Wireless Charging of Electric Vehicles

human exposure and foreign objects

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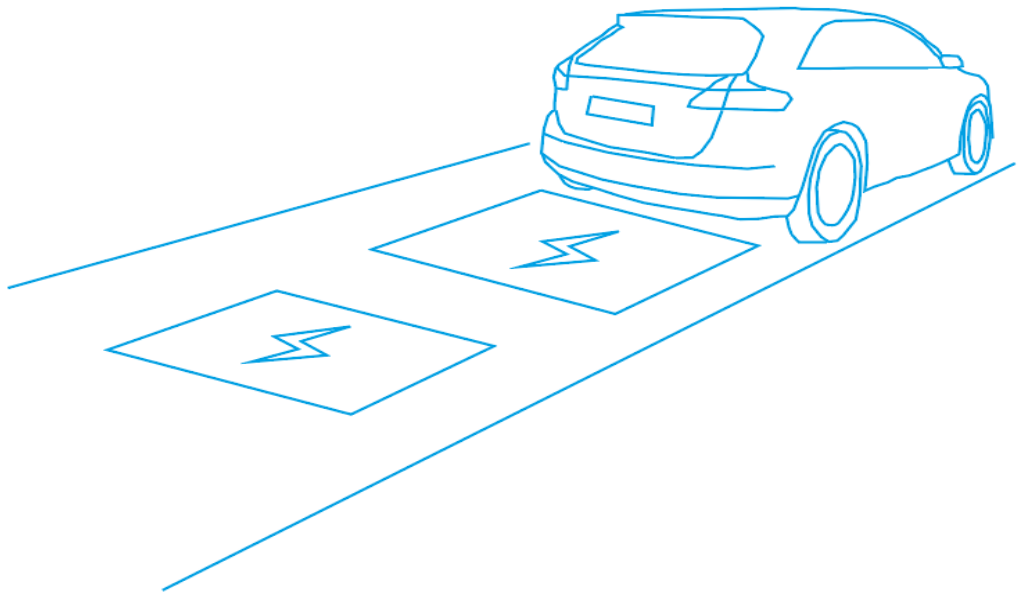

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Hotel van der Valk Vianen

Dinsdag 21 november

About me

Dr. Wenli Shi

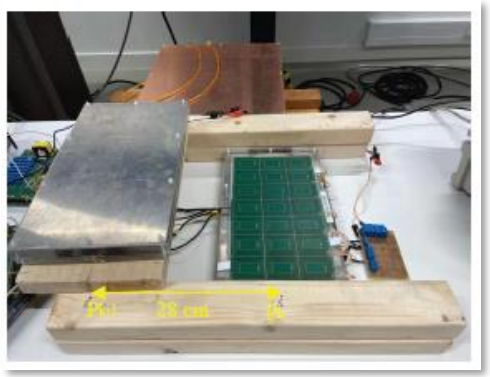
Education

- MSc in Mechanical Engineering, 2015-2018, "*Efficient Wireless Charger for EVs*"
- PhD in Electrical Engineering at TU Delft, 2018-2023

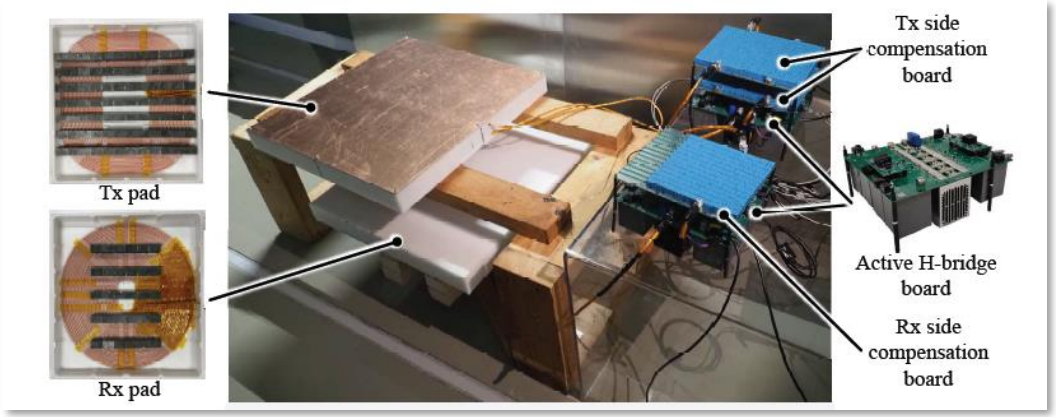
  Thesis title "Dynamic Wireless Charging of Electric Vehicles"

Work

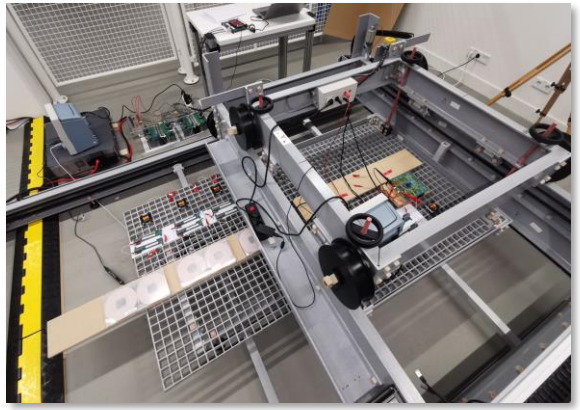
Postdoctoral researcher in DCE&S group at TU Delft, 2023-Now



wireless charger with integrated detection system



20 kW wireless charger with 97.4% dc-dc efficiency



dynamic wireless charger with low power fluctuation

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Outline

- Basics of wireless power transfer
- Human exposure of wireless power transfer
- Foreign object detection of wireless power transfer
- Conclusions

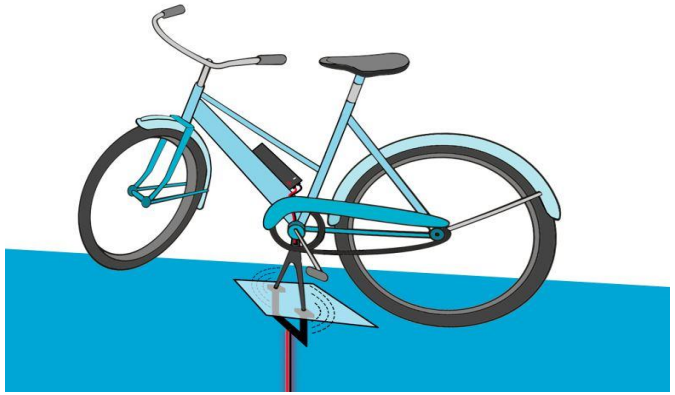
WPT applications

TU Delft Prototypes:

- 20 kW at 97.4% dc-dc power efficiency
- 50 kW at 97.7% dc-dc power efficiency

Essential functional elements (SAE J2954):

- Power transfer function
- Communication function
- Safety: human exposure and metal foreign objects



Wireless E-bike Charging
www.tudelft.nl

Inductive Power Transfer for Electrical Vehicles
www.witricity.com

*Based on: Beckers. C. et al (2021), “The State-of-the-Art of Battery Electric City Buses. Paper presented at 34th International Electric Vehicle Symposium and Exhibition (EVS34), Nanjing, China.

