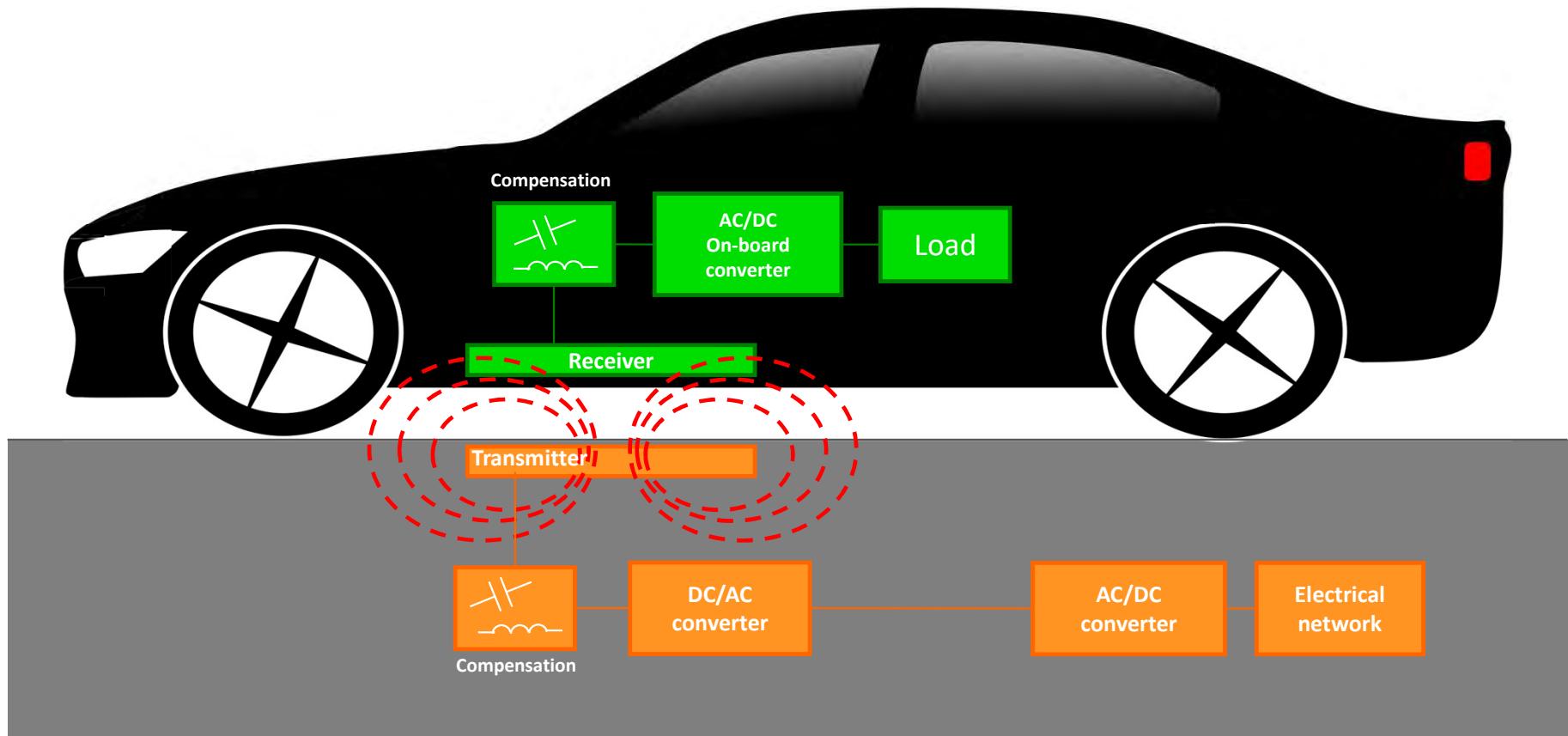
Dipartimento di Ingegneria dell'Energia Elettrica e dell'Informazione – Università di Bologna

Istituto Superiore di Sanità - Aula Bovet  
Viale Regina Elena 299, 00161 Roma

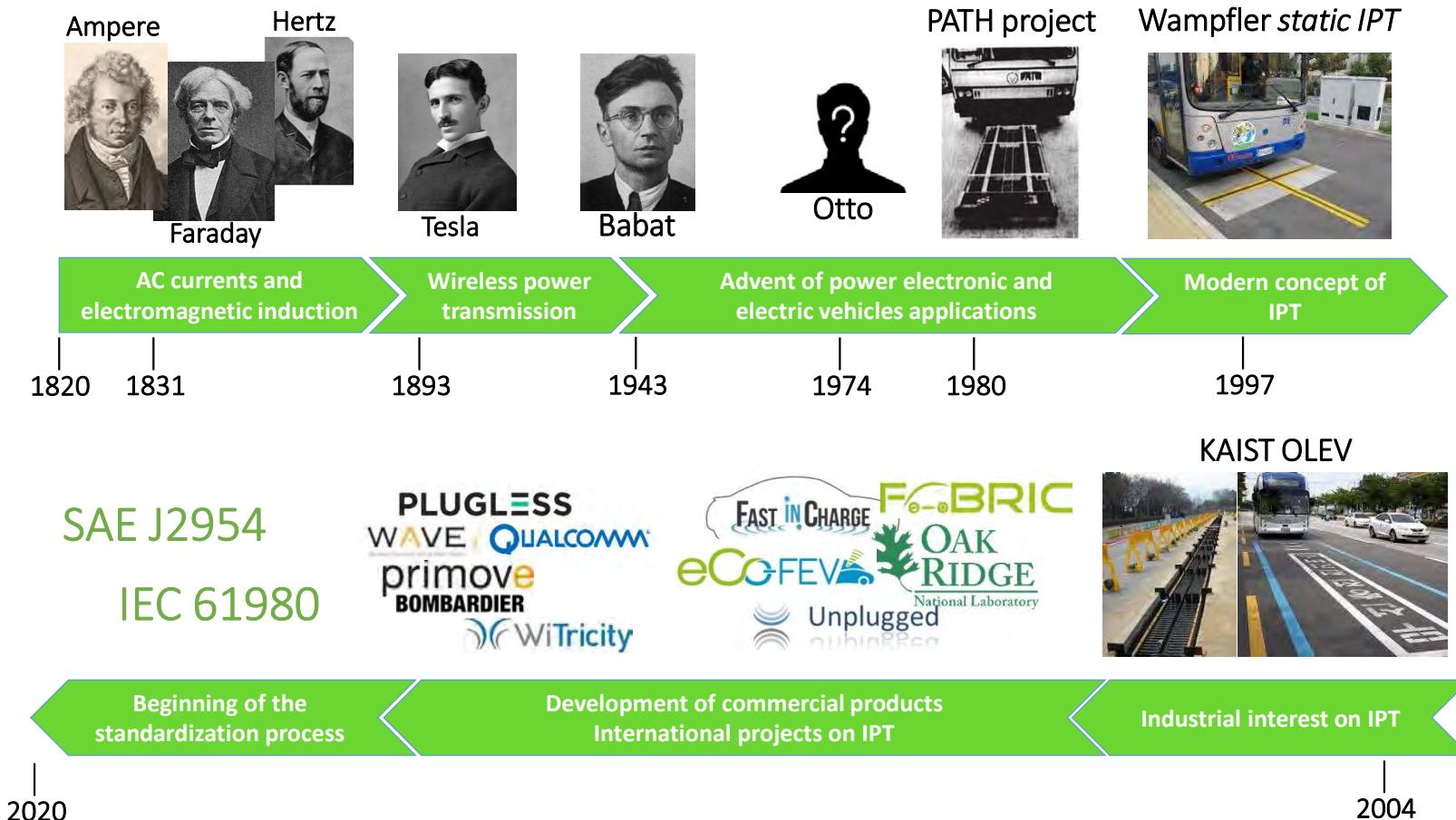
# Topics

- Introduction
- Basic circuit modelling and current waveforms
- Reference values
- Stationary IPT
- Dynamic IPT
- Magnetic structure design and optimisation

