Session 3C: Infrastructure (2013-11-19)

Inductive Battery Charging System for Electric Vehicles

Dr. Juan Luis Villa Gazulla

CIRCE Building / Ebro River Campus / Mariano Esquillor Gómez, 15 / 50018 ZARAGOZA

Tfno. (+34) 976 761 863 / Fax (+34) 976 732 078 / web: www.fcirce.es / email: jvilla@unizar.es

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA 17th-20th November 2013

Organized by Fira Barcelona, avele

Hosted by AVERE

In collaboration with Ajuntament de Barcelona

Supported by EVAAP, EDTA, European Commission

Index

- Introduction
- Optimal 30 kW IPT unshielded system
- Optimal 30 kW IPT shielded system
- Conclusions

1- Introduction

Why using inductive charge?

1-Introduction

- **For pure electric vehicles to reach the expected development and become an alternative to conventional or hybrid vehicles, it is still necessary to solve several problems:**
  - Increasing the range of the vehicle
  - Making the charging process cleaner and safer
  - Achieving a charging process as quick as possible

- **Inductive Power Transfer (IPT) systems can be the solution for the first two problems:**
  - Sufficient charging points on public roads that allow not only “Static charge” but also “Static on route charge" or even the possibility to have dedicated charging lanes, which is called “ Dynamic on route charge”
  - No need for human intervention since there is not connection between the vehicle and the infrastructure, which results in increased safety for the users

1-Introduction

Conductive Charge

- Advantages
  - No need for precise positioning
  - Mature Technology
- Disadvantages
  - Human intervention
  - Visual Impact in the cities
  - Vandalism

1-Introduction

Inductive Charge

- Advantages
  - Safer and cleaner charging process
  - No visual impact
  - Not affected by vandalism
  - Weatherproof
  - No connectors or mechanical parts
  - Charge with the vehicle stopped or in route
  - Increases the opportunities for charging

1-Introduction

- **But there are still some drawbacks compared to conductive charge:**
  - Lower efficiency
  - Need for a good alignment between coils
  - Compliance with international standards for human exposure to electromagnetic fields, especially at high power
    - A suitable shielding system is required

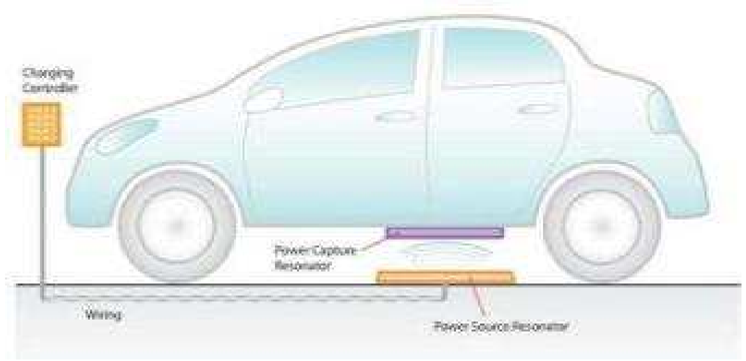
This paper focuses on this last topic and shows the experimental development of a 30 kW inductive charger totally shielded, and how the shield affects the theoretical IPT design

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

2-Optimal 30 kW IPT unshielded system

2-Optimal 30 kW IPT unshielded system

- **An IPT system comprises:**
  - An emitter coil located under (above) the road
  - A receiver coil at the bottom of the vehicle
    separated by a distance comparable to coil size
  - Resonance capacitors
  - A high/medium frequency voltage source