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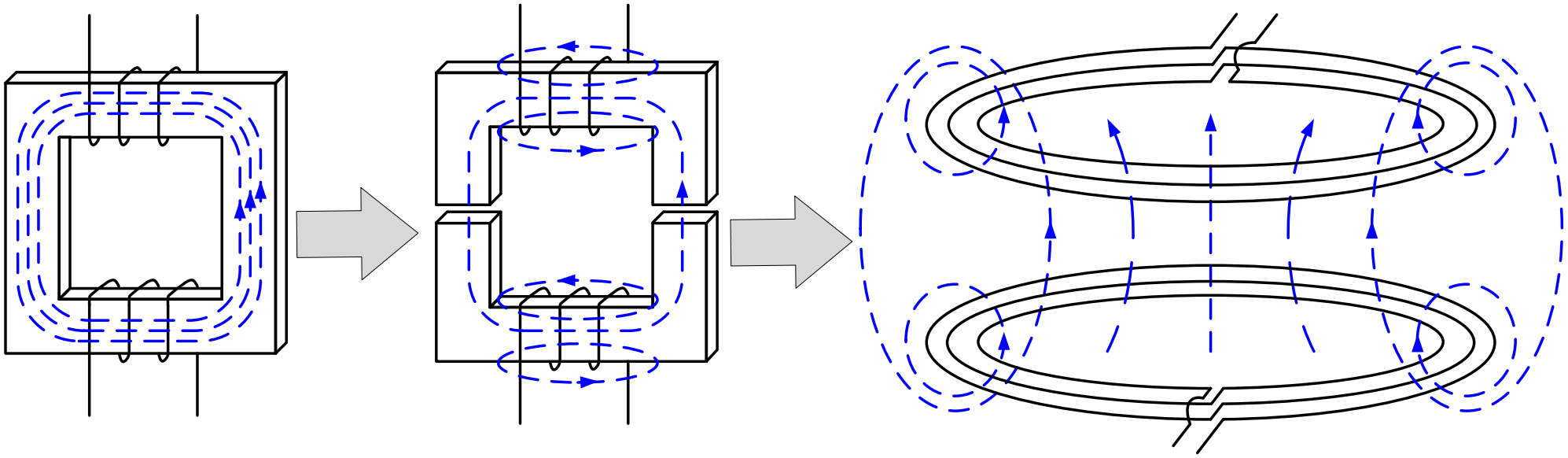
WPT principles