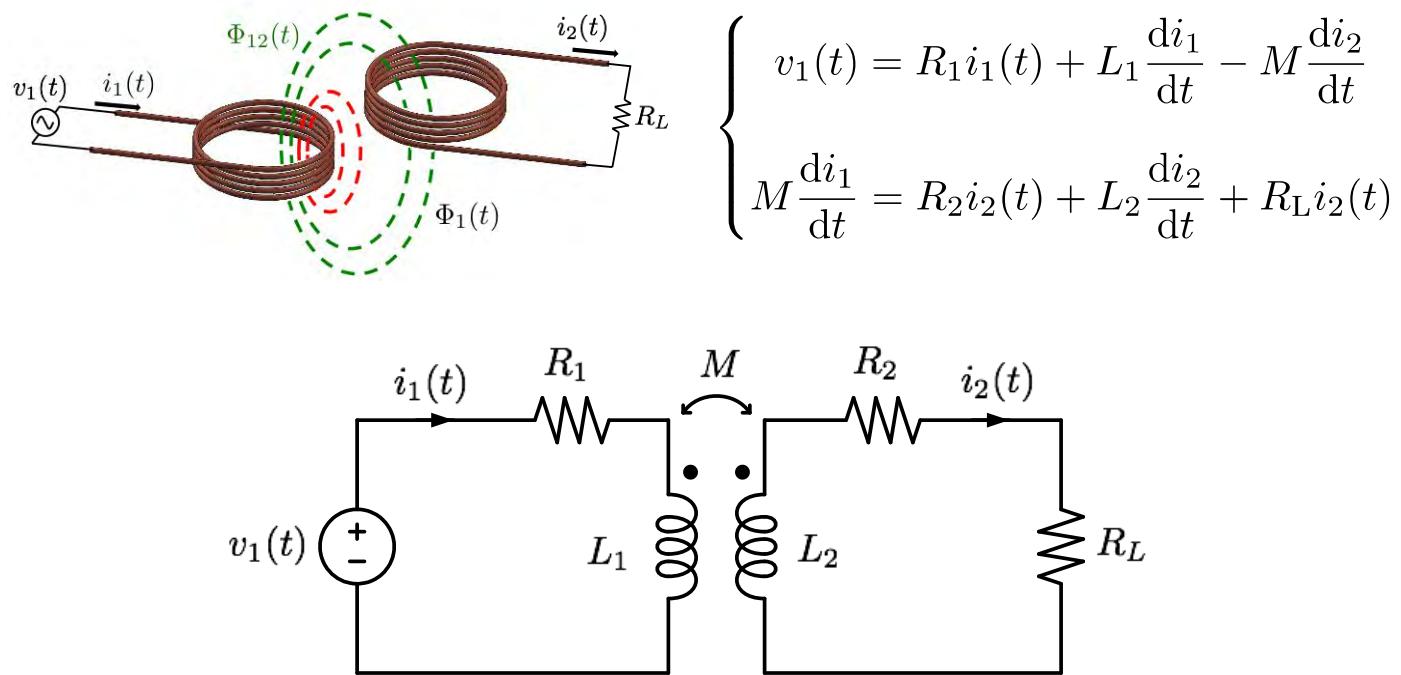
# IPT basics - Main components



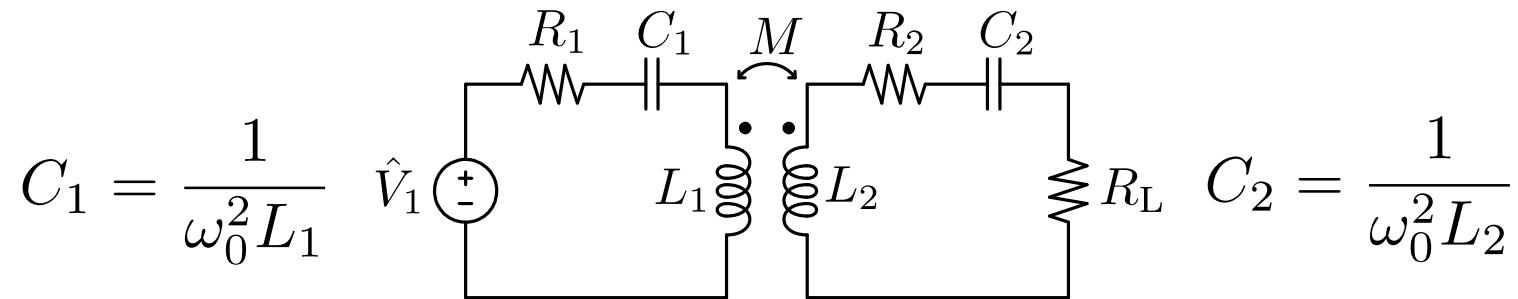
# IPT evolution



# IPT basics - Circuit modeling



## IPT basics - Introducing resonance



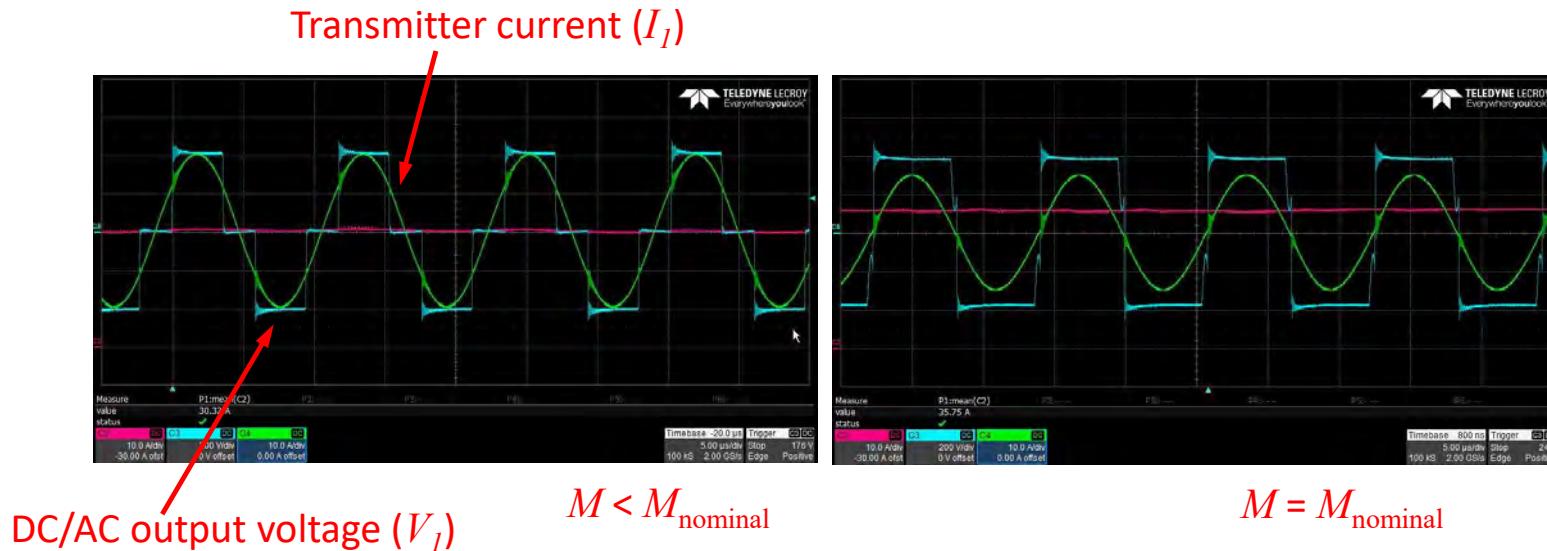
$$\hat{Z}_T = j \left( \omega L_1 - \frac{1}{\omega C_1} \right) + \frac{\omega^2 M^2}{\left( R_L + j \left( \omega L_2 - \frac{1}{\omega C_2} \right) \right)}$$

$$\omega = \omega_0$$

A large green arrow pointing downwards from the term  $\omega = \omega_0$  to the simplified equation below.

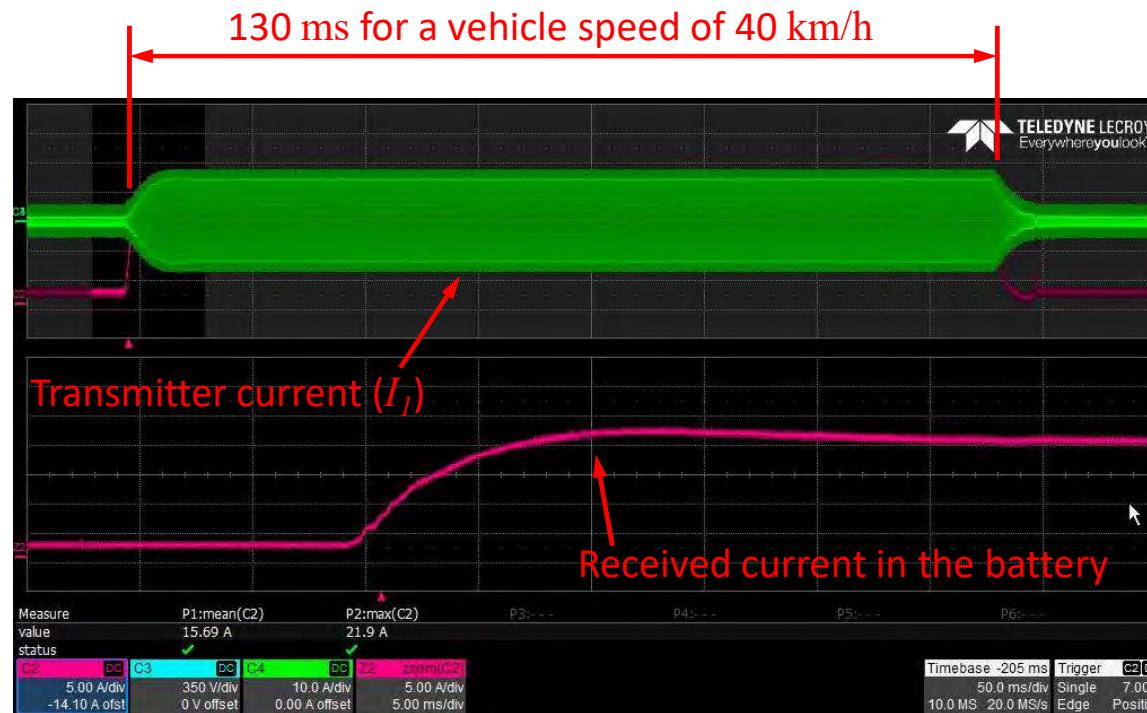
$$\hat{Z}_T = R_1 + \frac{\omega_0^2 M^2}{R_2 + R_L} \approx \frac{\omega_0^2 M^2}{R_L}$$

# Current waveform



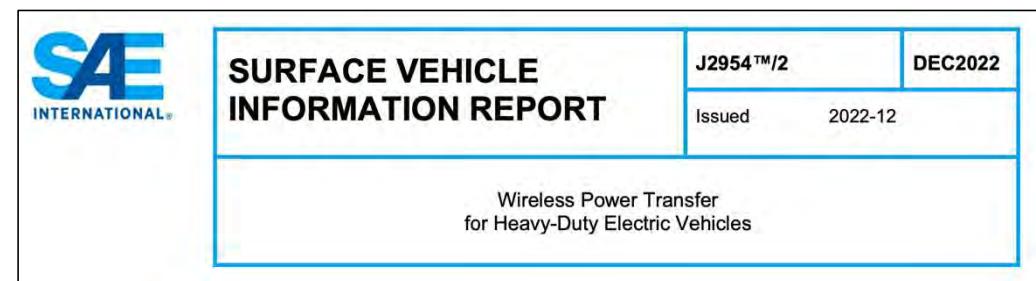
The currents remain  
sinusoidal in each  
working condition

# Current waveform



Dynamic IPT → Pulsed magnetic field

# REFERENCE FOR THE ASSESSMENT



## 10.2.1 Cardiac Implantable Electronic Device (CIED) EMF Requirements

CIED WPT magnetic interoperability assessment limits are defined herein by setting CIED EMF reference levels in a manner analogous to ICNIRP limits. Based on the ISO 14117 Appendix M, it is expected that CIEDs operate as designed when 79 to 90 kHz magnetically induced lead voltages, in a 225 cm<sup>2</sup> loop area, are less than the levels defined as  $V_{MAX\_INDUCED\_RMS} = \frac{3\sqrt{2}}{2} \text{ mV} \times \text{Frequency (kHz)}$  (e.g., 180.31 mVrms at 85 kHz). These voltages are the basis for the field limits in the SAE J2954 CIED EMF reference levels shown in Table 14, which should not be exceeded for any realistic CIED lead loop position associated with a reasonably foreseeable human body torso position in Regions 2 or 3. Under the CIED EMF reference level measurement distance constraints described in 10.4, the Table 13 levels provide an alternative, but conservative, assessment of CIED WPT magnetic interoperability, utilizing the same 100 cm<sup>2</sup> field probe used for human EMF assessment. All field measurement limits are conservatively expressed as the magnitude (root sum squared) of the X, Y, and Z components of the magnetic field (e.g.,  $|B_{FIELD}| = \sqrt{B_X^2 + B_Y^2 + B_Z^2}$ ).

**NOTE:** If the WPT fields are modulated, substantially non-sinusoidal, or include overshoot during amplitude transitions, the CIED EMF assessments should be performed using peak limits equal to the rms limits times 1.41.

**NOTE:** The limits and precautionary measures for CIEDs may be revisited in the future based on data as per the ISO 14117 Committee. Additional limits for other IMDs are under consideration.

**Table 14 - CIED EMF reference level**

Quantity	Flux Density or Magnetic Field Limit Regions 2 and 3 (rms)
Flux density or magnetic field strength	15.0 µT or 11.9 A/m <sup>(1)</sup> (for 22 to 25 kHz and 79 to 90 kHz)

<sup>(1)</sup> These limits apply when using 100 cm<sup>2</sup> standard field probe. Perform four measurements in a 2 x 2 grid and spaced at 7.5 cm (probe centered at each point) centered around the location of each reading above 15.0 µT. Average these four measurements.

**15 µT @ 85 kHz**

# REFERENCE FOR THE ASSESSMENT

GUIDA



CEI 106-45:2021-01



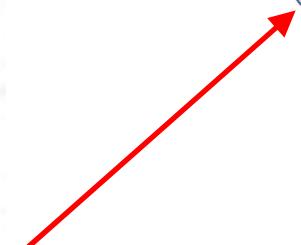
## A.1 Lavoratori portatori di dispositivi medici impiantati attivi

Per quanto riguarda i campi elettromagnetici, la **Direttiva 2007/47/CE** stabilisce che i dispositivi medici siano progettati e fabbricati in modo da eliminare o ridurre al minimo i rischi connessi con condizioni ambientali ragionevolmente prevedibili, in particolare i rischi connessi con i campi magnetici, le influenze elettriche esterne, le scariche elettrostatiche. Nella pratica questo si traduce nell'applicazione, da parte dei fabbricanti dei dispositivi, di specifiche Norme tecniche armonizzate (**CEI EN 45502-1** [37] e la serie **CEI EN 45502-2-X** di norme particolari), i cui requisiti di immunità elettromagnetica sono derivati dai livelli di riferimento della **Raccomandazione 1999/519/CE** per la protezione della popolazione.

Le norme suddette non valutano però l'immunità dei dispositivi a segnali associati a sorgenti particolari presenti nei luoghi di lavoro, per i quali rimandano ad analisi ulteriori da effettuarsi direttamente con il costruttore del dispositivo, con il datore di lavoro e con il medico curante (ad esempio per la possibilità di impostazioni non standard per il DMIA).