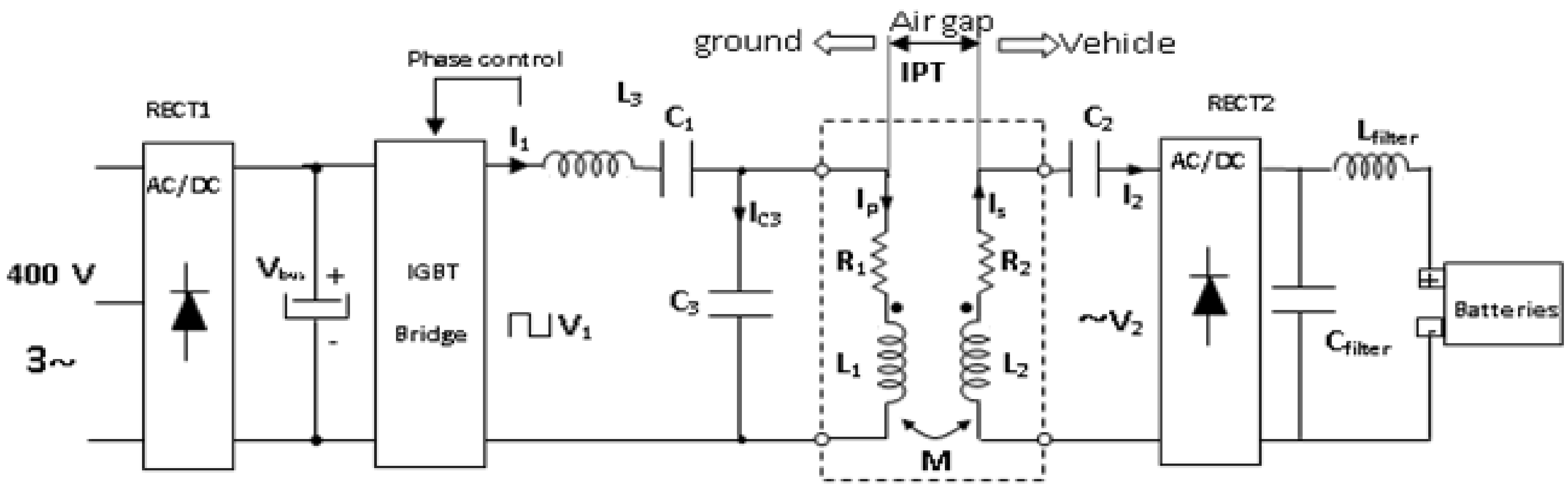
- **The power transferred to the battery is given by the equation:**

$$P_2 = \frac{\omega_o M^2 Q_s}{L_2} I_p^2$$

Where the coefficient "M" is very low compare to "L_2", which makes it necessary to work at high frequencies ($\omega_0\uparrow$) and/or in resonance mode ($Qs\uparrow$) i.e. "tuning" the receiver coil via capacitors to the working frequency.

2-Optimal 30 kW IPT unshielded system

- Among the different resonance topologies with capacitors, SP-S topology has been selected because it shows……..:
  - Better performance when there is a possibility of misalignment between coils
  - Current source behavior, which is suitable for charging batteries



2-Optimal 30 kW IPT unshielded system

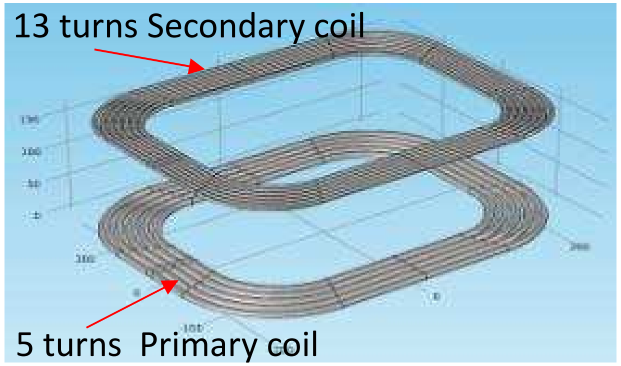
- The IPT optimal design comprises the selection of the number of turns in primary and secondary, sections of the coils and resonant capacitors.
- Among all possible combinations of turns, the best is the one that presents the higher efficiency and stability (Qp >= Qs) and whose working frequency is the one desired (in general this value will be the maximum frequency possible depending on the technology)
- An iterative mathematical process is required to find this optimal combination, in our case is the next :

	N_1 (Litz turns)	N_2 (Litz turns)	S_1 (mm^2)	S_2 (mm^2)	C_1 (μF)	C_2 (μF)	C_3 (μF)	L_1 (mH)	L_2 (mH)	M (mH)	L_3 (mH)
Value	5	13	125	25	0.28	0.66	3.67	19.3	124	8,6	220