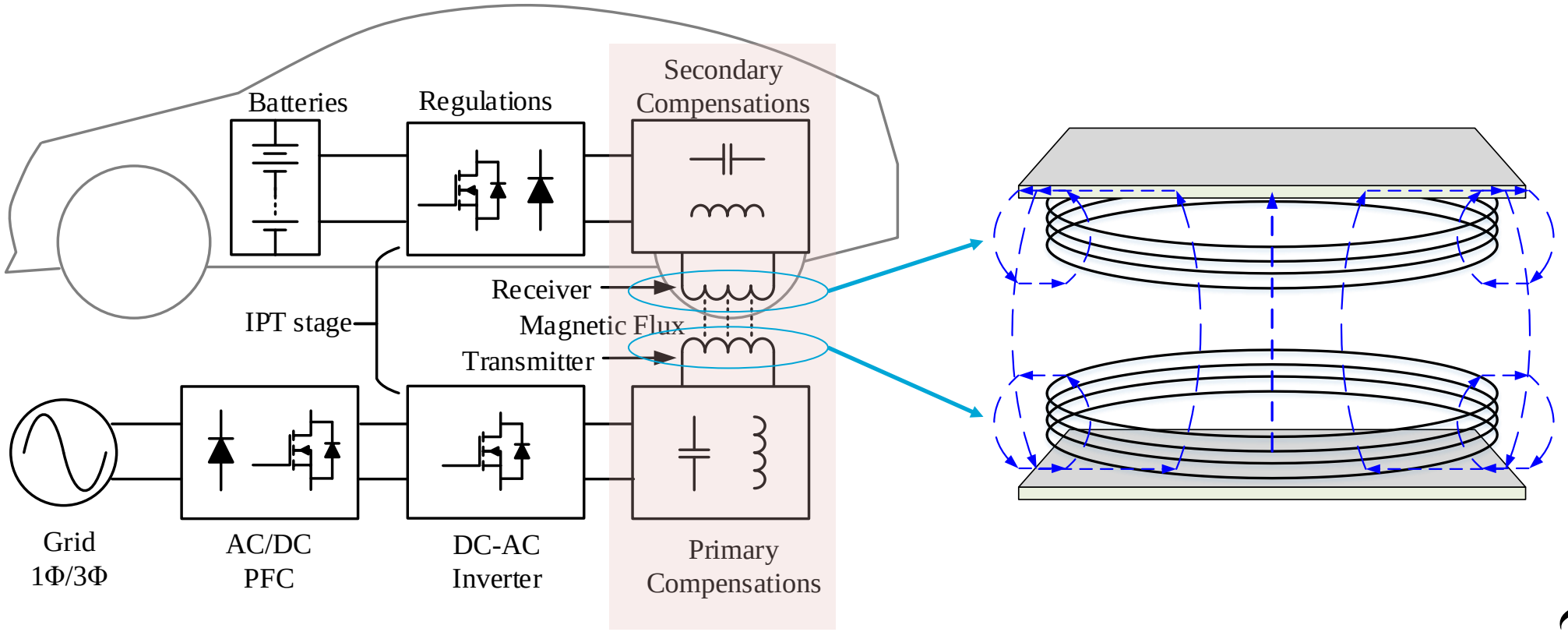


Highly coupled transformer

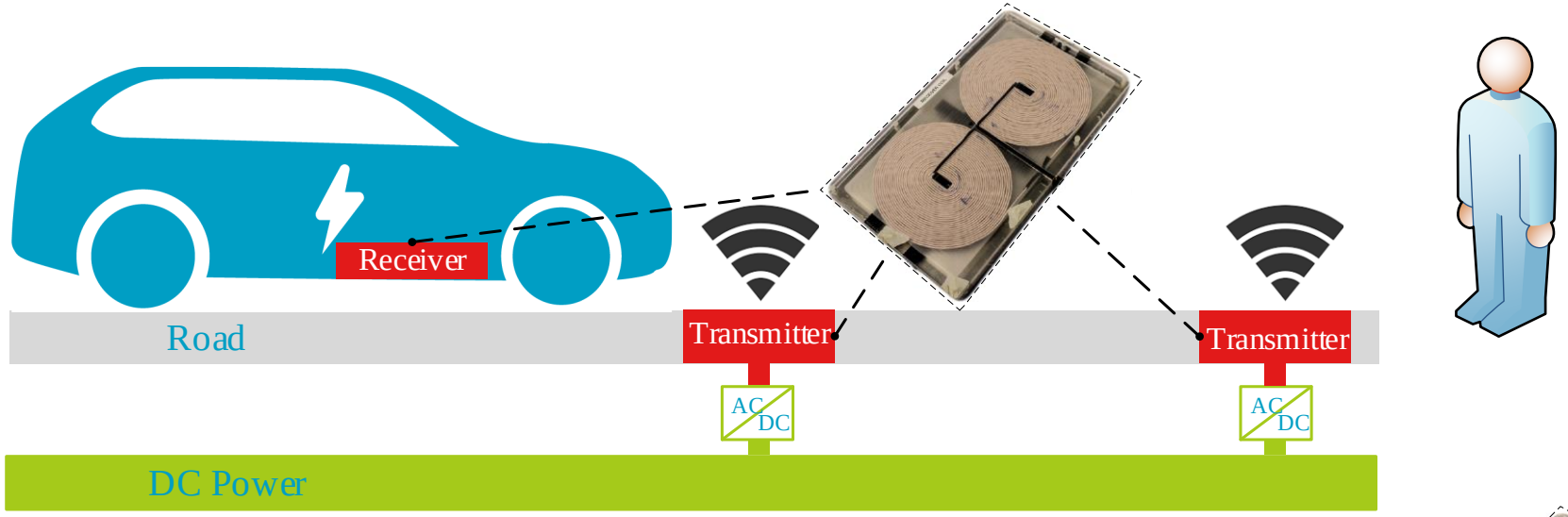
Splitted core transformer

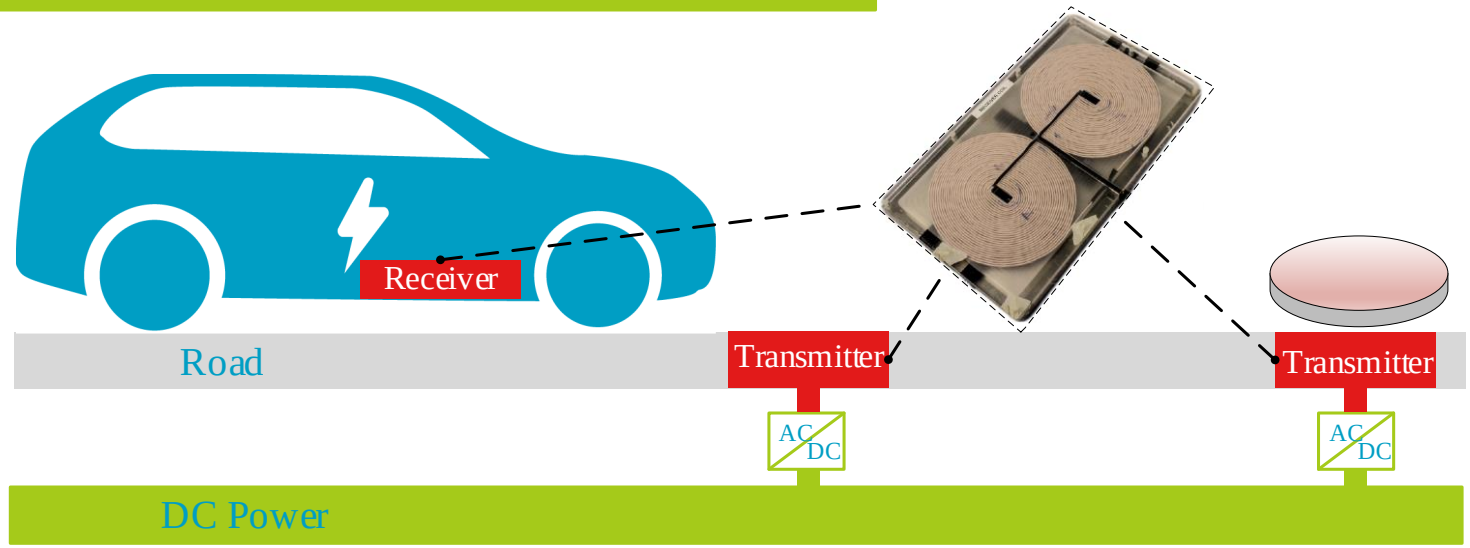
Air core transformer

WPT principles



WPT safety issues





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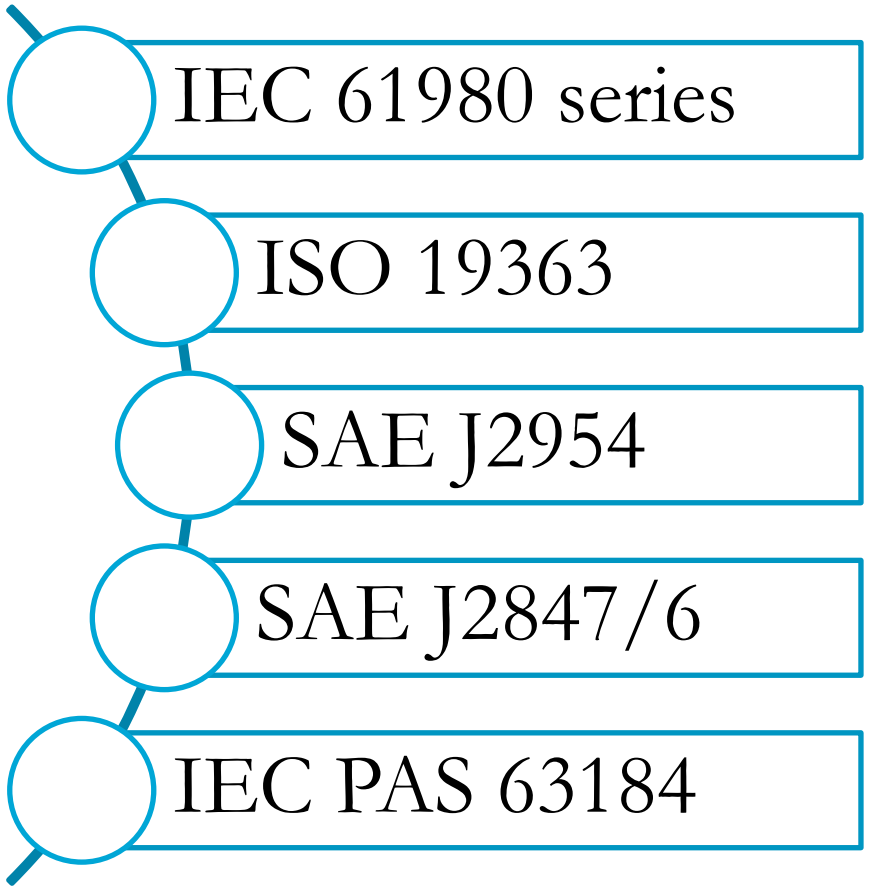
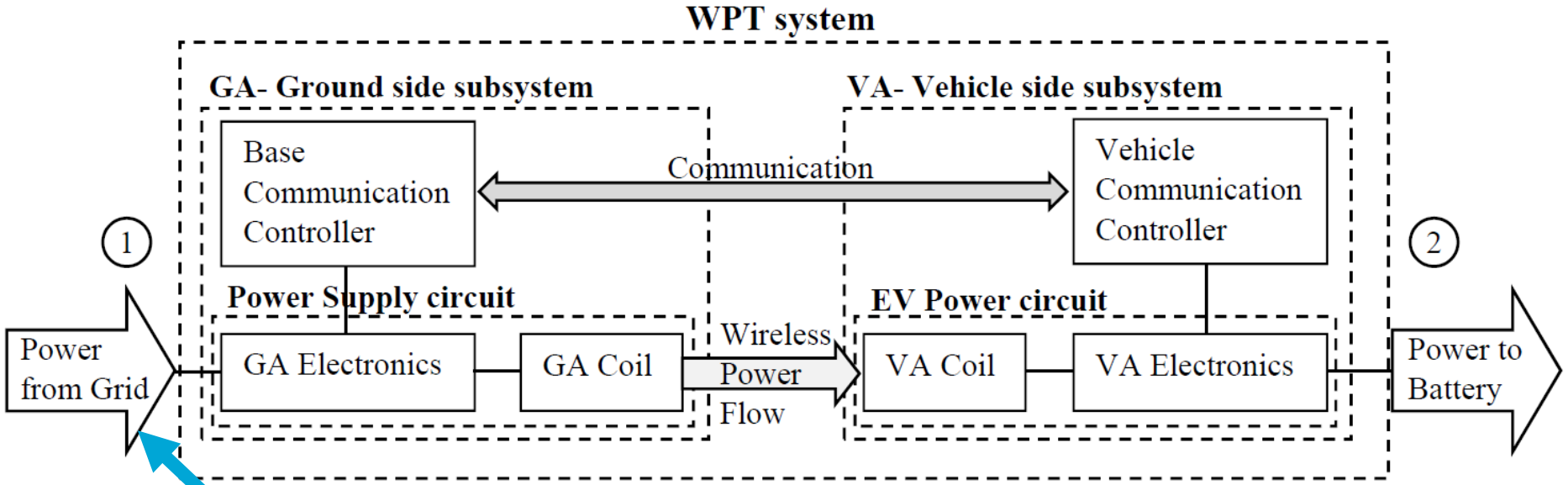
WPT standards

From 2015 until now:

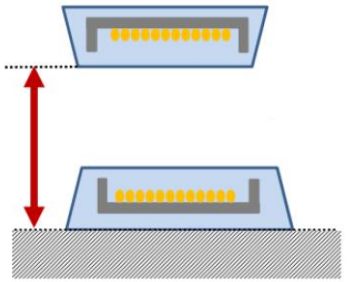


- Power levels and reference designs
- Communications
- Interoperability
- Protection against electric shock
- Human exposure
- Foreign objects
- …

IEC 61980-3, ISO 19363, SAE J2954



	Power classes				
	WPT1	WPT2	WPT3	WPT4*	WPT5*
Maximum input (kVA)	3.7	7.7	11.1	22	60
*under consideration					