La Norma tecnica **CEI EN 50527-1** [45] descrive la procedura generale di valutazione del rischio derivante dall'esposizione sul luogo di lavoro ai CEM nell'intervallo di frequenza da 0 Hz a 300 GHz, per i lavoratori portatori di DMIA. La norma indica come effettuare una valutazione generale del rischio e come determinare se sia necessario procedere con un'ulteriore valutazione dettagliata. La Norma fornisce, inoltre, una tabella contenente una lista di apparati/condizioni espositive conformi a priori/giustificabili ai LR per la popolazione della Raccomandazione 1999/519/CE. **Al fine di garantire l'immunità dei DMIA, il confronto con i LR della Raccomandazione 1999/519/CE deve essere su base istantanea, cioè senza includere alcuna media temporale.**

**6.25 µT @ 85 kHz**



# REFERENCE FOR THE ASSESSMENT

**Tabella3.** Livelli di riferimento per l'esposizione professionale a campi elettrici e magnetici variabili nel tempo (valori quadratici medi del campo imperturbato)

Intervallo di frequenza	Intensità del campo elettrico E (kV/m)	Intensità del campo magnetico H (A/m)	Induzione magnetica B(T)
1 Hz – 8 Hz	20	$1.63 \times 10^5 / f^2$	$0.2 / f^2$
8 Hz – 25 Hz	20	$2 \times 10^4 / f$	$2.5 \times 10^{-2} / f$
25 Hz – 300 Hz	$5 \times 10^2 / f$	$8 \times 10^2$	$1 \times 10^{-3}$
300 Hz – 3 kHz	$5 \times 10^2 / f$	$2.4 \times 10^5 / f$	$0.3 / f$
3 Hz – 10 MHz	$1.7 \times 10^{-1}$	80	$1 \times 10^{-4}$

**Tabella4.** Livelli di riferimento per l'esposizione del pubblico a campi elettrici e magnetici variabili nel tempo (valori quadratici medi del campo imperturbato)

Intervallo di frequenza	Intensità del campo elettrico E (kV/m)	Intensità del campo magnetico H (A/m)	Induzione magnetica B (T)
1 Hz – 8 Hz	5	$3.2 \times 10^4 / f^2$	$4 \times 10^{-2} / f^2$
8 Hz – 25 Hz	5	$4 \times 10^3 / f$	$5 \times 10^{-3} / f$
25 Hz – 50 Hz	5	$1.6 \times 10^2$	$2 \times 10^{-4}$
50 Hz – 400 Hz	$2.5 \times 10^2 / f$	$1.6 \times 10^2$	$2 \times 10^{-4}$
400 Hz – 3 kHz	$2.5 \times 10^2 / f$	$6.4 \times 10^4 / f$	$8 \times 10^{-2} / f$
3 Hz – 10 MHz	$8.3 \times 10^{-2}$	21	$2.7 \times 10^{-5}$

# REFERENCE FOR THE ASSESSMENT

**Tabella 2.** Restrizioni di base per l'esposizione a campi elettrici e magnetici variabili nel tempo

Caratteristiche dell'esposizione	Intervallo di frequenza	Campo elettrico interno (V/m)
<i>Esposizione professionale</i>		
Effetti sul sistema nervoso centrale		
	1 – 10 Hz	0.5 / f
	10 Hz – 25 Hz	0.05
	25 Hz – 400 Hz	$2 \times 10^{-3} \times f$
	800 Hz – 3 kHz	0.8
	3 kHz – 10 MHz	$2.7 \times 10^{-4} \times f$
Effetti sul sistema nervoso periferico		
	1 Hz – 3 kHz	0.8
	3 kHz – 10 MHz	$2.7 \times 10^{-4} \times f$
<i>Esposizione del pubblico</i>		
Effetti sul sistema nervoso centrale		
	1 – 10 Hz	0.1 / f
	10 Hz – 25 Hz	0.01
	25 Hz – 1000 Hz	$4 \times 10^{-4} \times f$
	1000 Hz – 3 kHz	0.4
	3 kHz – 10 MHz	$1.35 \times 10^{-4} \times f$
Effetti sul sistema nervoso periferico		
	1 Hz – 3 kHz	0.4
	3 kHz -10 MHz	$1.35 \times 10^{-4} \times f$

$$@85\text{kHz} \rightarrow E=22,95 \text{ V/m}$$

$$@85\text{kHz} \rightarrow E=11,48 \text{ V/m}$$

# REFERENCE FOR THE ASSESSMENT

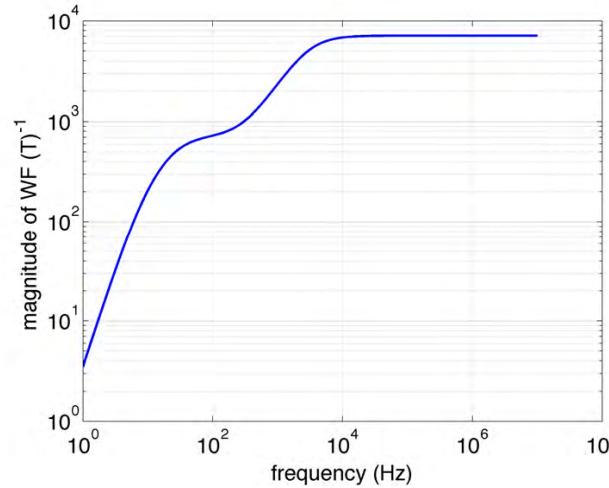
**WPM**

*j*th spectral component of the field under analysis

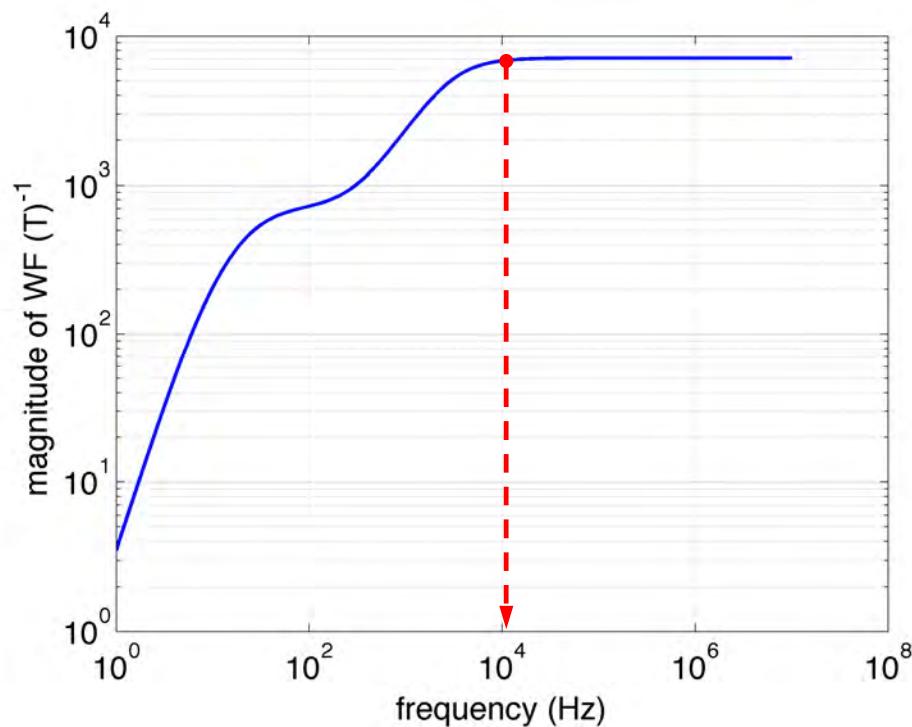
$$|W_j \overbrace{A_j}^{\text{jth spectral component}} \cos(2\pi f_j t + \theta_j + \varphi_j)| < 1$$

Amplitude of the weight function

Phase of the weight function

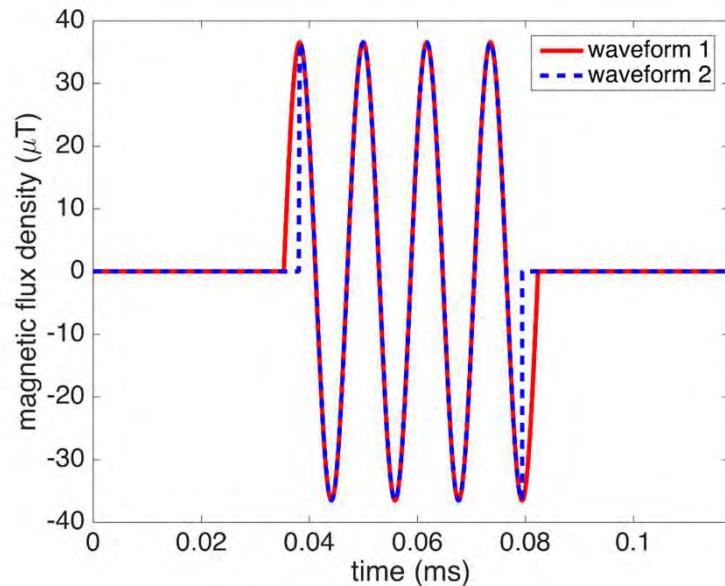


## REFERENCE FOR THE ASSESSMENT

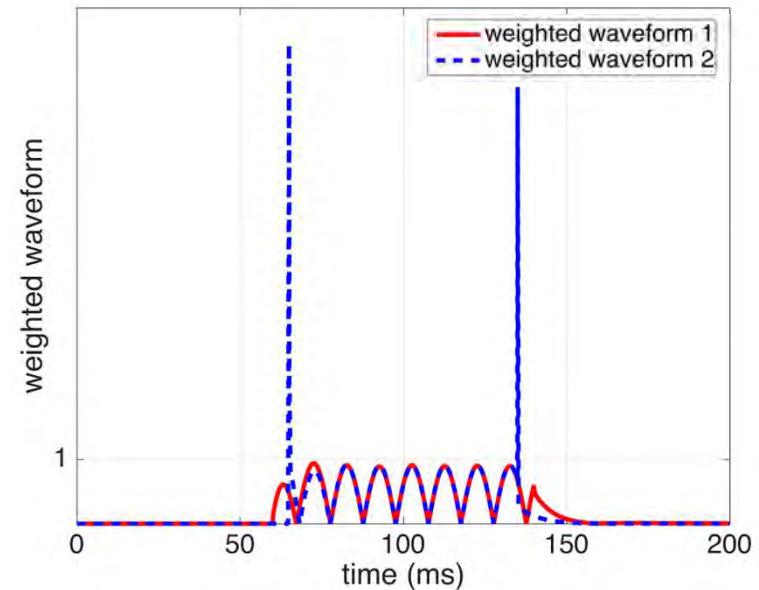
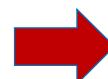