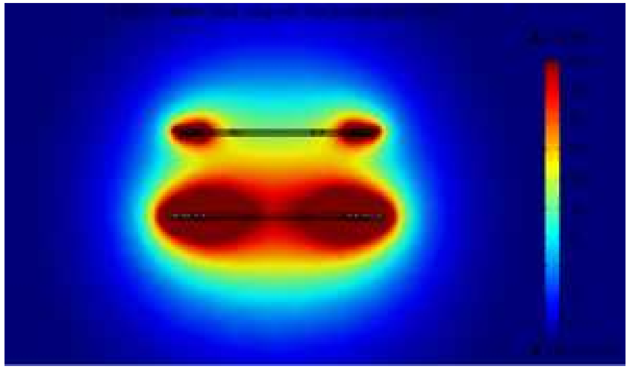
2-Optimal 30 kW IPT unshielded system

A lab prototype has been carried out to test the theoretical results

Primary =	0.3 × 0.4 m
Secondary =	0.3 × 0.4 m
Distance =	0.2 m
Frequency =	17 kHz
P1=	30800 W
P2=	29200 W
Efficiency =	95 %



We have probed that the system is able to transfer high power with high efficiency, but the magnetic field measured exceeds in thousands times the maximum human exposure even 3 m around the coils; which means it is dangerous



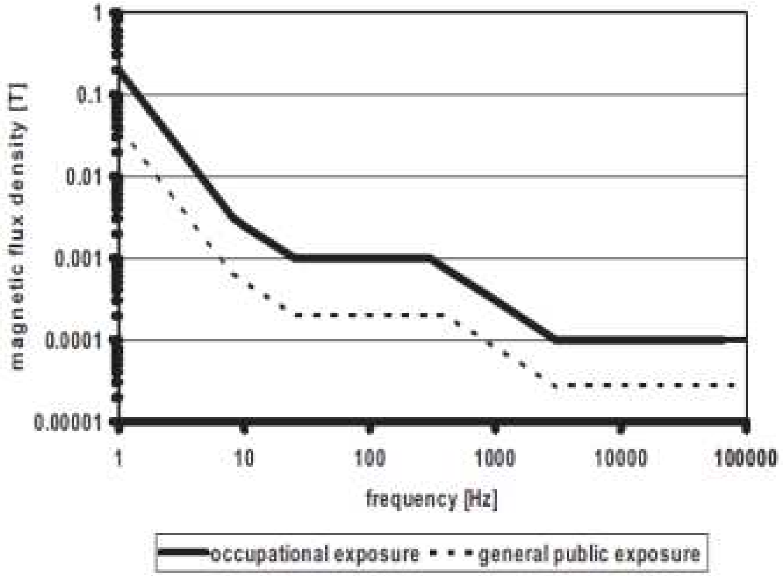
Magnetic field distribution up 0.15 Tesla

Test cage

3-Optimal 30 kW shielded system

3-Optimal 30 kW IPT shielded system

- According to 2010 International Standard ICNIRP guidelines, maximum magnetic field exposure for general public depends on the operating frequency.
- For typical operating frequencies used in charging IPT systems (10-150 kHz) the limit is set below 27 μT



Frequency range	Magnetic field strength H (A m^{-1})	Magnetic flux density B (T)
1 Hz–8 Hz	$3.2 \times 10^4/f^2$	$4 \times 10^{-2}/f^2$
8 Hz–25 Hz	$4 \times 10^3/f$	$5 \times 10^{-3}/f$
25 Hz–50 Hz	1.6×10^2	2×10^{-4}
50 Hz–400 Hz	1.6×10^2	2×10^{-4}
400 Hz–3 kHz	$6.4 \times 10^4/f$	$8 \times 10^{-2}/f$
3 kHz–10 MHz	21	2.7×10^{-5}

According to levels for general public and occupational exposure to time varying magnetic fields evs 27

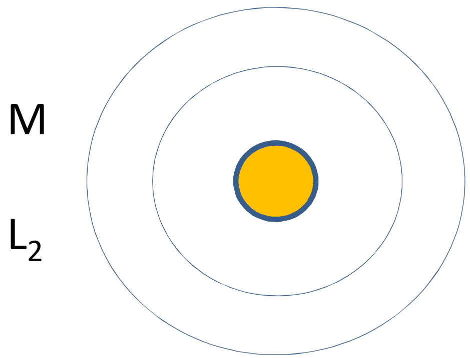
The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