		Z-classes		
		Z1	Z2	Z3
VA Coil ground clearance range (mm)	from	100	140	170
	to	150	210	250

Minimum efficiency betwee (1) and (2) :

→ 85 % aligned

→ 80 % offset

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IEC 61980-3, ISO 19363, SAE J2954

Magnetic field radiation limits

- IEC 61980-1
- ISO 19363

→ CISPR 11 Group 2*

<u>Environmental</u>

Class A
(non-residential)

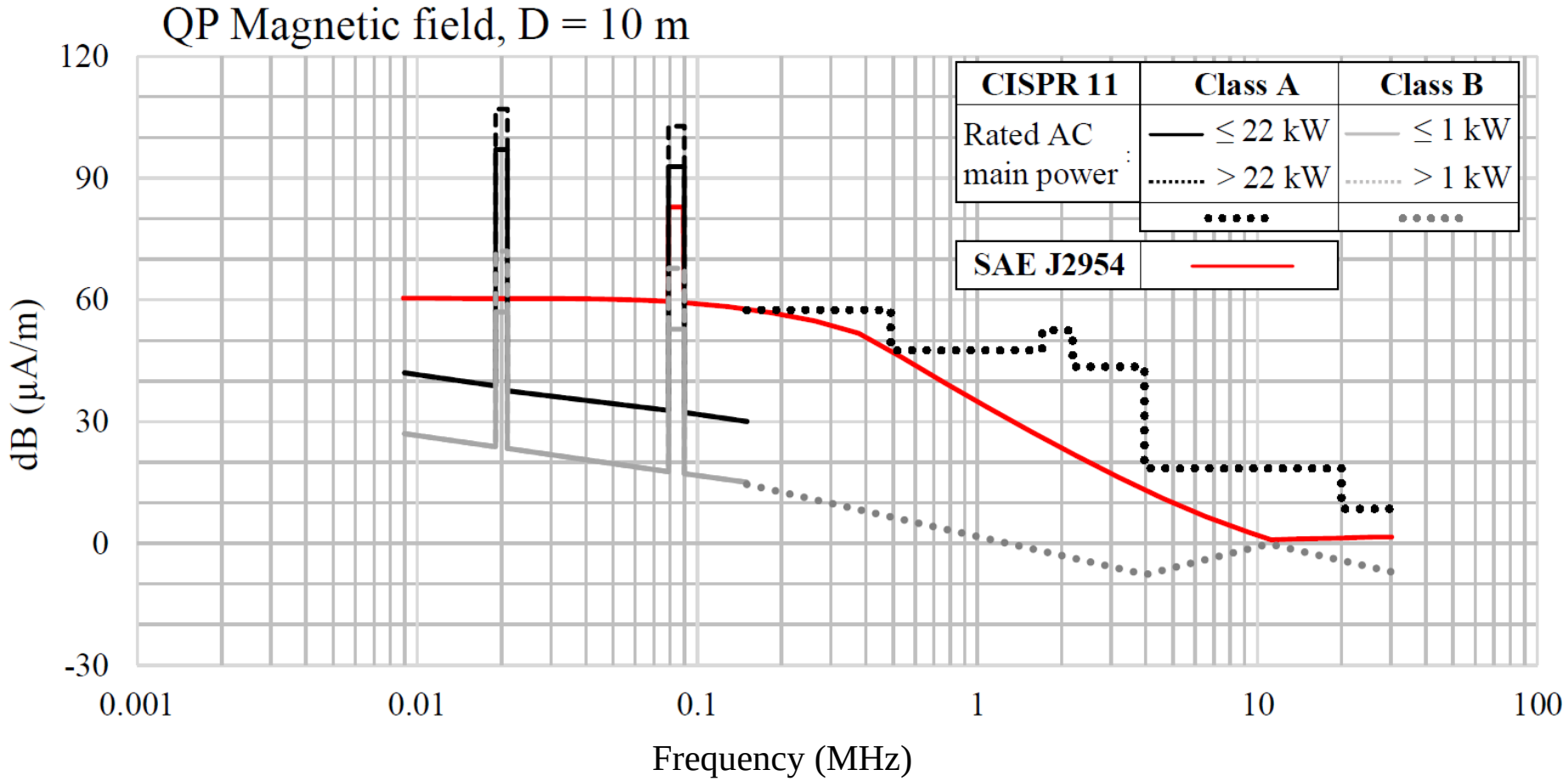
Class B
(residential)

- SAE J2954 → proposed Recommended Limits

*A specific part of CISPR 11 for WPT is under development

IEC 61980-3, ISO 19363, SAE J2954

Magnetic field radiation limits - Comparison



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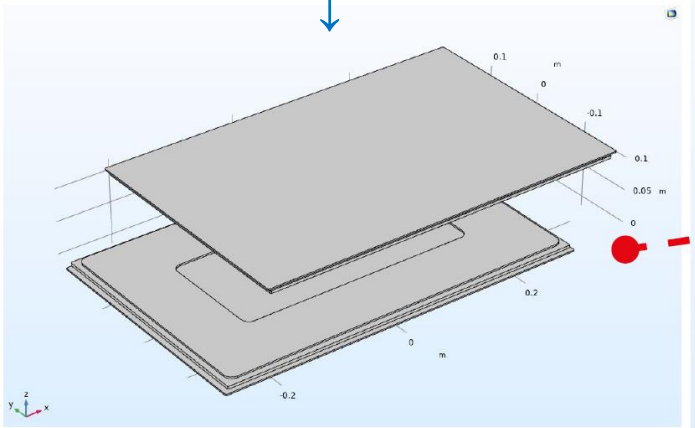
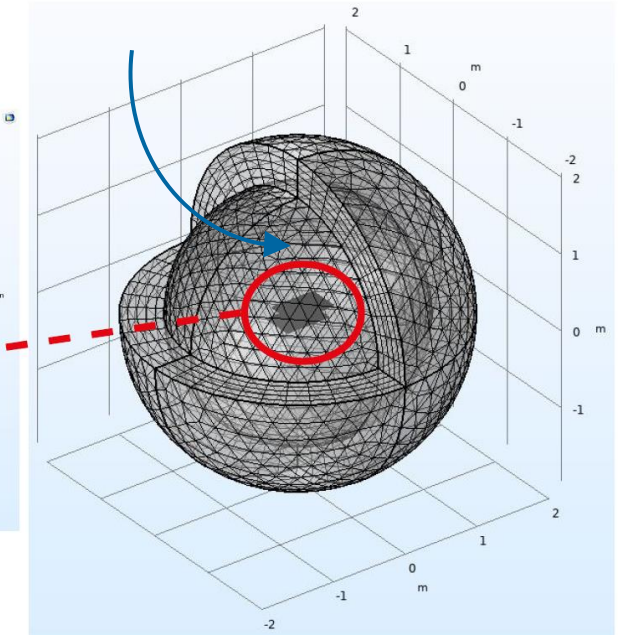
FEM simulation of the radiated magnetic field