**For a waveform whose spectrum is limited above 10 kHz the WPM corresponds to the application of a scale factor**

# REFERENCE FOR THE ASSESSMENT

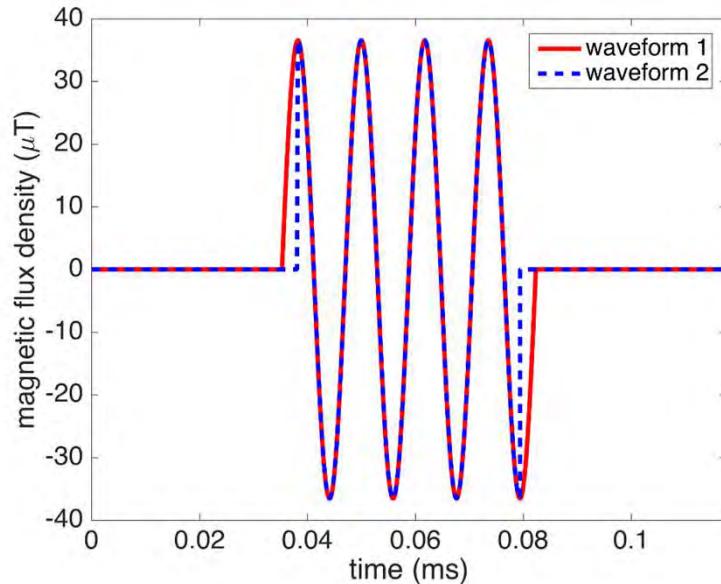


Sinusoidal bursts at 50 Hz

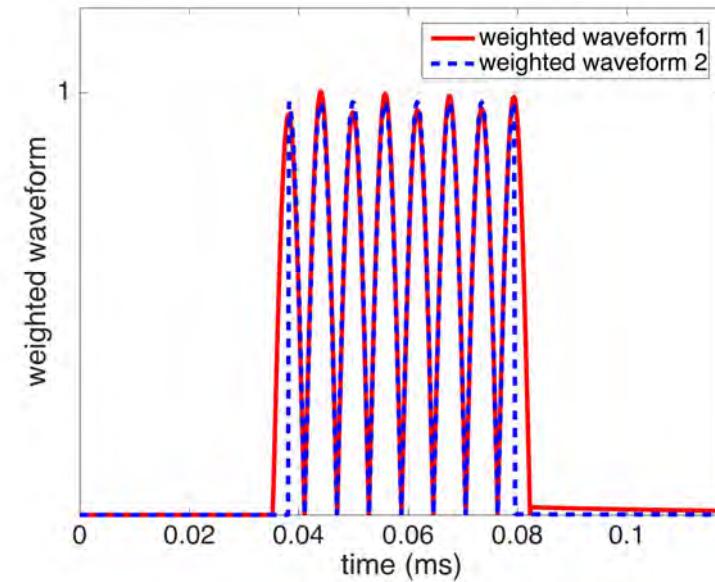
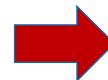


Weighted waveforms

# REFERENCE FOR THE ASSESSMENT



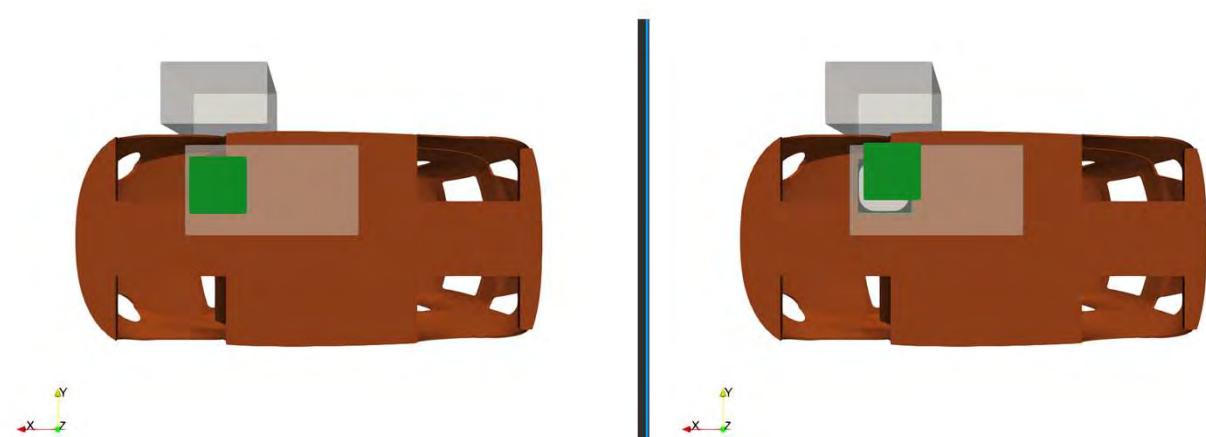
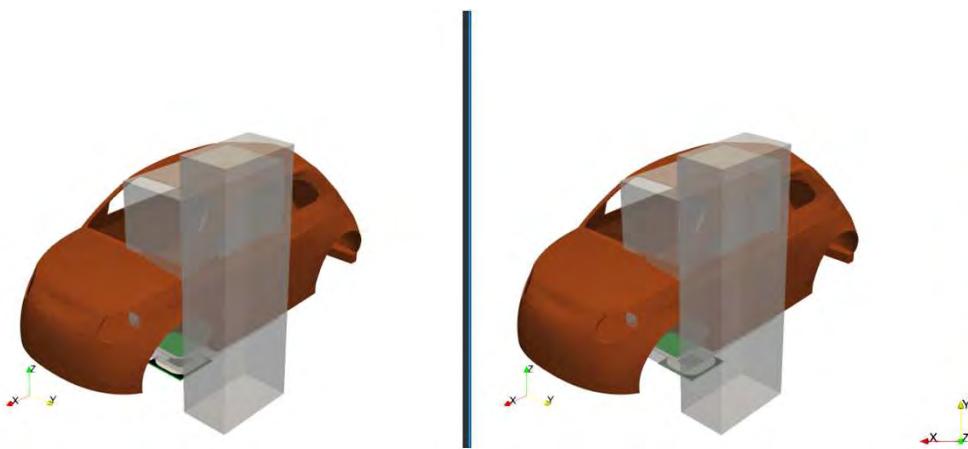
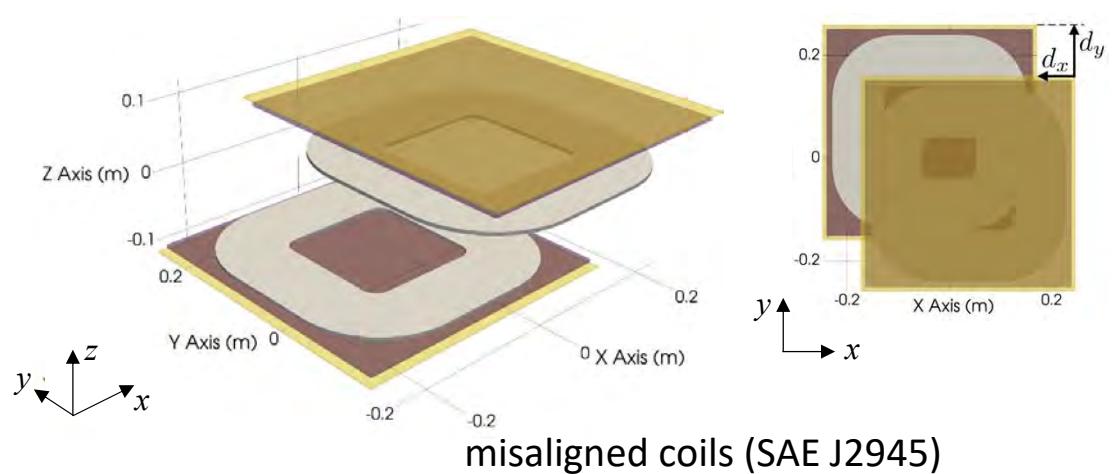
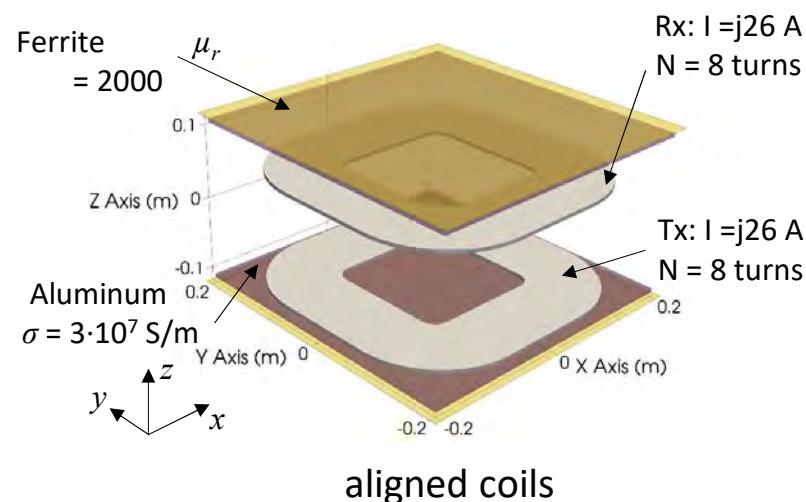
Sinusoidal bursts at 85 kHz



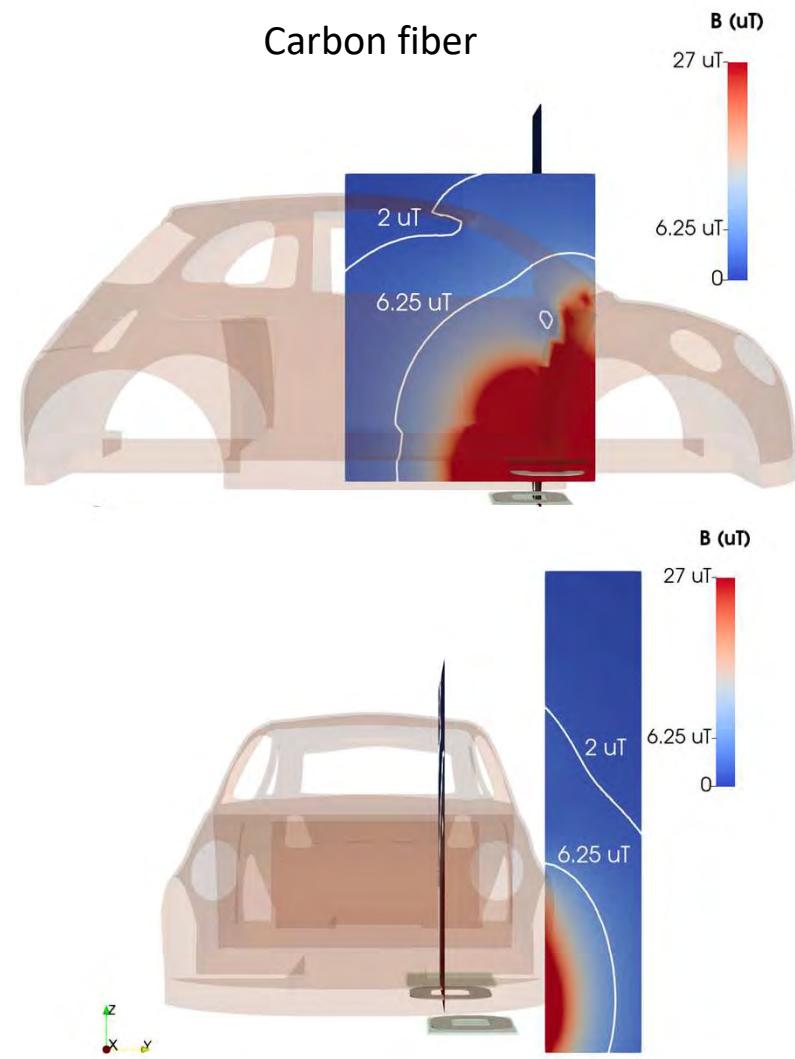
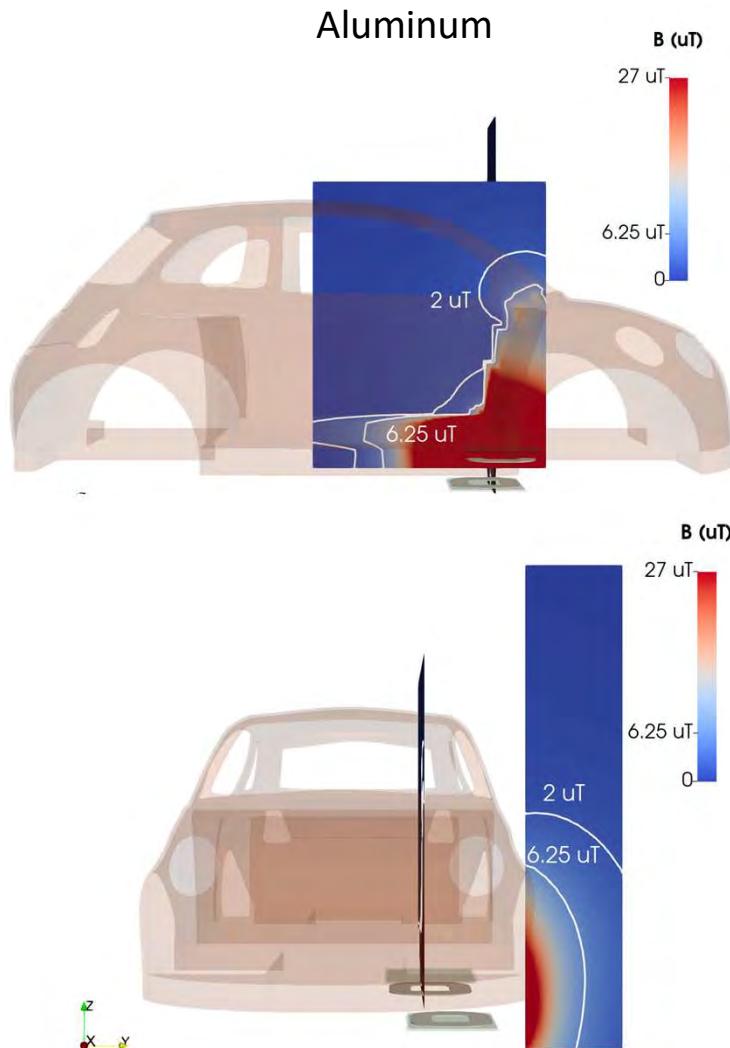
Weighted waveforms