BARCELONA 17th-20th November 2013

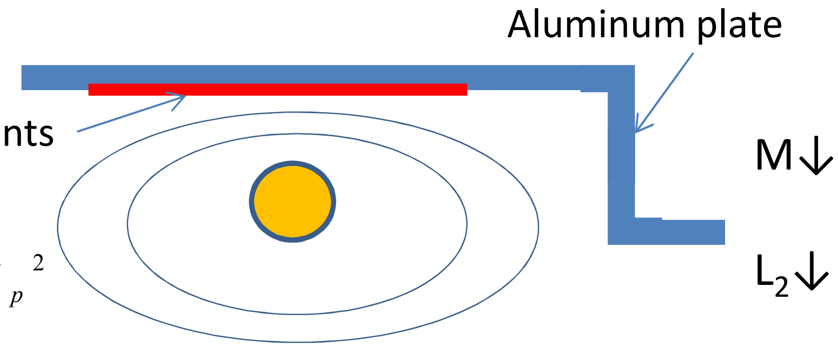
3-Optimal 30 kW IPT shielded system

circe RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION

- Therefore, an appropriated shielding system has to be designed, regarding the safety for the users
- Shielding is easily achieved by using eddy currents (induced currents in a conductive material that creates an opposing magnetic field), i.e. surrounding the coils with aluminum plates
- However, the presence of aluminum in the magnetic circuit changes the values of “M” and “L_2”, making the power transferred fall significantly. The system is not able to work in rated conditions