Harmonic amplitude, phase and frequency of the measured

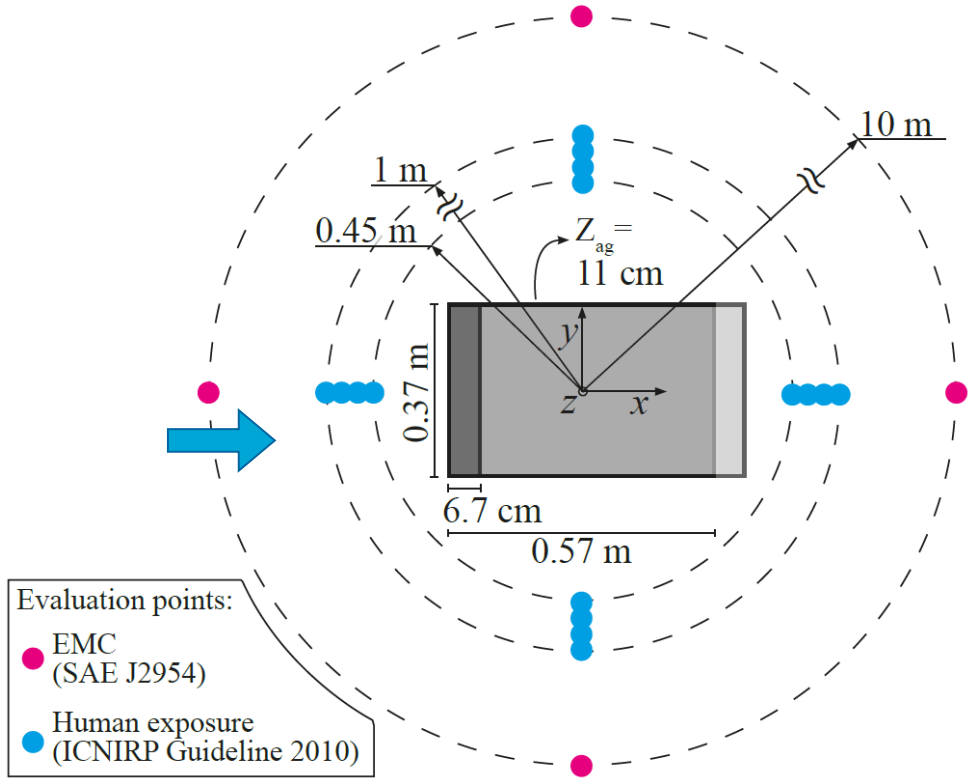
I_1, I_2



FEM model: infinite element domain



Evaluation of the radiated magnetic field



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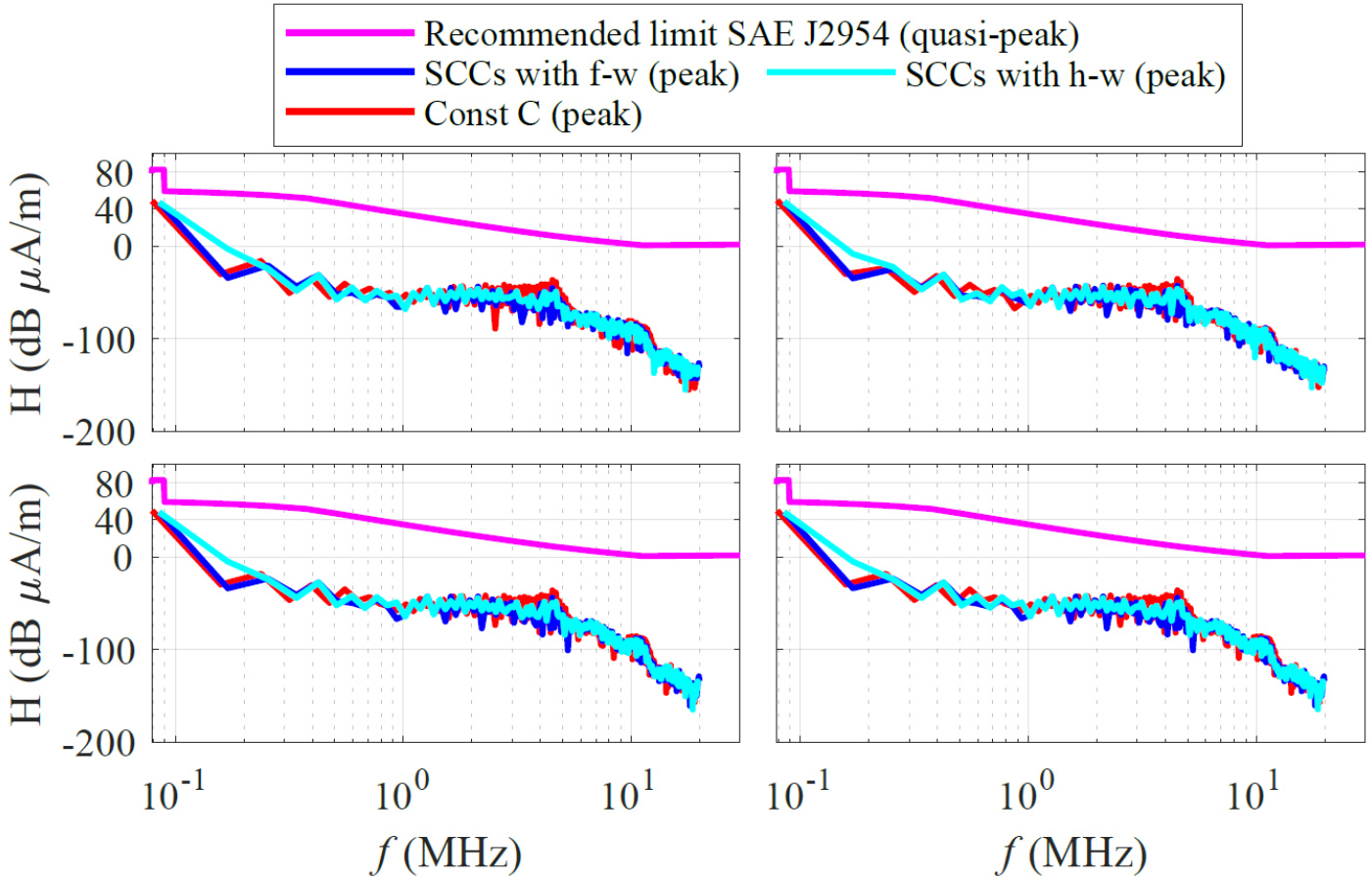
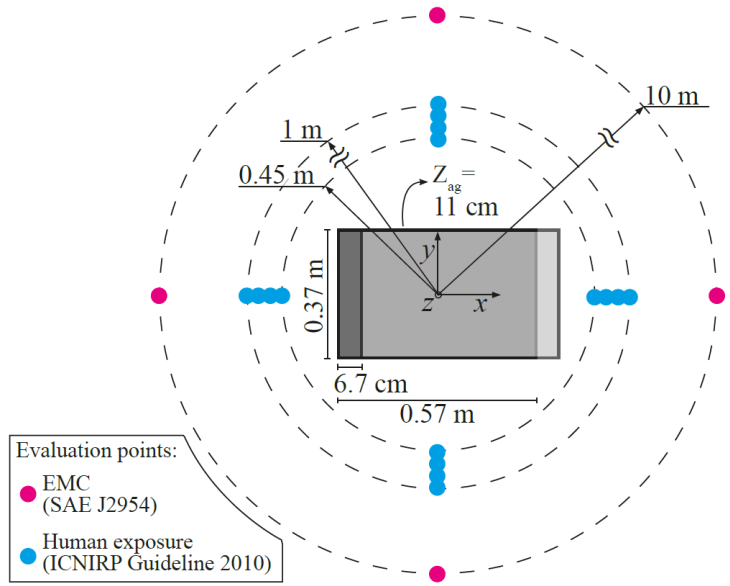
FEM simulation of the radiated magnetic field

