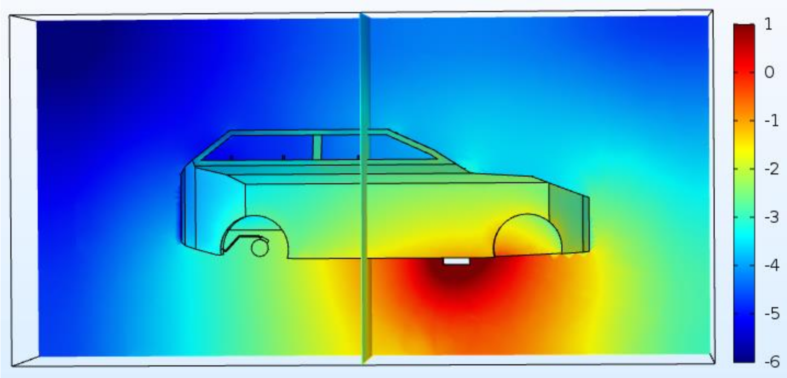
COMSOL CONFERENCE
2017 ROTTERDAM



EMC SIMULATIONS USING SOURCE RECONSTRUCTION

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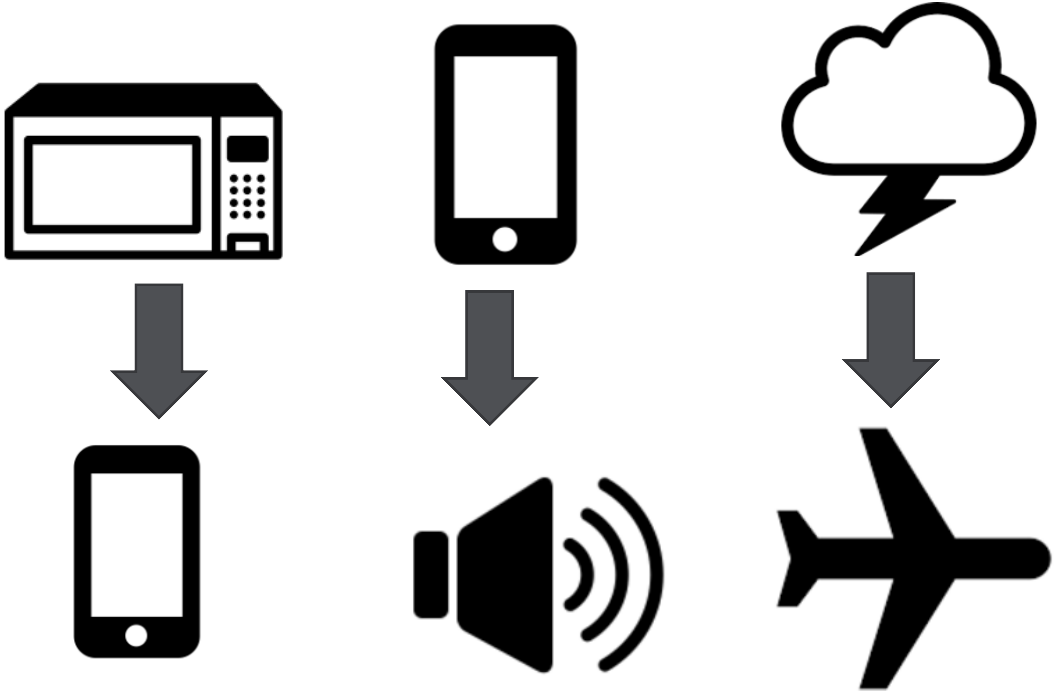
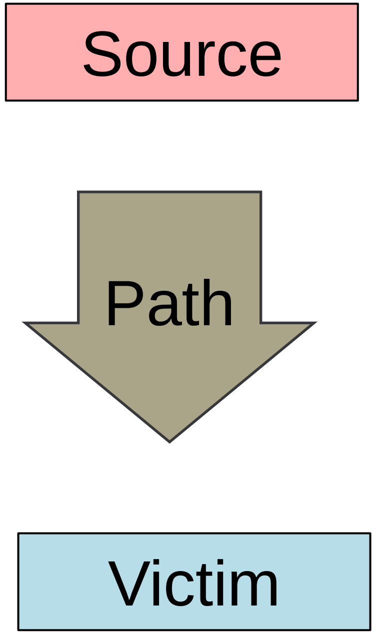
INTRODUCTION TO EMC

EMC = Electromagnetic compatibility

-Assure that electromagnetic components are compatible and do not interfer with each other.