**The peak exposure can be evaluated by means of a time-harmonic formulation**

# Stationary IPT system

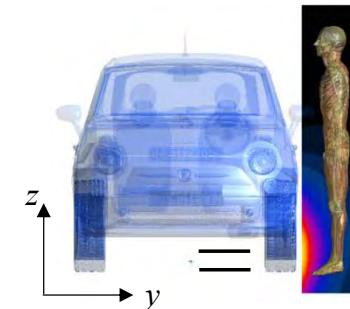
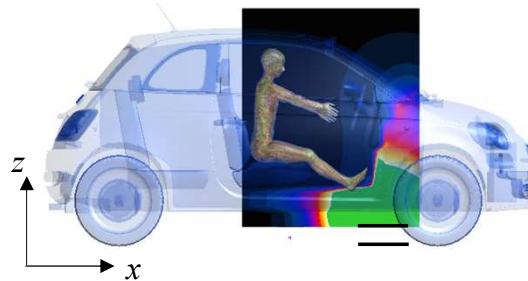


# Magnetic flux density

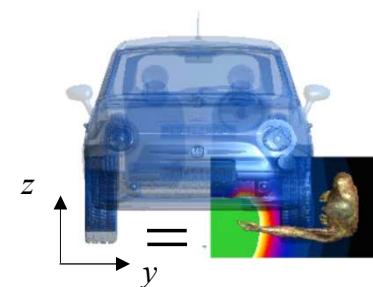
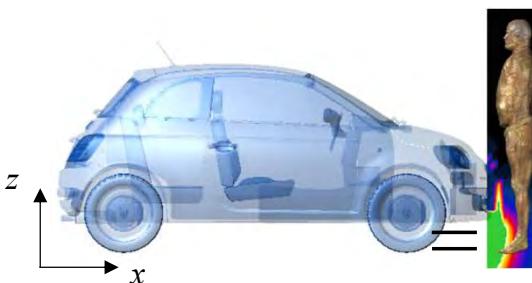


# Exposure scenario

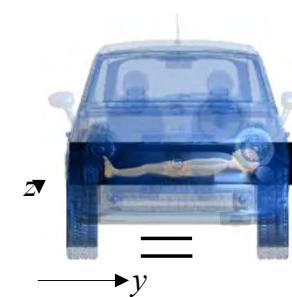
Exposure scenario 1



Exposure scenario 2



Exposure scenario 3



# Induced electric field

**Table 1.** Summary of the compliance with the BR for the considered exposure scenarios.

Exposure Scenario	Chassis Material	Coil Position	$E_{\max}$ (V/m)	$E_{99.9}$ (V/m)	$E_{99}$ (V/m)	Overexposure (dB)
#1 (from [15])	aluminum	Aligned	8.26	1.84	0.71	-24.17
		Misaligned	7.69	1.36	0.57	-26.08
	carbon fiber	Aligned	19.21	5.86	1.71	-16.48
		Misaligned	24.01	6.94	1.76	-16.23
#2 #3	steel	Aligned	31.84	10.39	5.65	-6.15
		Misaligned	33.51	10.52	5.73	-6.03
		Aligned	1.30	0.39	0.21	-34.75
		Misaligned	2.68	0.61	0.28	-32.25

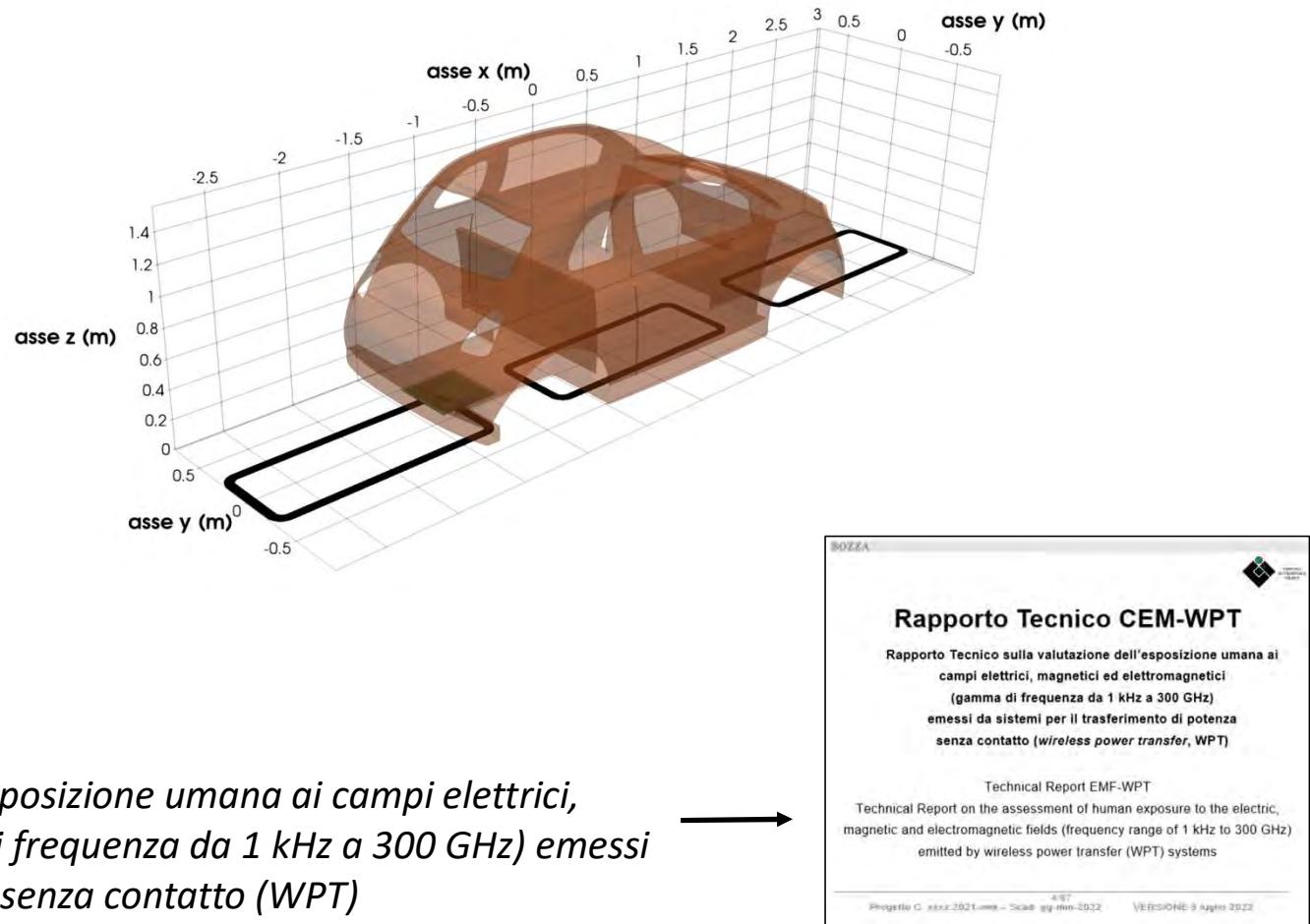
Further details:

[1] De Santis, V.; Giaccone, L.; Freschi, F. Chassis Influence on the Exposure Assessment of a Compact EV during WPT Recharging Operations. *Magnetochemistry* **2021**, *7*, 25. <https://doi.org/10.3390/magnetochemistry7020025>

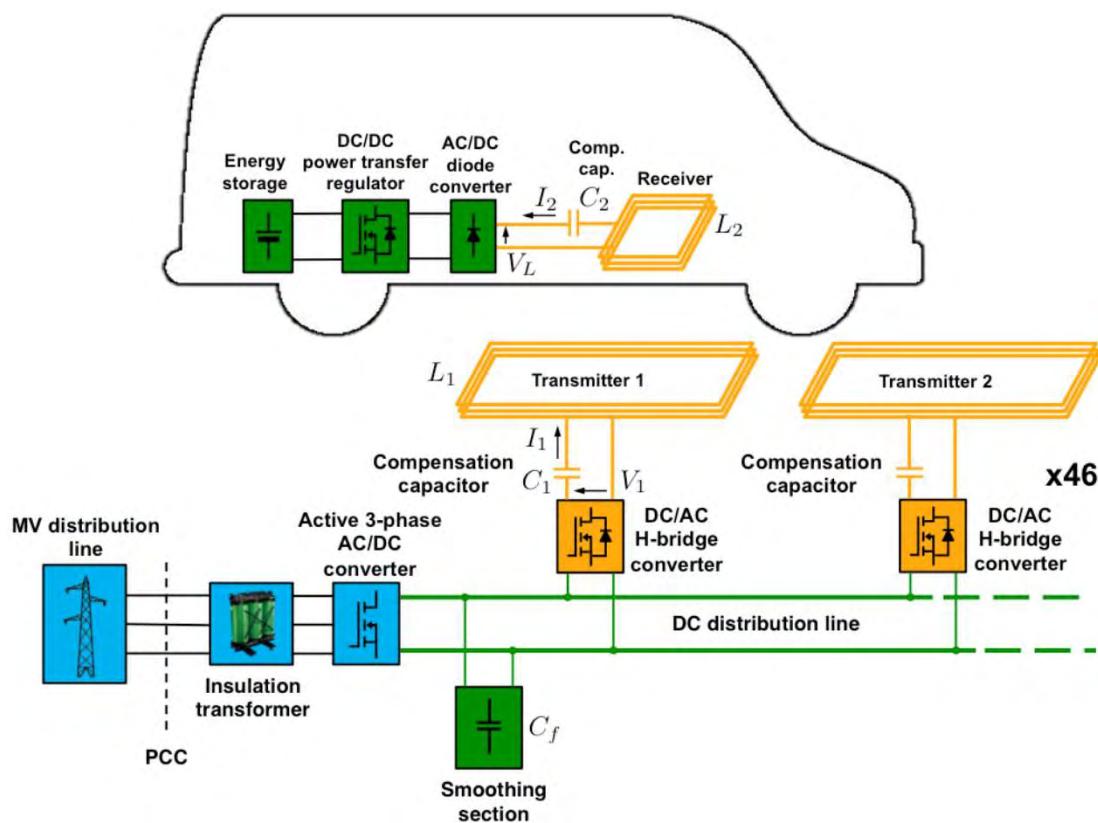
[2] De Santis, V.; Giaccone, L.; Freschi, F. Influence of Posture and Coil Position on the Safety of a WPT System While Recharging a Compact EV. *Energies* **2021**, *14*, 7248. <https://doi.org/10.3390/en14217248>