Magnetic field radiation at 10 meter distance

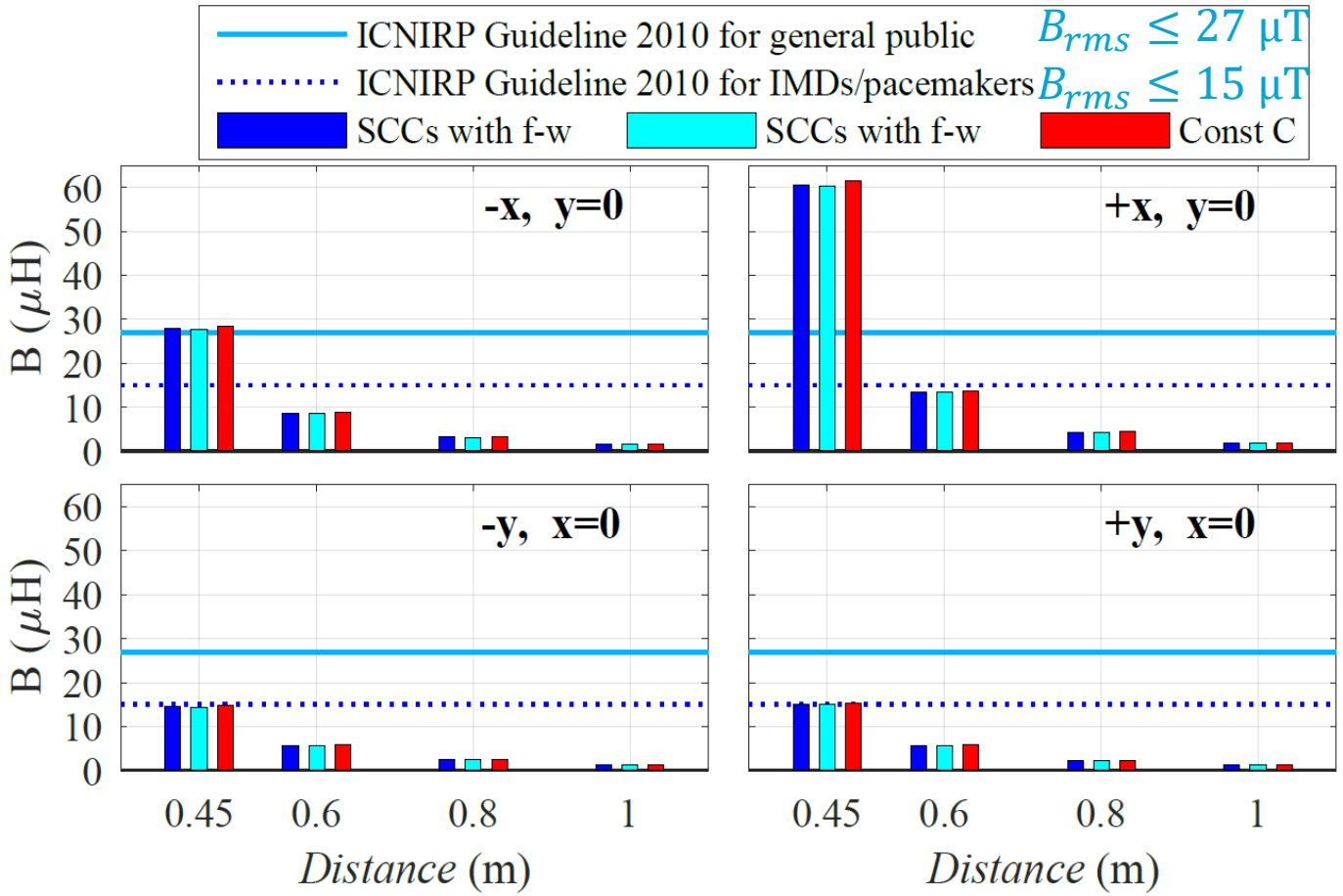


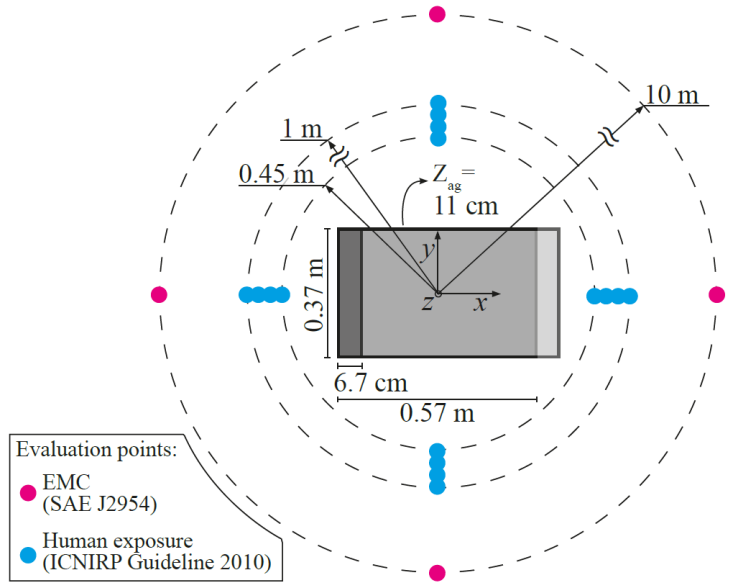
$$\overbrace{H_{peak}}^{(dB_{\mu A/m})} = 20 \cdot \log_{10}\left[\frac{\overbrace{B_{peak}}^{(T)}}{\mu_0} \cdot 10^6\right]$$



FEM simulation of the radiated magnetic field

Magnetic field radiation < 1 meter distance





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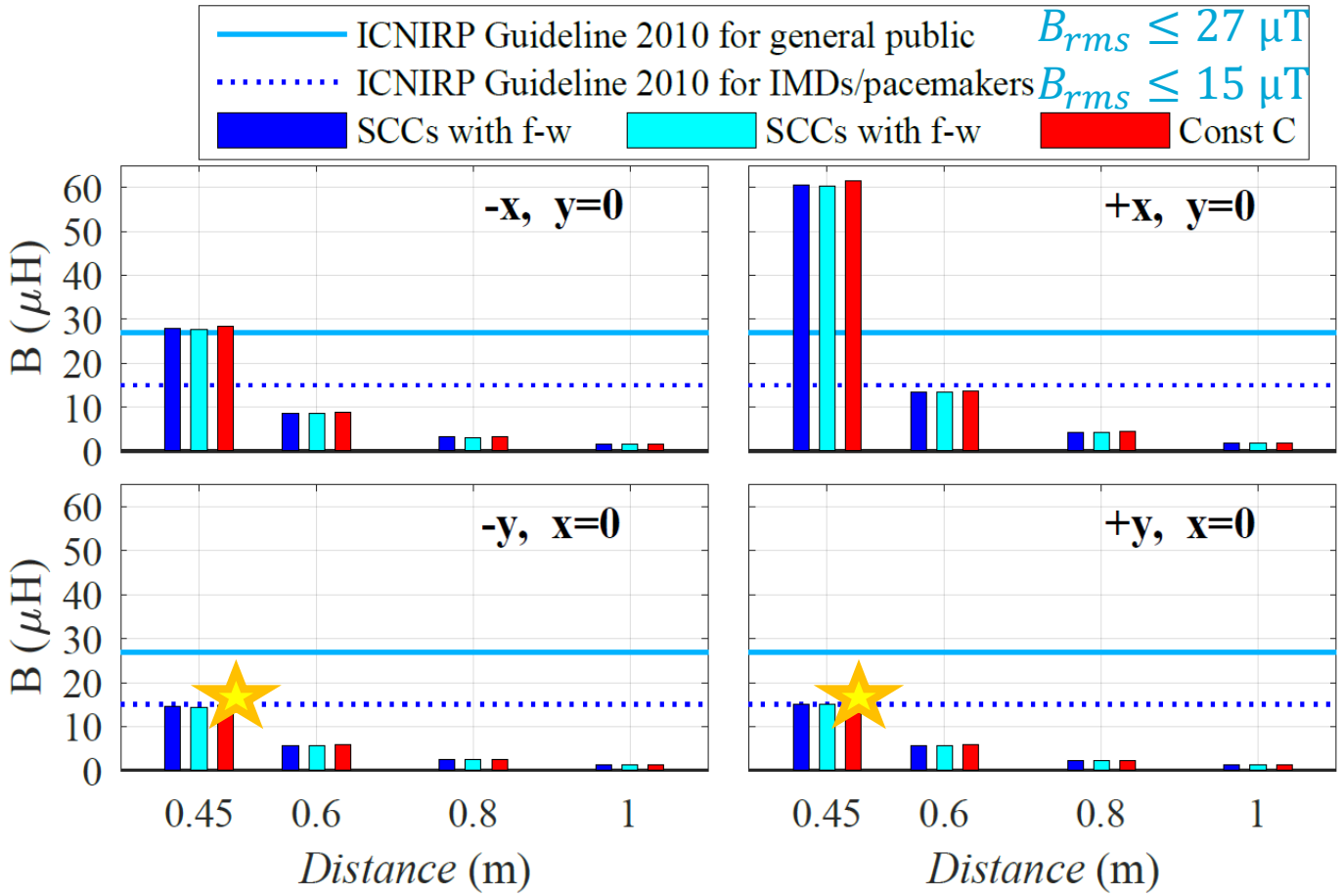
FEM simulation of the radiated magnetic field