INTRODUCTION TO EMC



Origin of disturbance

Antenna emitters, electric motors, power converters, ligthning,...

Coupling path from source to victim

A few distinct types (explained on next page)

Object exposed to disturbance

Antenna receivers, sensors, circuit boards, humans,...

TYPES OF COUPLING PATHS IN EMC

- Conductive — Electric Currents (ec); Electrical Circuit
- Inductive — Magnetic Fields (mf); Magnetic and Electric Fields
- Capacitive — Electrostatics (es)
- Radiation — Electromagnetic Waves

Different coupling paths correspond to different subsets of Maxwell's equations

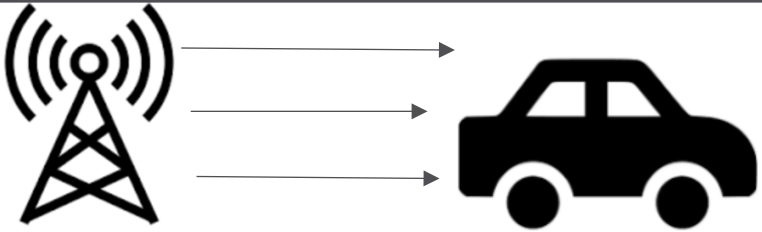
Different physics interfaces in COMSOL.

Inductive path is focus of this presentation

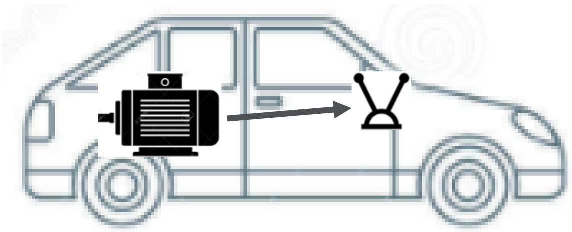
AUTOMOTIVE EMC

- The electromagnetic fields generated by a vehicle should not exceed certain limits.

- A vehicle must be able to withstand a certain amount of electromagnetic fields.



- The different electromagnetic systems within a car should not disturb each other.