# Dynamic IPT system

- 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



# Dynamic IPT system: experimental application



eCoFEV  F<sub>o</sub>BRIC 

# Dynamic IPT system: experimental application

**100 m of charging lane (46 transmitters)**

**Rated power 22 kW**

**Rated frequency 85 kHz**

**Magnetic gap 25 cm**

**Maximum tested speed 70 km/h**

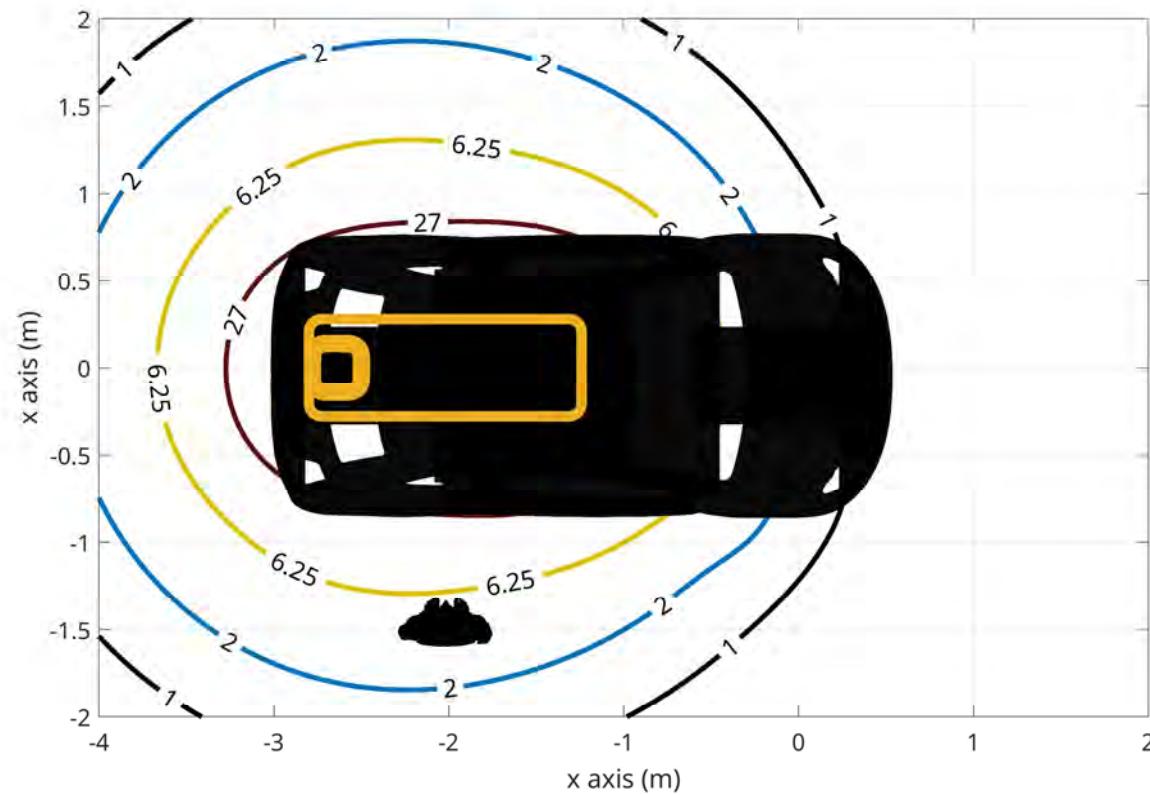
**Maximum static efficiency 91% (power referred)**