Magnetic field radiation < 1 meter distance



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Outline

- Basics of wireless power transfer
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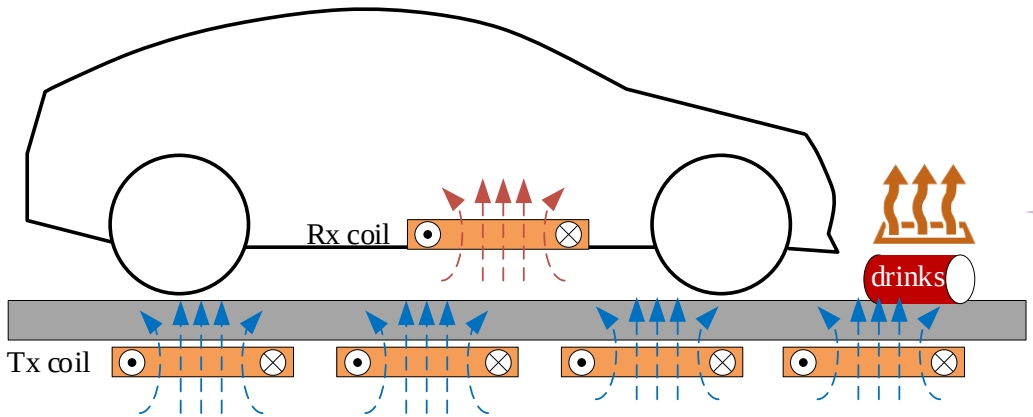
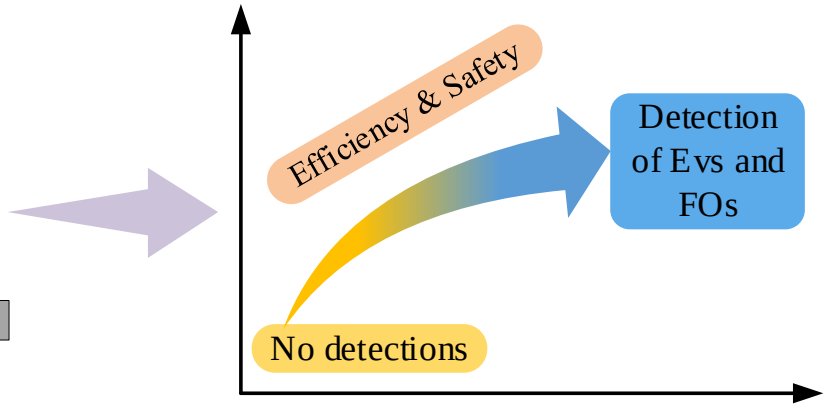
Metal foreign objects detection

The potential hazards with metallic foreign objects fall into three areas (SAE J2954):

- Metallic object **becomes hot enough to damage the surface** with which it is in contact.
- Metallic object is heated to a temperature that is **dangerous to touch** at the time that the object becomes accessible.
- Metallic object in contact with a flammable item becomes hot enough and **cause ignition of the flammable item**.

IEC 61980-3:
80 °C for metal parts bare metallic surfaces
90 °C for parts with non-metallic surfaces

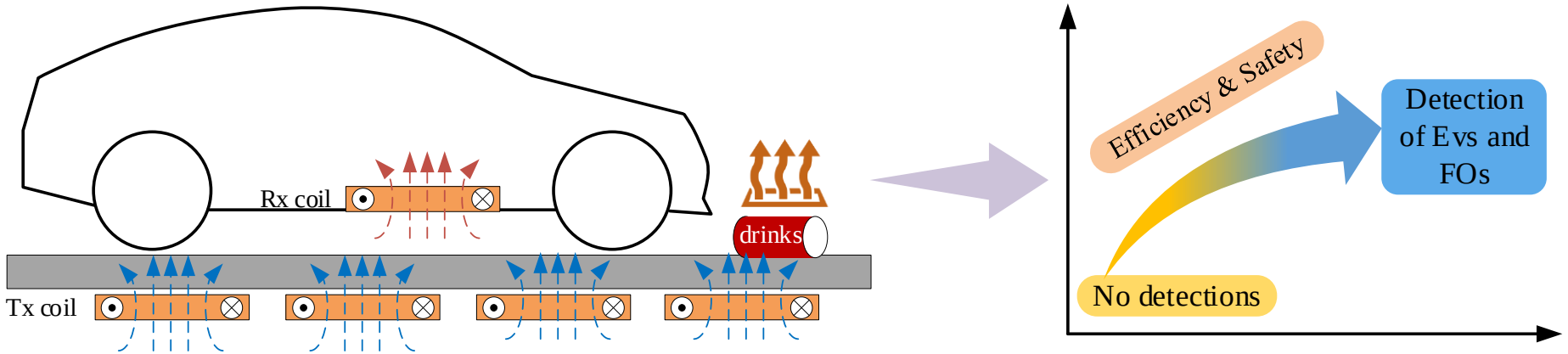




Metal foreign objects detection

Solutions to prevent the hazards (SAE J2954):

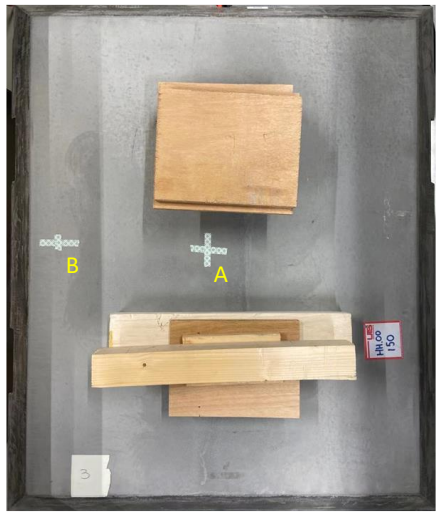
- Control the produced magnetic field through **design of GA coils** such that dangerous temperature cannot occur.
- Use **FOD system to detect metal objects** and cause the system to take actions.



Experimental measurement of metal foreign objects

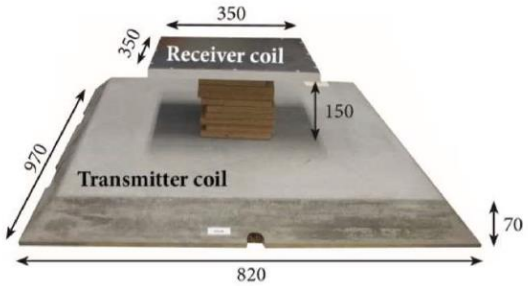
Experimental test conditions

- A WPT system operating at 2 kW
- Three metal objects
- Temperature rise and power transfer efficiency are measured



Two test points

Inverter



Charging pads

Rectifier

Coke can

Key

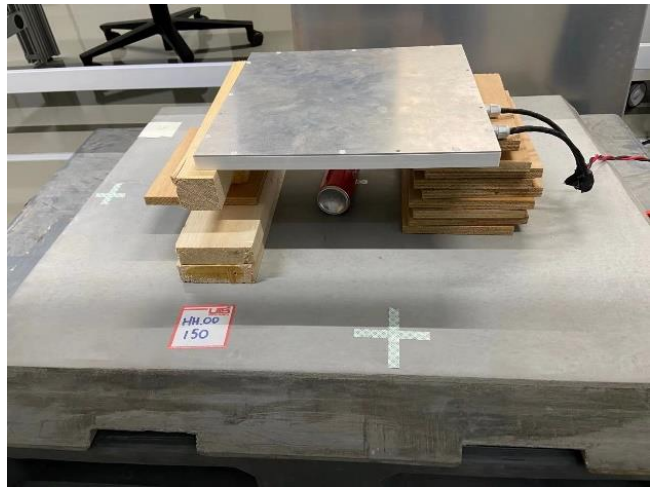
Bolt

Experimental measurement of metal foreign objects

Experimental results

- Lagest power loss increase 30.3 W
- Highest efficiency drop 1.159%
- Highest temperature rise below 20 °C