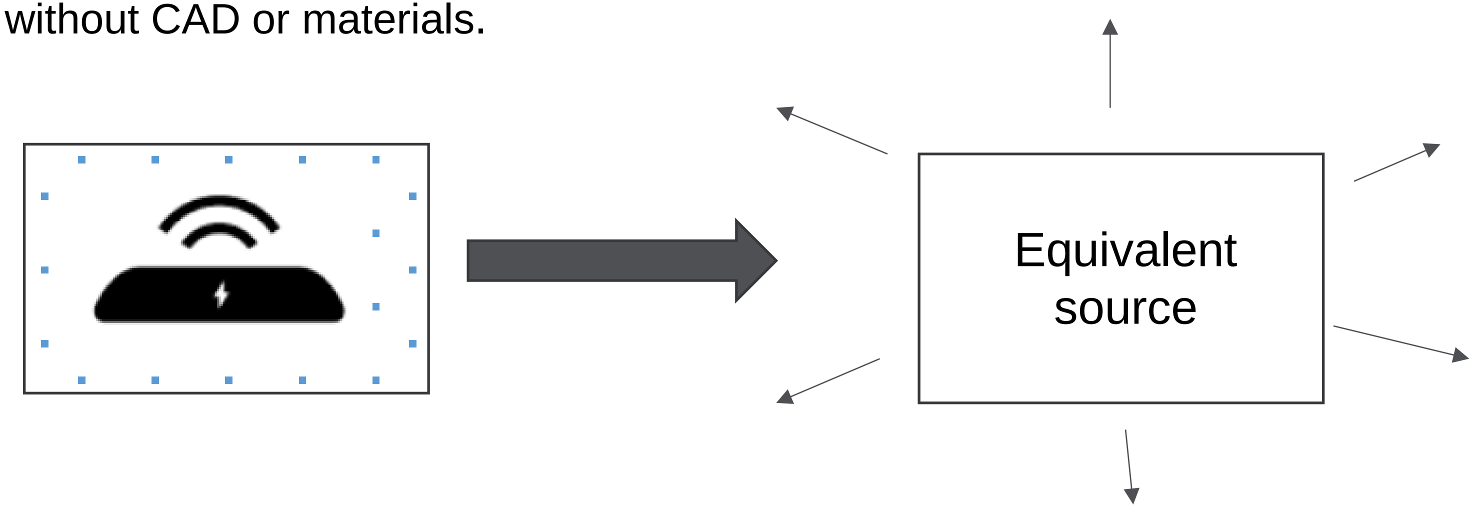
BLACK BOX MODELS OF PARTS

- Modern cars contain a huge number of electric components.
  Most are bought from suppliers rather than made internally.
- Suppliers will often not share detailed information (CAD models, material properties, etc.)
- Challenge: How simulate EMC impact of components without such information?
- No existing standard for exchange of models or data relevant to EMC.

BLACK BOX MODELS OF PARTS

- Suppliers may be willing to provide electric/magnetic field values in a point cloud surrounding the part.
- This data may come from their 3D simulations or from measurements.
- Alternatively, the vehicle manifacturer may perform measurements.

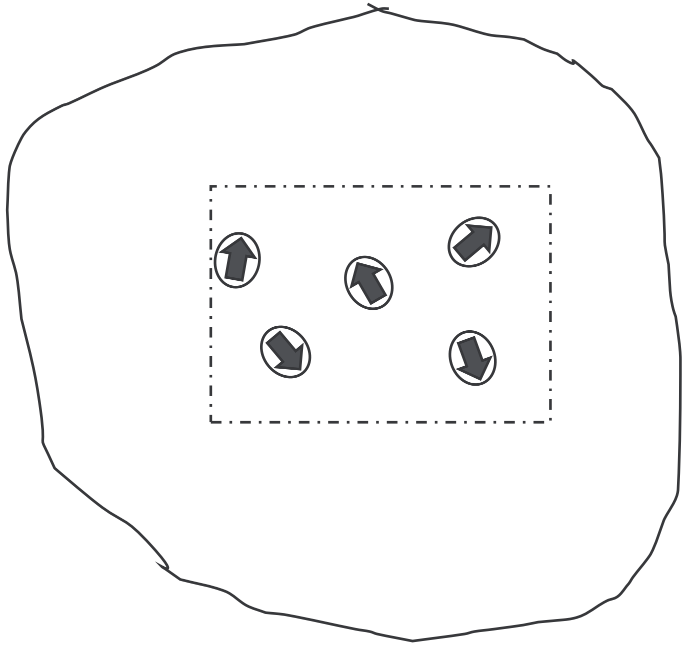
Idea: Obtain a point cloud and generate a black box model representing an equivalent source without CAD or materials.



SOURCE RECONSTRUCTION

Basic idea:
Any magnetic field source (applied or induced current, permanent magnet, soft magnet) can be approximated by a set of magnetic dipoles.

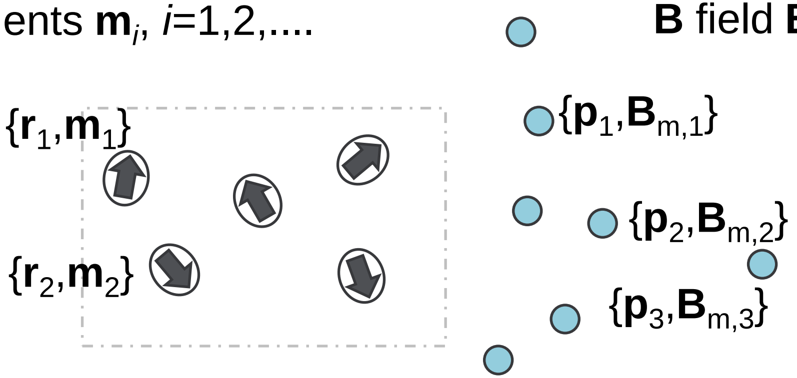
Use optimization to find the set of dipoles that "best" recreates the point cloud field values.