**Max. in-motion efficiency 85% (energy referred)**

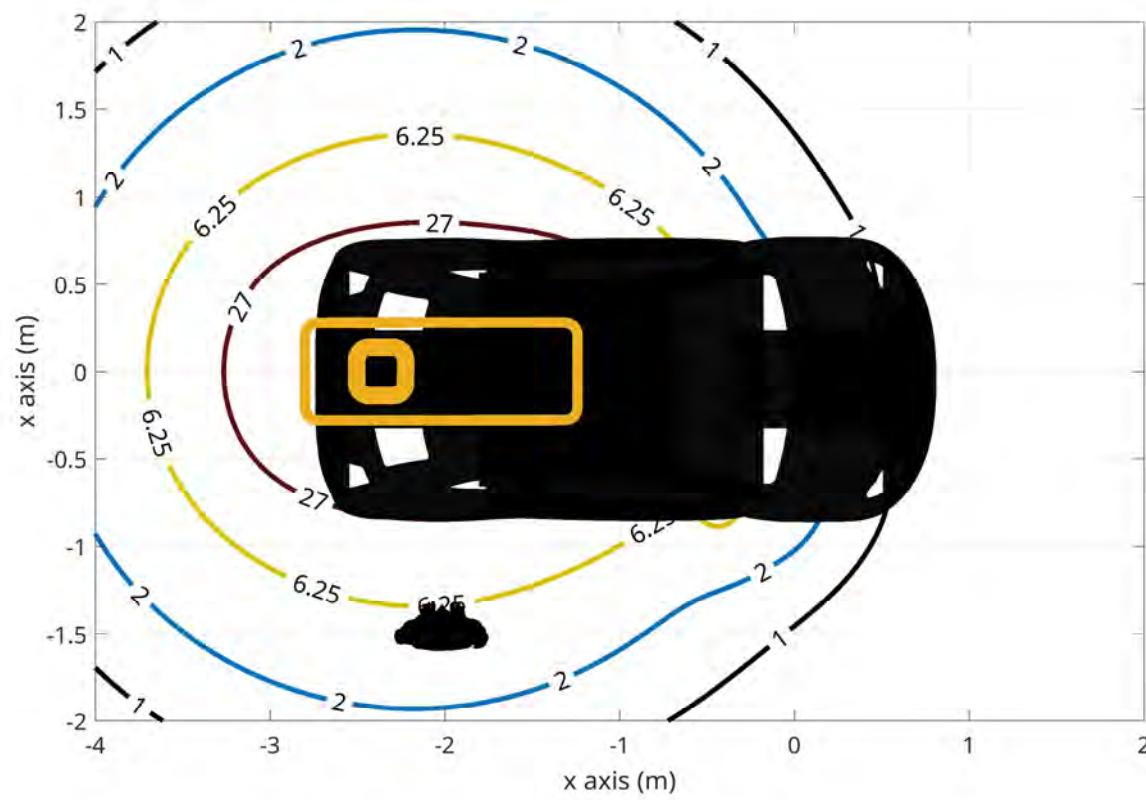


**eCoFEV** **FABRIC**

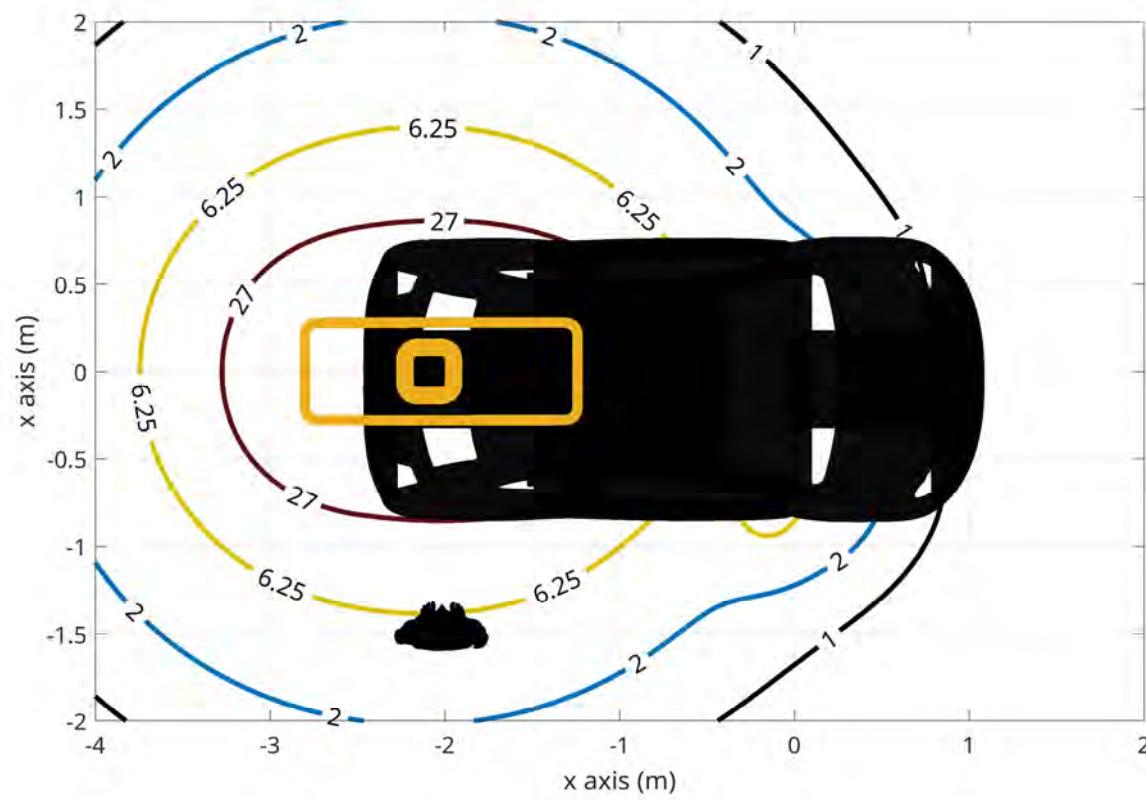
# Dynamic IPT system



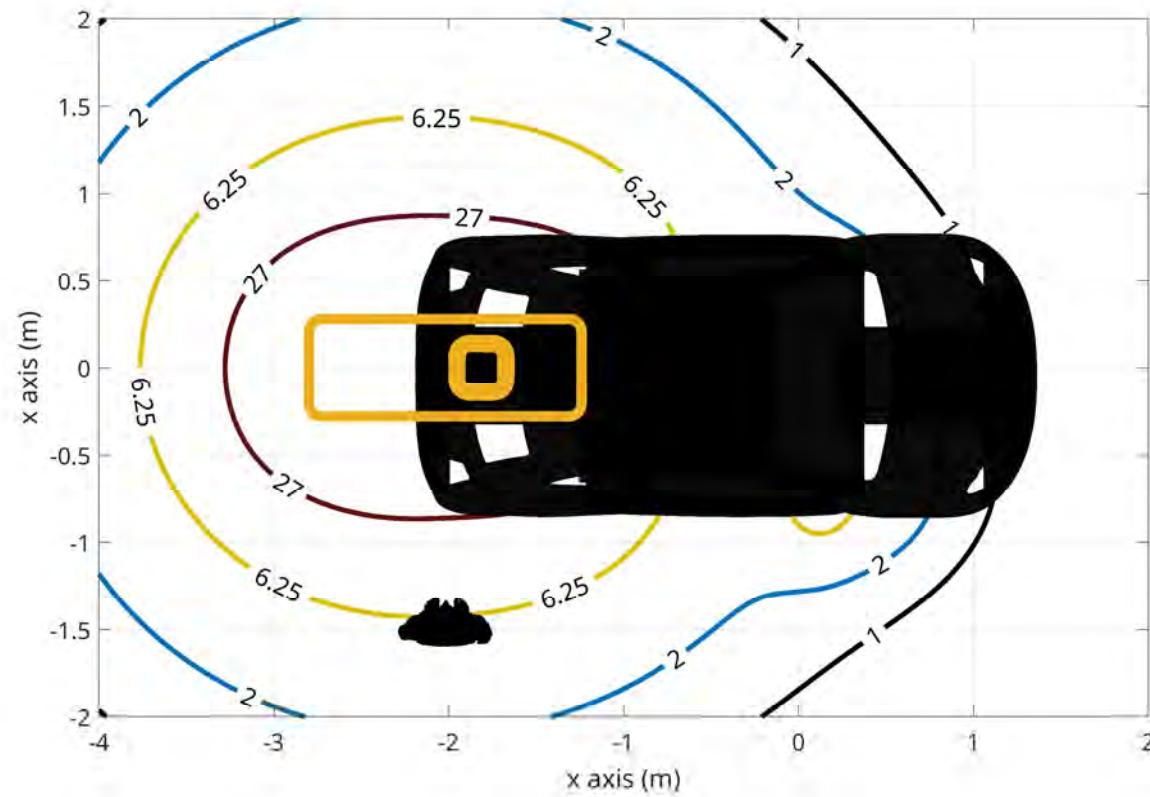
# Dynamic IPT system



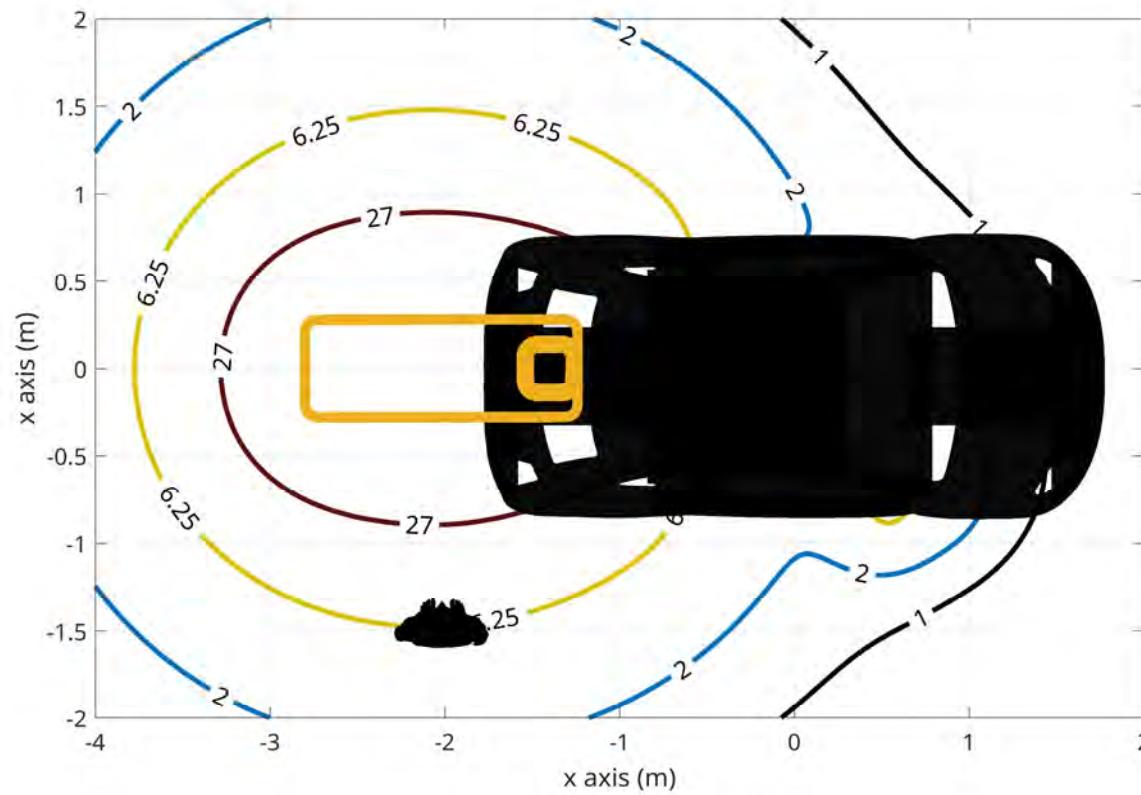
# Dynamic IPT system



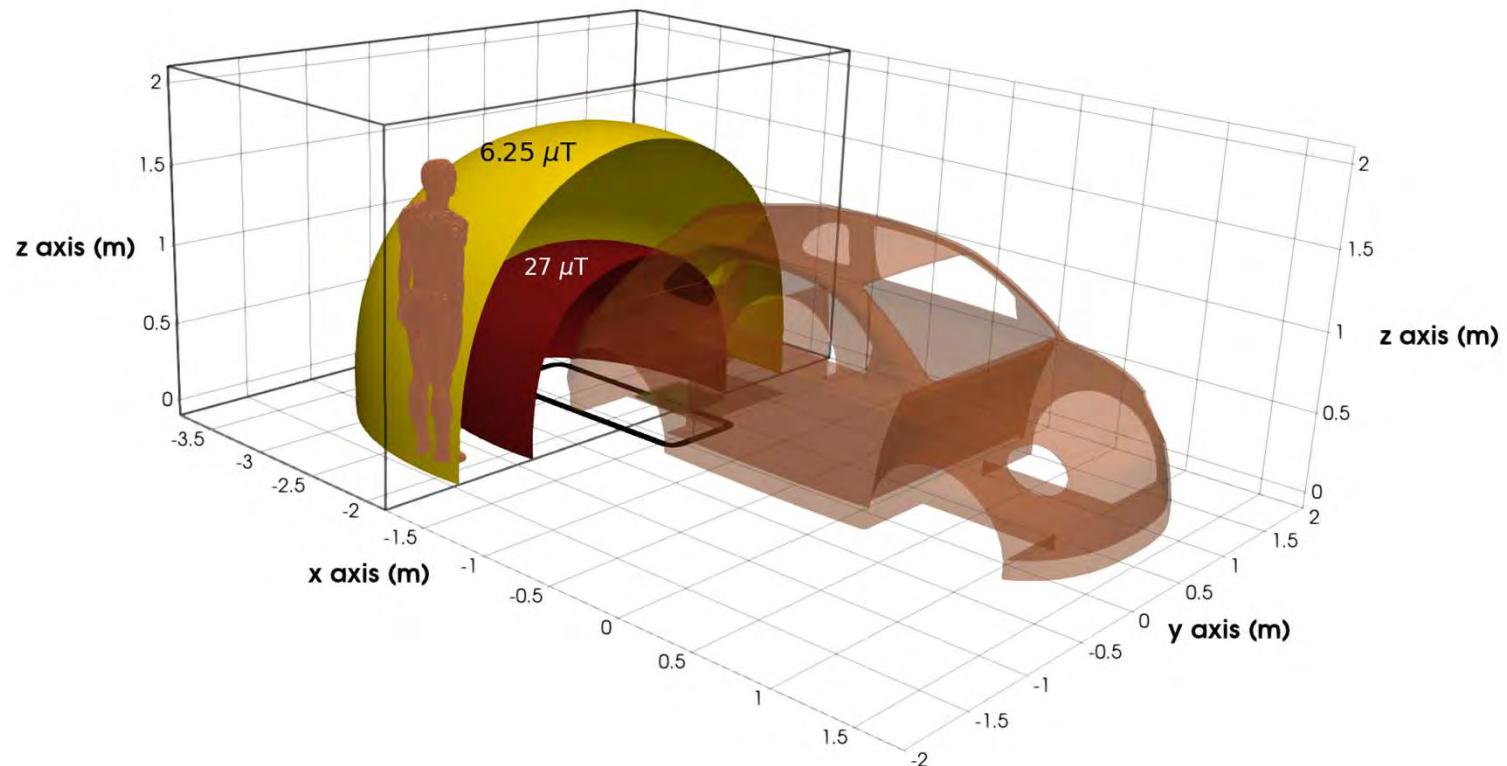
# Dynamic IPT system



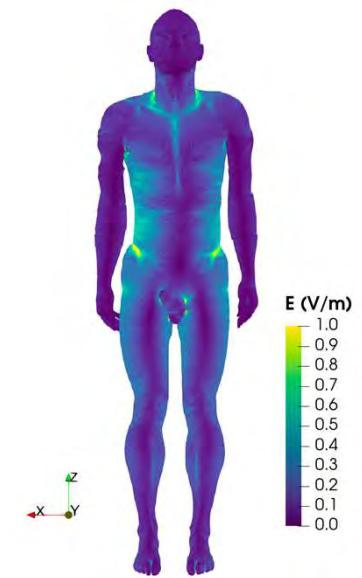
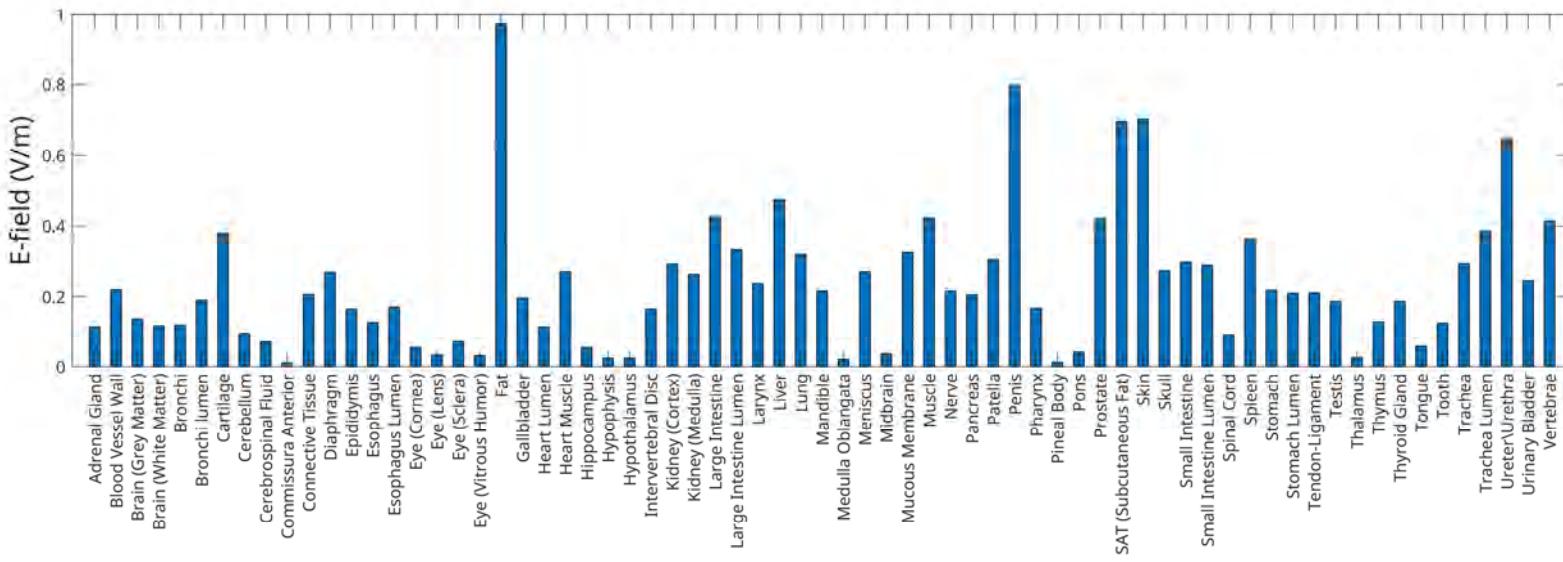
# Dynamic IPT system