Case	Condition	Power Loss Increase (W)	Efficiency Decrease (%)	Temperature Rise (T_{amb}=19°C) (°C)
1	Coke can, point A	30.3	1.159	20
2	Coke can, point B	1.4	0.049	7
3	Key, point A	2.3	0.104	14
4	Bolt, point A	2.2	0.088	13



Coke can at point A

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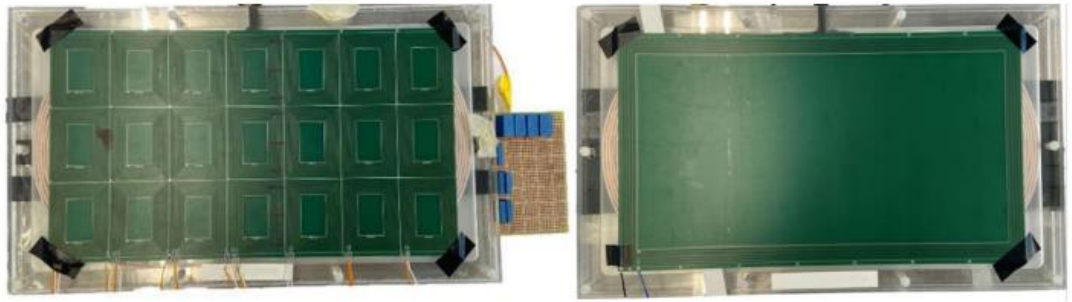
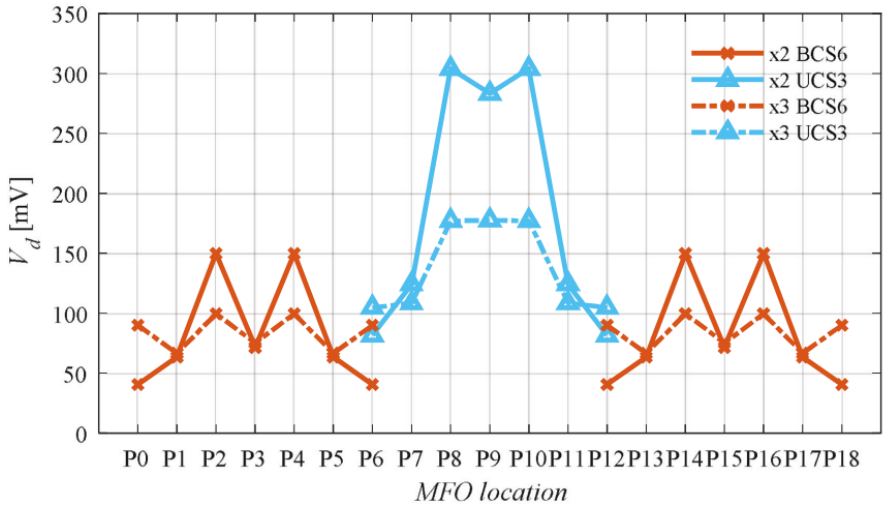
TU Delft foreign object detection method

FOD using PCB coils

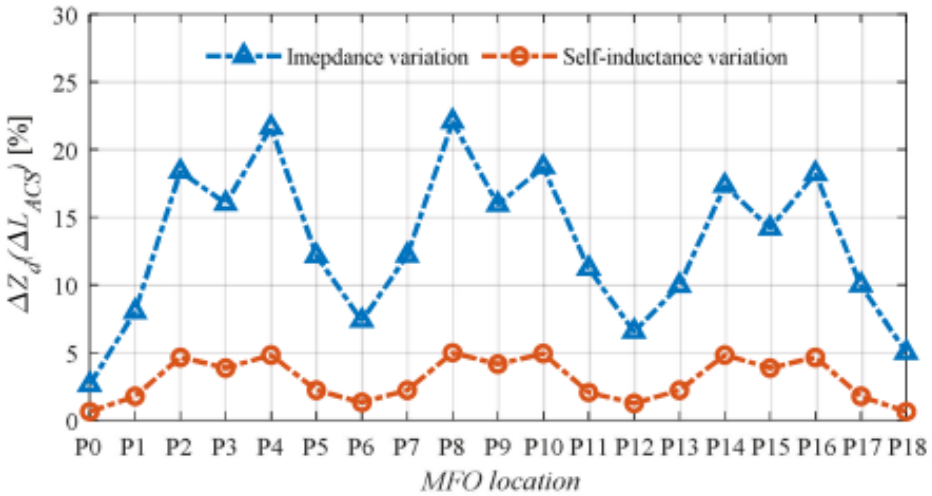
- High sensitivity, effectively detect a one euro coin
- No blind zone
- Electric vehicle detection integrated



PCB coils on charging pads



Experiment measurements of passive detection



Experiment measurements of active detection

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Conclusions

1) WPT technology can realize high-efficiency EV charging, but **special attention should be paid to safety requirements**.

2) Internation standards made **clear reqirements on human exposure and foreign objects issues**, which are summarized in this presentation.

3) Based on simulation results, the **radiated magnetic field can be maintained below the limits through proper designs**. The measurement on the 3.7 kW prototype can be a proof.

4) Based on experimental results, the temperature rise and power loss caused by **metal foreign objects with limited size are not significant**, but **FOD is necessary** for safety and efficiency.

5) PCB coils can be used to achieve **high-sensitivity FOD** for WPT systems.

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Thanks for your attention!

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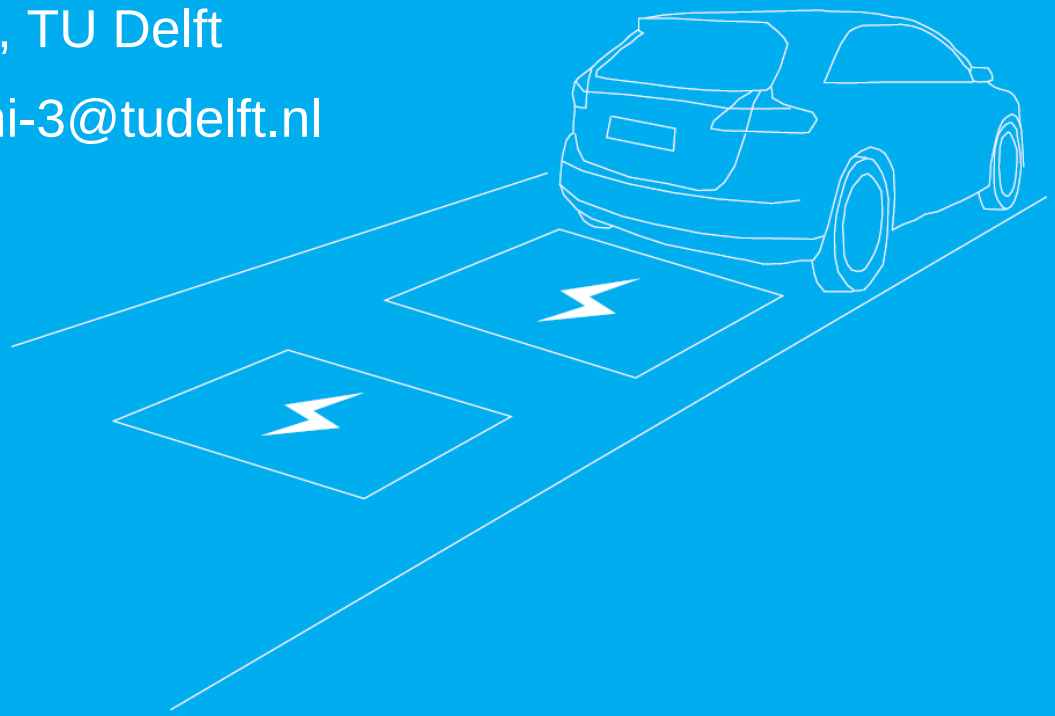

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Dinsdag 21 november