SOURCE RECONSTRUCTION

Dipoles in vacuum with positions $\mathbf{r}_i$, magnetic moments $\mathbf{m}_i$, i=1,2,....

Point cloud with positions $\mathbf{p}_j$, **B** field $\mathbf{B}_{m,j}$, j=1,2,...



Analytically: Field from dipoles

$$\mathbf{B}_{\mathrm{dp}}(\mathbf{p}_j) = \frac{\mu_0}{4\pi|\Delta\mathbf{r}_{i,j}|^5} \times \sum_i \left(3\Delta\mathbf{r}_{i,j}(\mathbf{m}_i \cdot \Delta\mathbf{r}_{i,j}) - |\Delta\mathbf{r}_{i,j}|^2 \mathbf{m}_i\right)$$

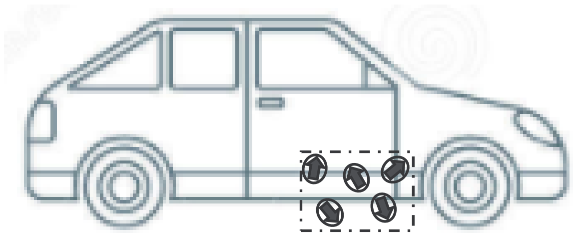
$$\Delta\mathbf{r}_{i,j} = \mathbf{p}_j - \mathbf{r}_i$$

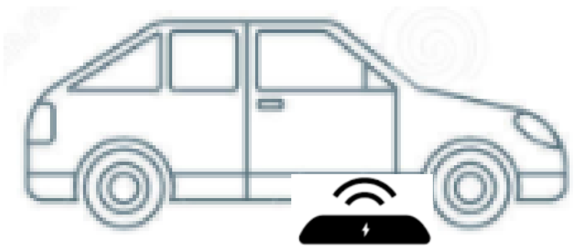
Goal: Find dipoles $\{\mathbf{r}_j,\mathbf{m}_j\}$ such that analytical field $\mathbf{B}_{\mathrm{dp}}(\mathbf{p}_j)$ matches point cloud field $\mathbf{B}_{\mathrm{m}}(\mathbf{p}_j)$

SOURCE RECONSTRUCTION

We wish to test the validity of the method so we component a part for which the 3D CAD is known, allowing comparison of

(model with dipoles + other parts)   vs (model with 3D CAD + other parts).



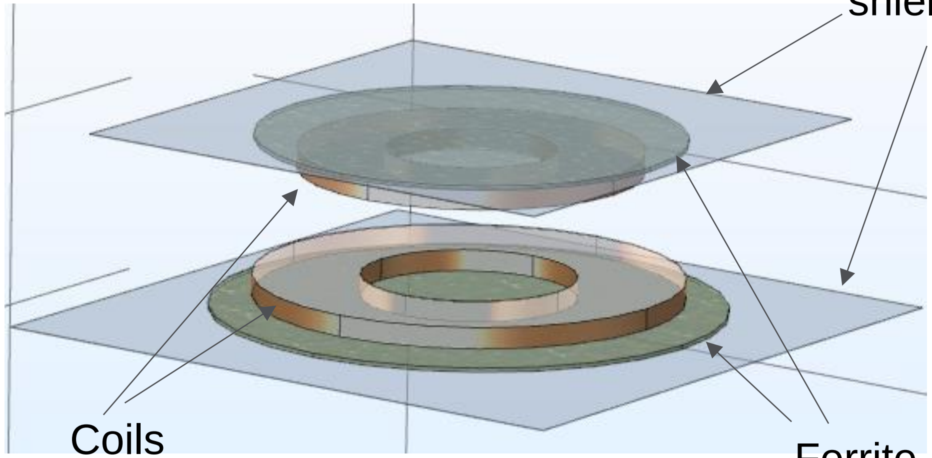


Furthermore, no supplier data can be shared here (even measurements) so we use a fictional design with the point cloud generated by our own simulations.