# Dynamic IPT system

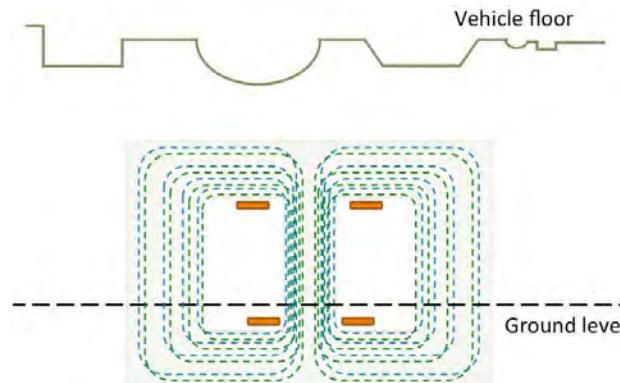
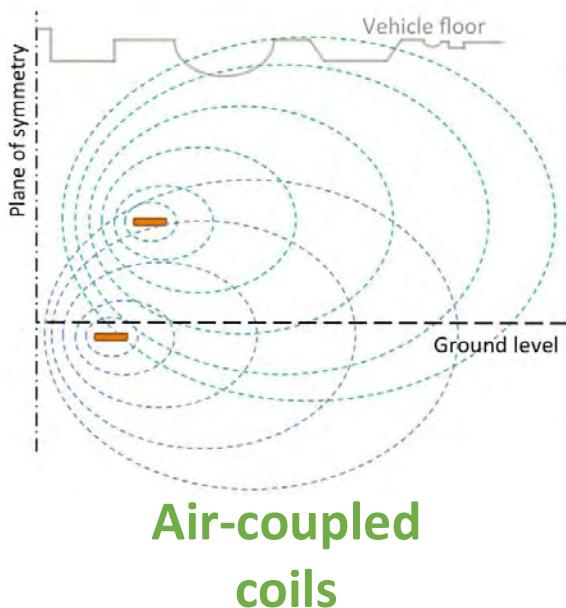


# Dynamic IPT system



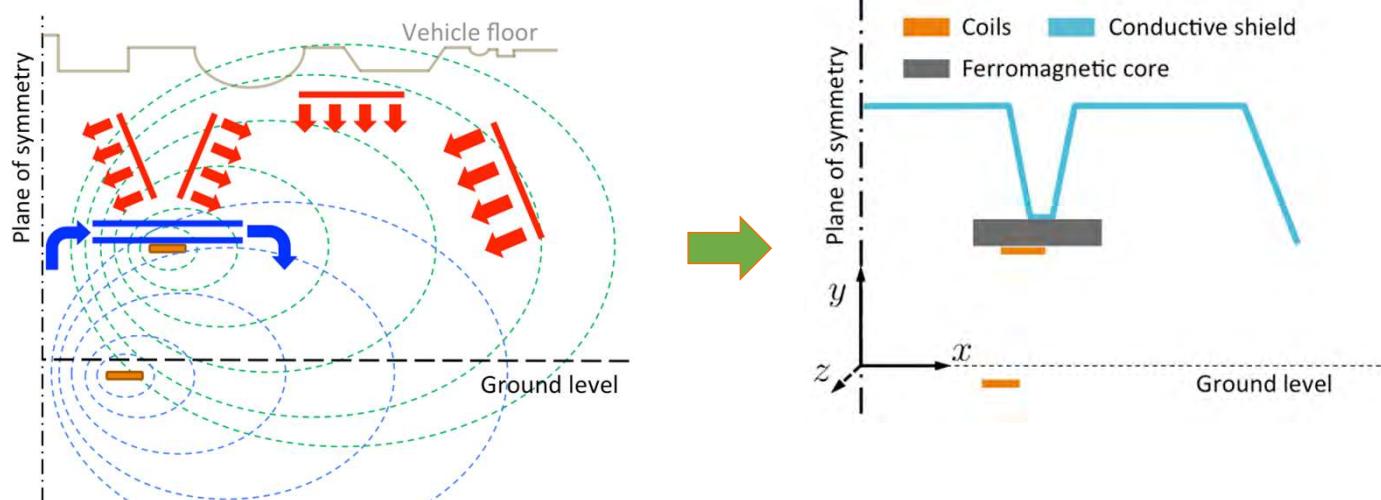
# Magnetic structure - Design

A magnetic structure is added in order to confine the magnetic flux in a better defined region



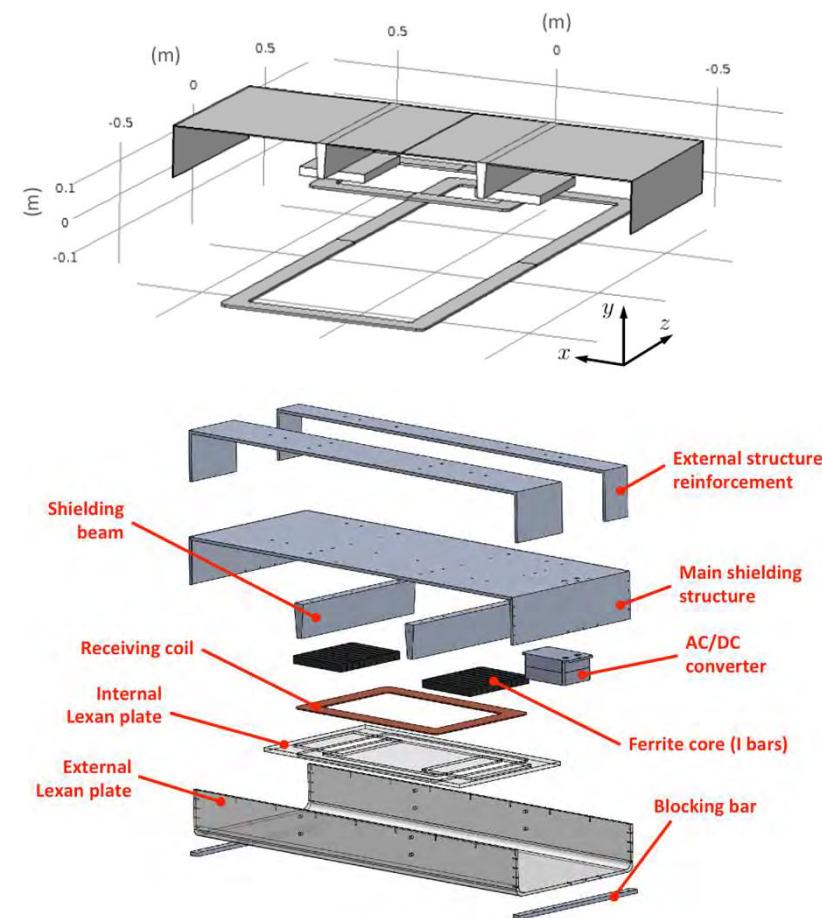
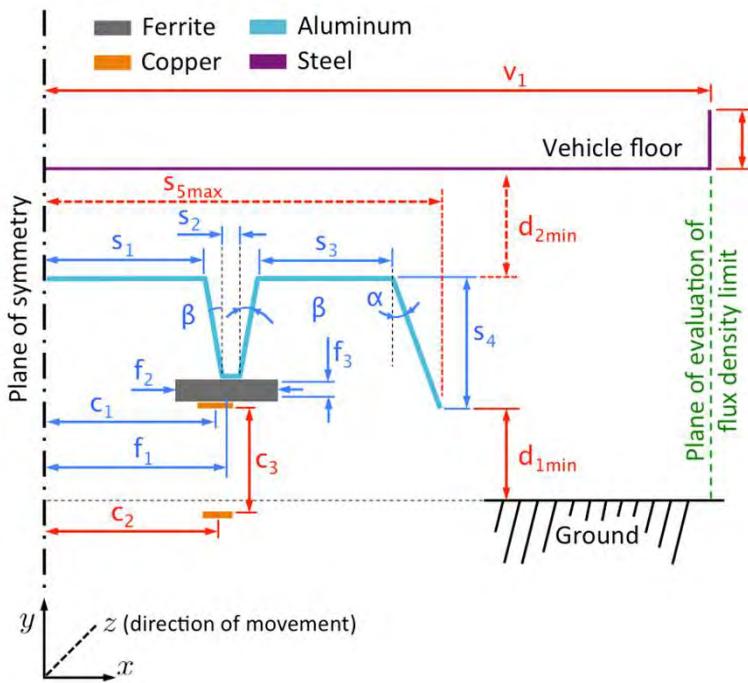
# Magnetic structure - Design

A magnetic structure is added in order to confine the magnetic flux in a better defined region

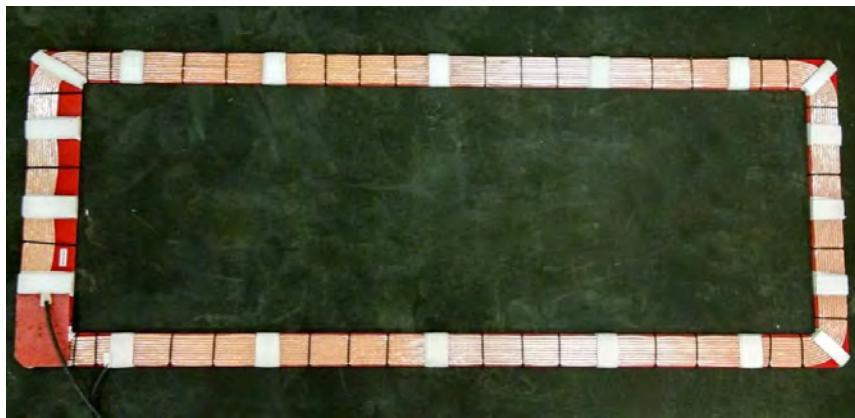


# Magnetic structure - Optimisation

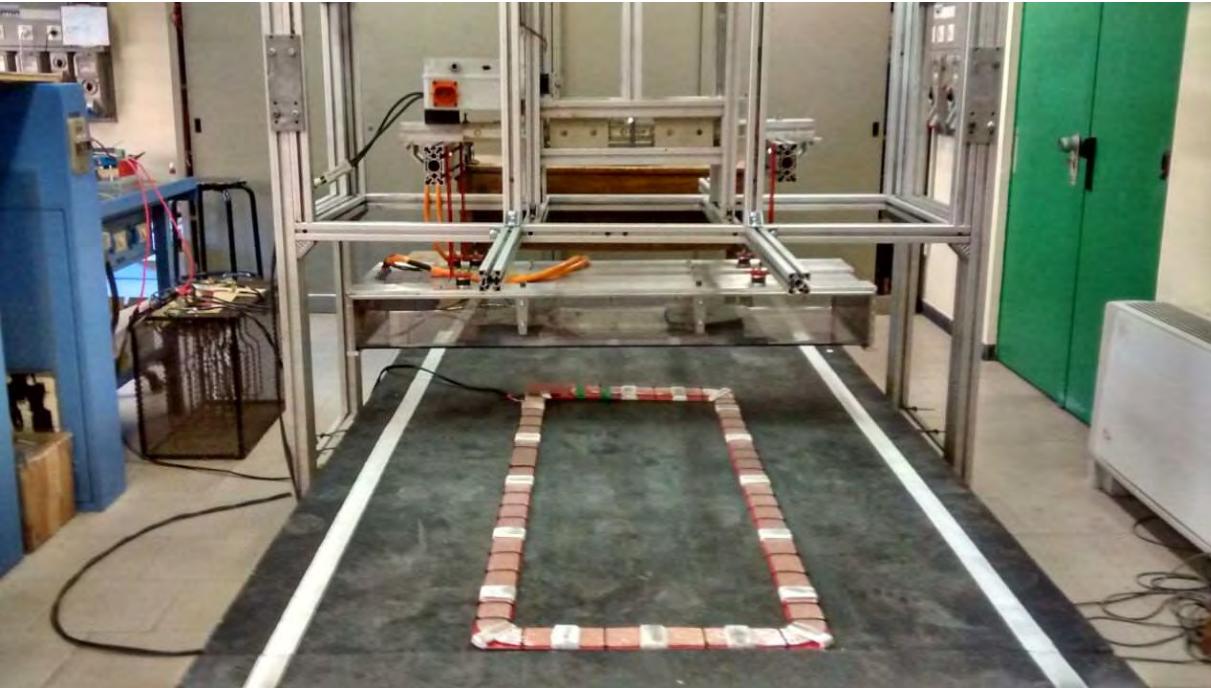
Optimization based on the differential evolutionary strategy algorithm



# Magnetic structure - Physical implementation



# Laboratory setup



# On-road installation - Coil embedding



Grazie per l'attenzione

aldo.canova@polito.it