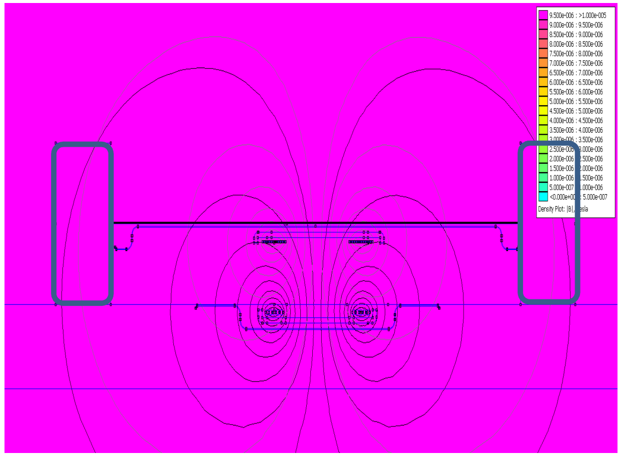


$$P_2 \downarrow = \frac{\omega_o M^2 Q_s}{L_2} I_p^2$$

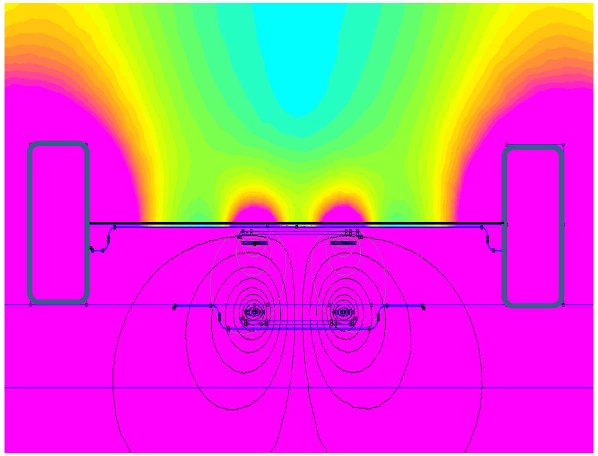


3-Optimal 30 kW IPT shielded system

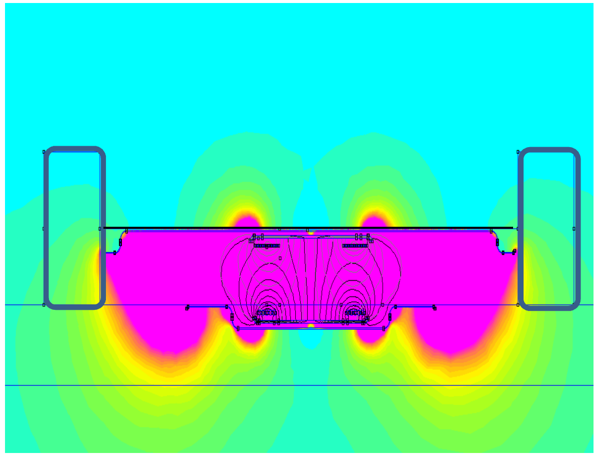
- This decrease in the inductances is not proportional, making the term M^2/L_2 lower than without aluminum and, according to the equation shown previously, the power that the system is capable of transferring to the load decreases considerably (In pink magnetic field above 27 μT)



Without aluminum
Pload= 30 kW



Aluminum under the vehicle
Pload=12 kW



Aluminum under the vehicle and ground
Pload= 4 kW

3-Optimal 30 kW IPT shielded system

- If we want to maintain the power transferred to the load in its nominal value, it is necessary to include a ferromagnetic material which increases the values of M and L_2 (i.e. ferrite)
- The new design should maintain the "power transfer capability ratio" M^2/L_2 as close as possible to one of the unshielded system

	L_2(μH)	M(μH)	M^2/L_2	P1(kW)	P2(kW)	Effi.(%)
Unshielded	124	8.6	0.596	30.8	29.2	95
Aluminum shielding	61	1.2	0.024			
Aluminum- ferrite shielding	195	10.8	0.598	32	29.5	92

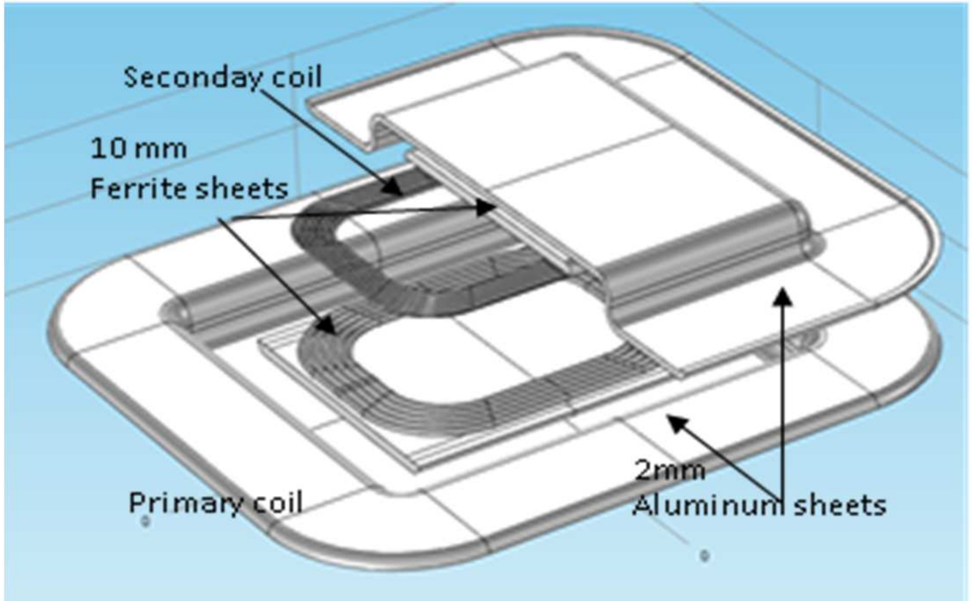
- The new system is able to transfer the rated power but with lower efficiency, due to the losses in the aluminum plate and ferrite eVS 27