EXAMPLE PART: WIRELESS CHARGER

Receiver
(in car)

Transmitter
(in ground)



Represent entire device by set of dipoles.

SOURCE RECONSTRUCTION: OPTIMIZATION

Dipoles are found by minimizing the difference the difference between field from dipoles in vacuum and point cloud field:

$$\varepsilon = \left\| \mathbf{B}_{\mathrm{dp}} - \mathbf{B}_{\mathrm{m}} \right\|_2^2$$

In this work, dipole positions are fixed and dipole moments are design parameters ➔ Convex optimization problem, gradient-based algorithm is efficient.

These problems are often ill posed (solution typically not unique) ➔ Risk of overfitting.

Point cloud divided into:

- Training set (close to device), used for optimization
- Test set (further away), used for checking

SOURCE RECONSTRUCTION: OPTIMIZATION

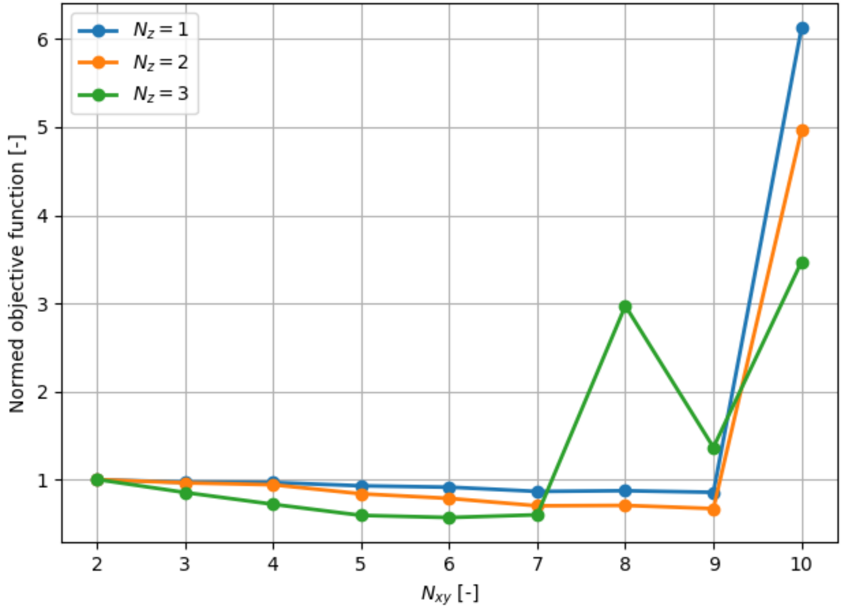
Place dipoles in cartesian grid
$N_{xy} * N_{xy} * N_z$

and vary N_{xy} , N_z.
Find magnetic moments.

Then compare difference in **B** in test points.

Very poor results in test points when N_{xy} gets large → Overfitting!

Objective function vs N_{xy} for different N_z for the test data.



Optimization done with separate Python script

COMSOL SETUP

- Magnetic fields interface (Magnetic and Electric Fields interface also possible)

- 3D

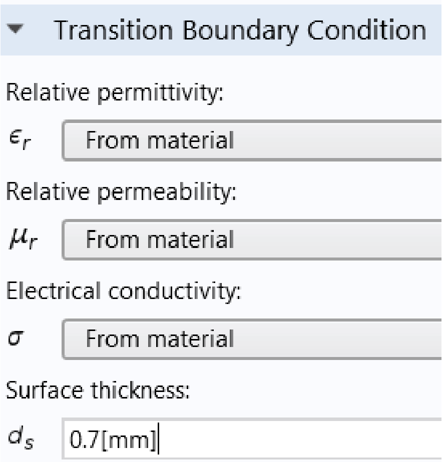
- Frequency domain, 85 kHz (industry standard for automotive wireless charging)

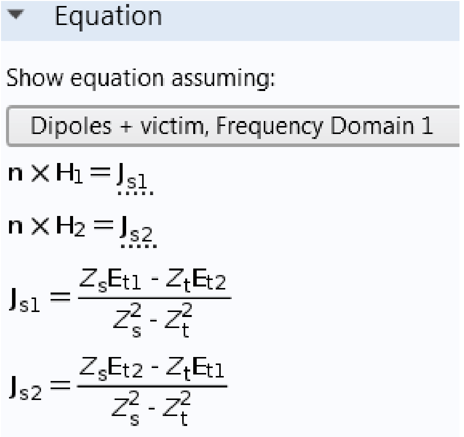
- Models set up for both dipole representation and CAD representation and results compared.

- Grid of 5x5x2 dipoles used

COMSOL SETUP

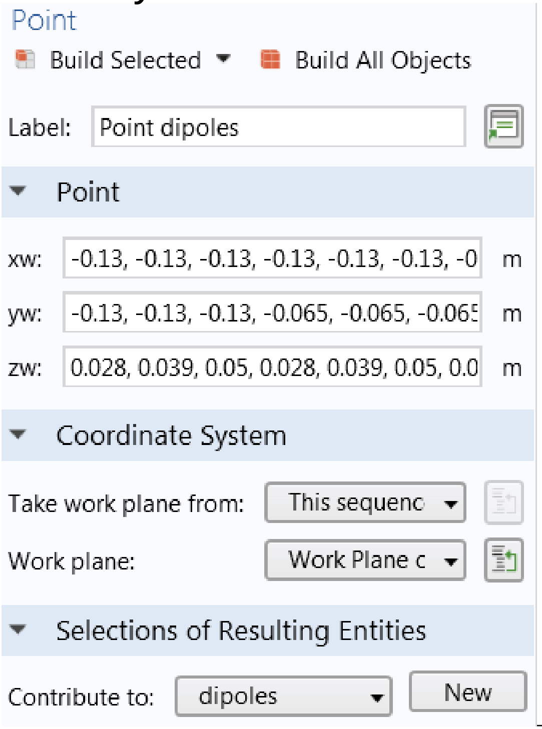
- Thin metallic sheets occur in various places and skin effect is very significant.
- Model as surfaces and use Transition Boundary Condition, skin effect automatically calculated from permeability, conductivity, and thickness.