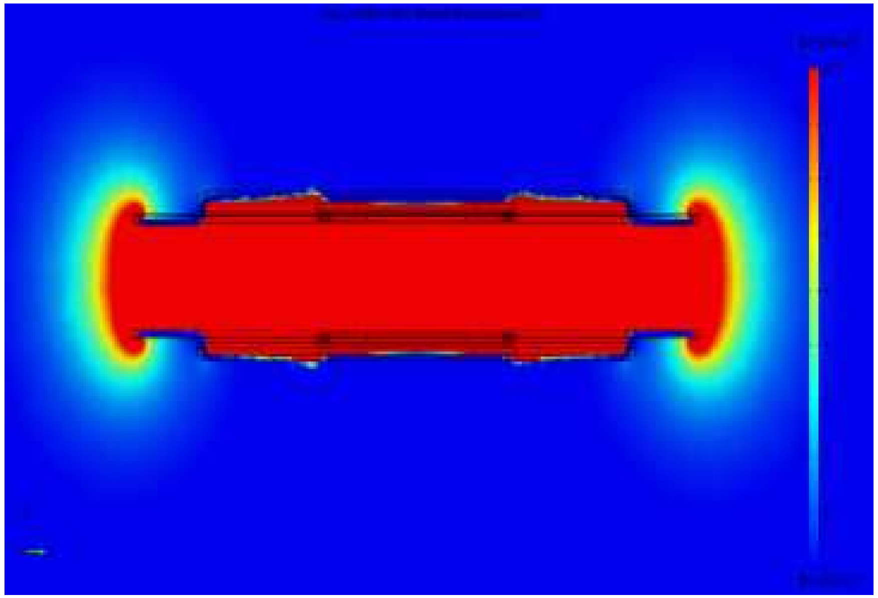
The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

3-Optimal 30 kW IPT shielded system

circe
RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION

- With this final design, the magnetic field is perfectly enclosed inside the area surrounded by aluminum plates and the power is 30 kW
- Position, shape, distance between materials and thickness must be obtained using a 3D Finite Element program.





3-Optimal 30 kW IPT shielded system

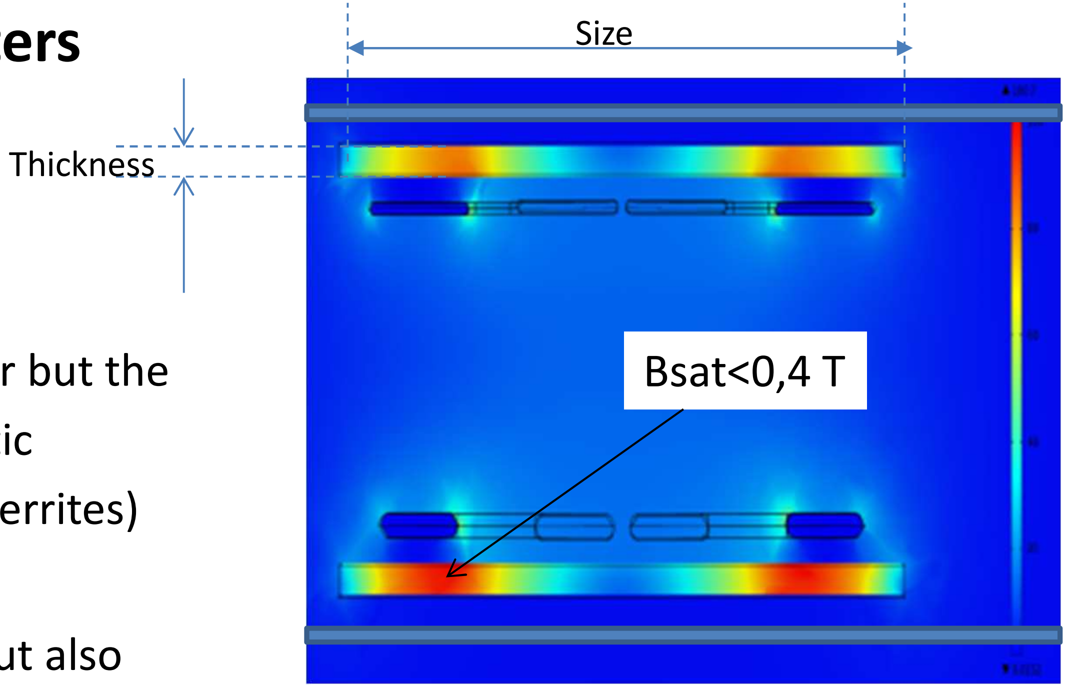
circe RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION

Main Design Parameters

Ferrites

- Size and distance to the coils
- Distance to the aluminum plate
- Thickness

The closer to the coils, the higher is the power but the thickness must be increased to avoid magnetic saturation(that means lost of linearity in the ferrites)