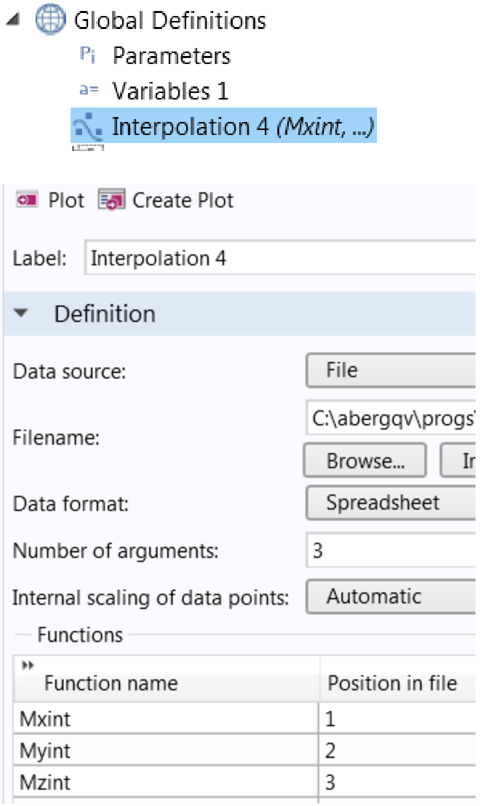


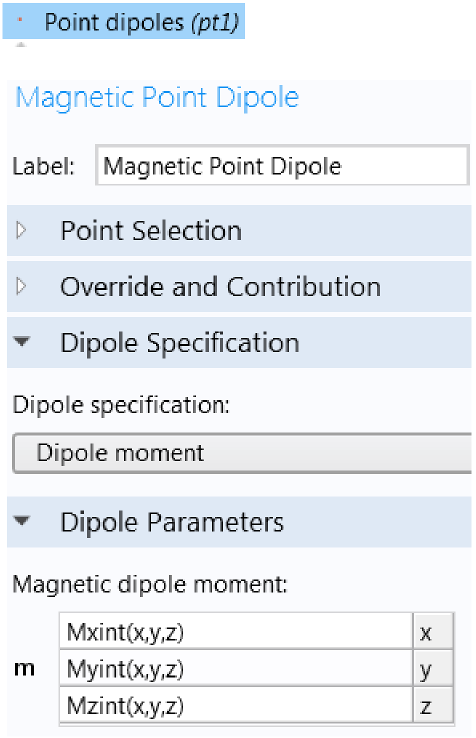
COMSOL SETUP: DIPOLE DEFINITION

Locations defined with Geometry Point feature



Moments defined with interpolation table

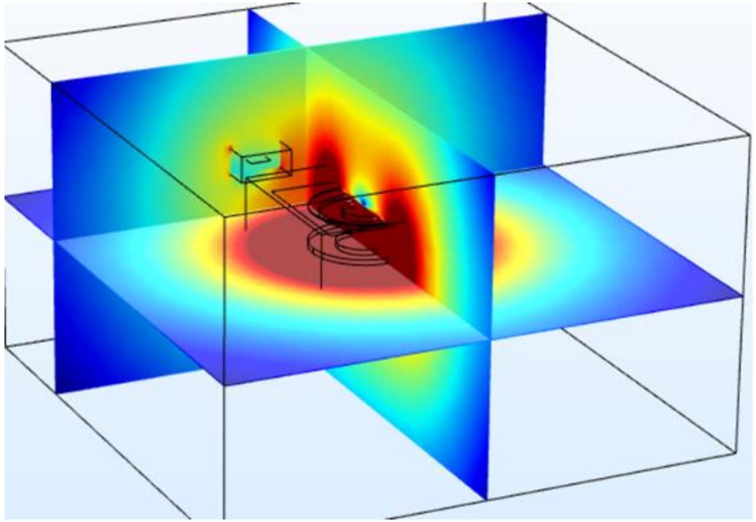




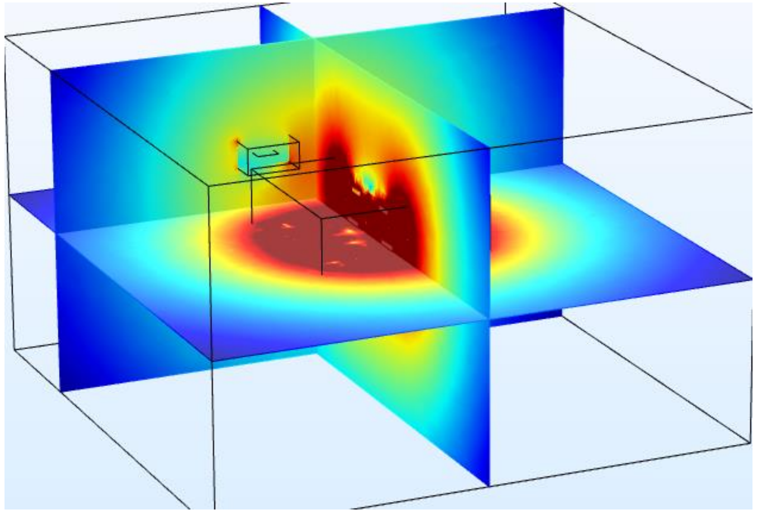
RESULTS

Magnetic field close to charger
(logarithmic scale $\log_{10}$[H/(A/m)])

CAD representation of charger



Dipole representation of charger

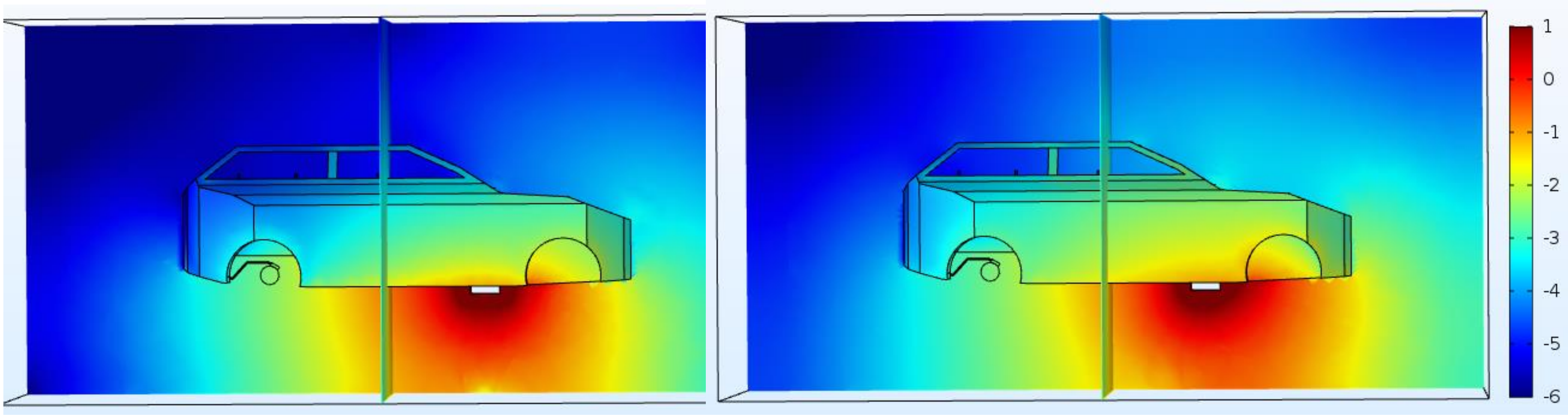


RESULTS

Magnetic field surrounding vehicle
(logarithmic scale $\log_{10}[H/(A/m)]$)

CAD representation of charger

Dipole representation of charger

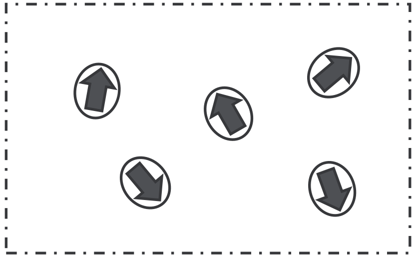


CONCLUSIONS AND FUTURE WORK

- Conceptual test of source reconstruction as possible method for modeling unknown parts in EMC simulations.
- Initial results promising

Further work:
- What point cloud data is needed/useful?
  - Number of points
  - Location: Close/far away?
- Optimization techniques
  - Allow number of dipoles and locations to be design variables
- Extend to full wave simulations

SOURCE RECONSTRUCTION



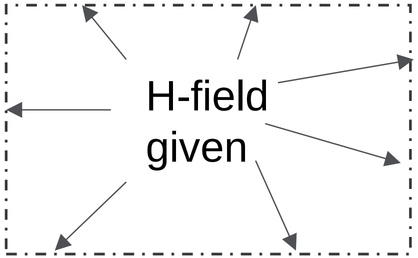
Alternative method:
Any magnetic field source (applied or induced current, permanent magnet, soft magnet) can be approximated by a set of magnetic dipoles.

- Conceptually more complicated.
- Finding the "best" set of dipoles requires optimization.

+ Very flexible with regards to point cloud data: Does not have to be dense or surround all sides of the part, can employ points from a wide range of distances from the part.
+ Magnetic field in points is not fixed but can be changed by the presence of other parts.

BLACK BOX MODELS OF PARTS

Possible method:
Apply values from point cloud as boundary condition on box surrounding part.



+ Conceptually simple
+ Easy to employ in simulation

- Point cloud must be reasonably dense and form a closed surface surrounding the part.
- Cannot use data from various distances, far field values,...
- Another part placed nearby will change the magnetic field, making the boundary condition invalid.