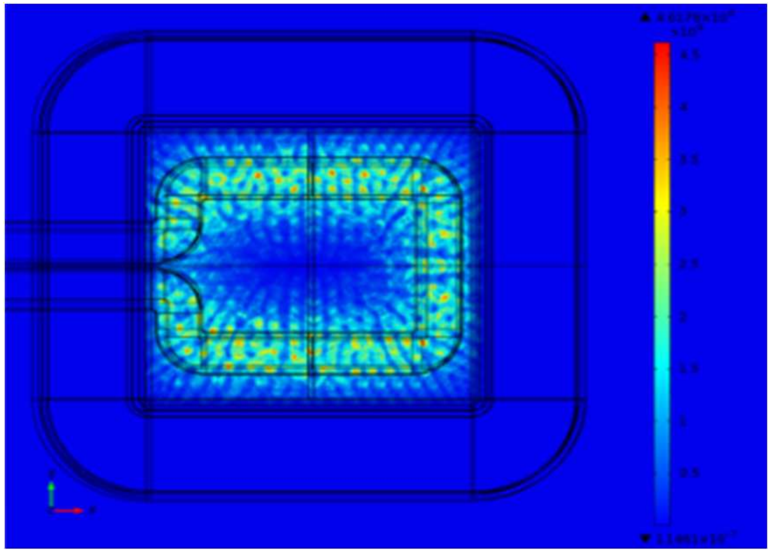
Aluminum

- Right size to cover not only the coils but also the desired maximum misalignment distance
- Thickness is not very important because there are only currents in the inner face of the aluminum plate (due to Skin effects)
- The distance to the ferrites comes imposed for the available space under the EV

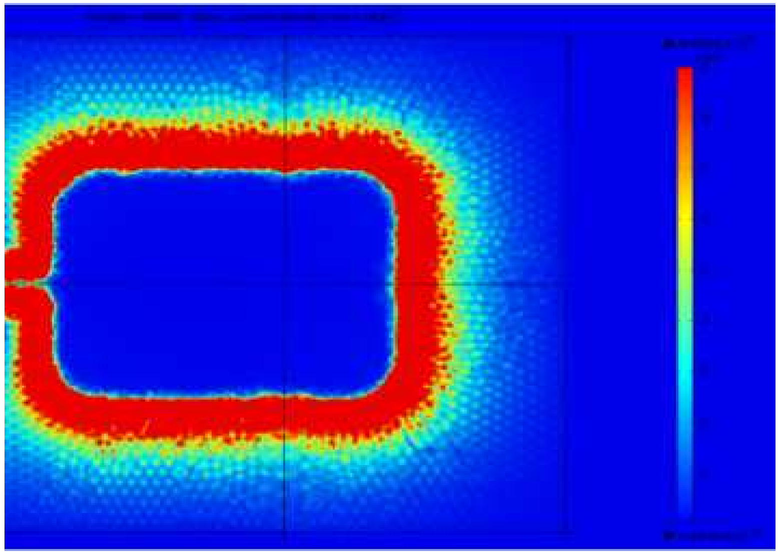
3-Optimal 30 kW IPT shielded system

Main Design Parameters

- Due to flux concentration near the ferrites, the current inside the aluminum plates increases, and so do the losses



Maximum current density in the aluminum without ferrites



Maximum current density in the aluminum with ferrites (4.5 A/mm^2)

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

Conclusions

Organized by Hosted by In collaboration with Supported by

Conclusions

- IPT charging systems are a **good solution** to solve many aspects in the charging process, making it **safer**, **cleaner** and **more convenient**
- For high power, a suitable **shielding** system is required to comply with exposure standards
- An appropriate **aluminum-ferrite** combination is required to transfer the same rated power as the unshielded system
- A Finite Element design is needed to **avoid magnetic saturation** in the ferrites and **minimize losses** in the aluminum plate
- The final **efficiency is lower** compared to the unshielded system

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
17th-20th November 2013

RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION

Session 3C: Infrastructure (2013-11-19)

THANK YOU VERY MUCH FOR YOUR ATTENTION