COMSOL
CONFERENCE
BOSTON
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Contactless Power and Data Transfer for Multiple Nonlinear Loads

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Introduction

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Contactless Power and Data Transfer
Application in Industrial Automation

De- centralized automation with distributed sensors & actors   (e.g. conveyer)

Introduction

Basic Layout

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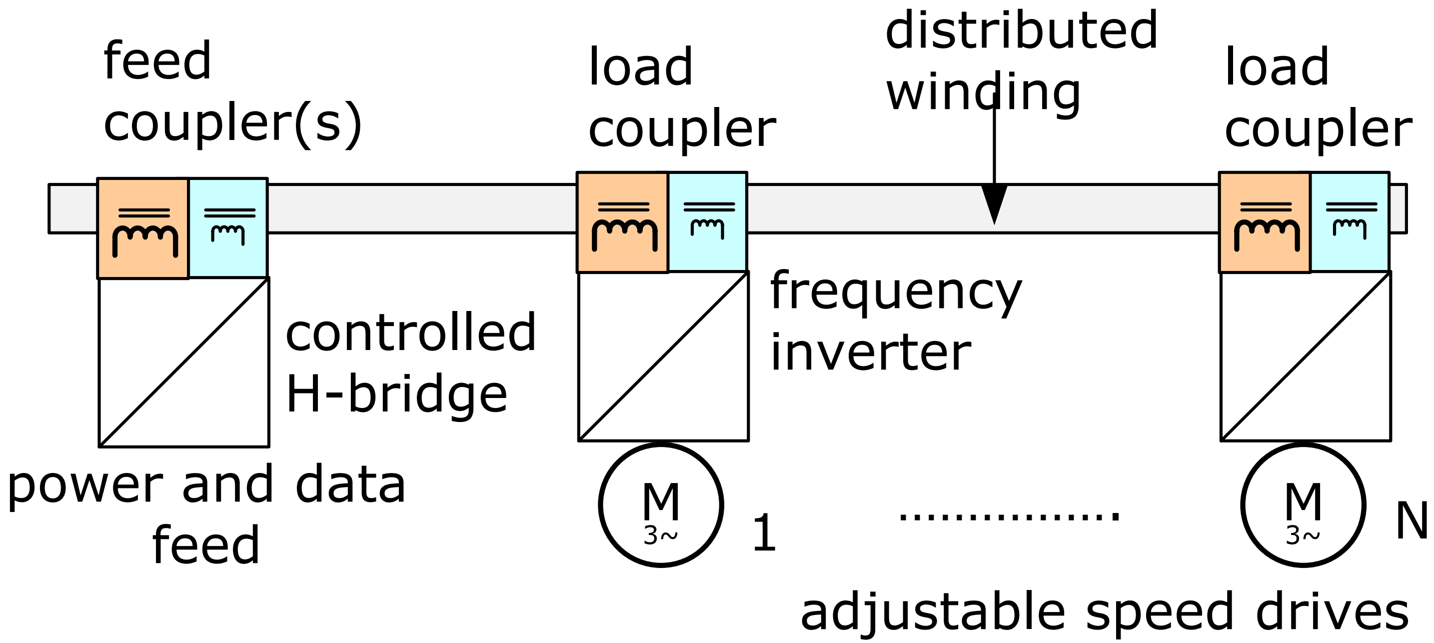

Intrdouction

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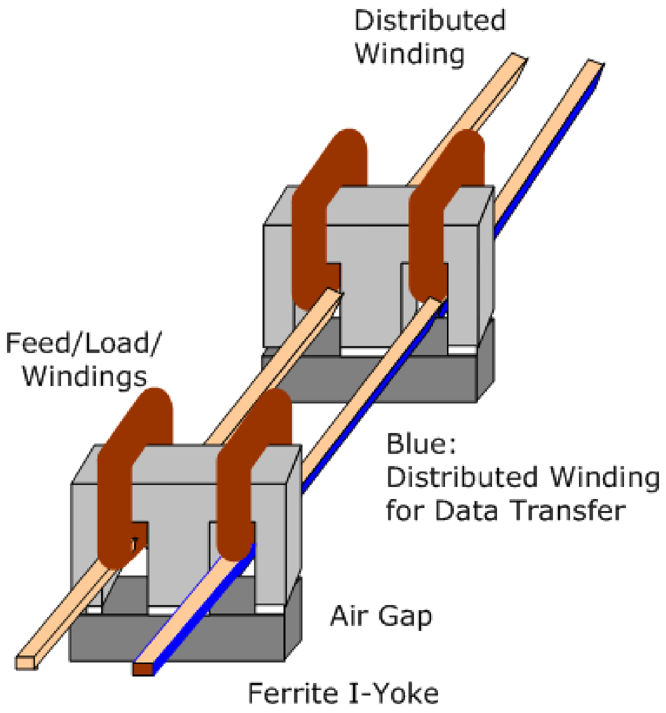
Multi-winding transformer with one "distributed" winding

- Power transfer
  - Feed < 10 kW
  - Load < 0.5 kW (typical)
- Data transfer
  - 500 kBit/s
  - Cycle time < 2ms
- Frequency range
  - 20-   70 kHz power
  - 20- 600 kHz data
- Extension
  - Length < 100 m / 300 ft



Objectives

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AC/DC COMSOL for quasi-static conditions in 2D and 3D EM calculations AND eventually couple with "equation-based"

Realize design goals such as:

- Voltage must not vary too much at loads regardless of number of loads (resonances , variable loads …)
- Minimize losses while not increasing cost

Ongoing work utilizes version COMSOL 4.3

- Determination of lumped parameters such as
  - self and mutual inductances
  - capacitances (not dealt with here)
- Studies in frequency domain
- Time depended calculations (not yet…)

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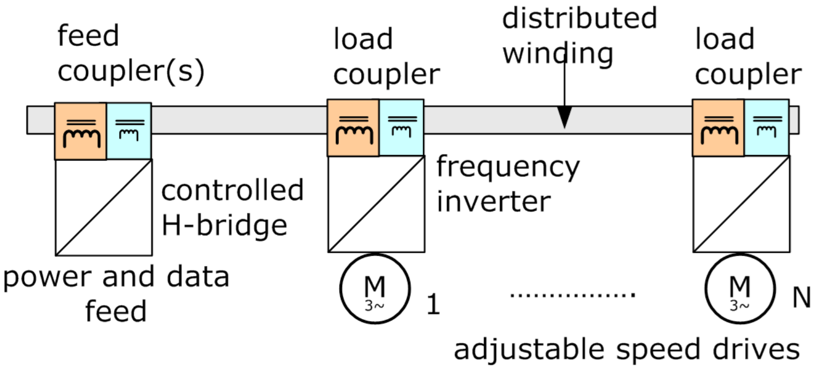
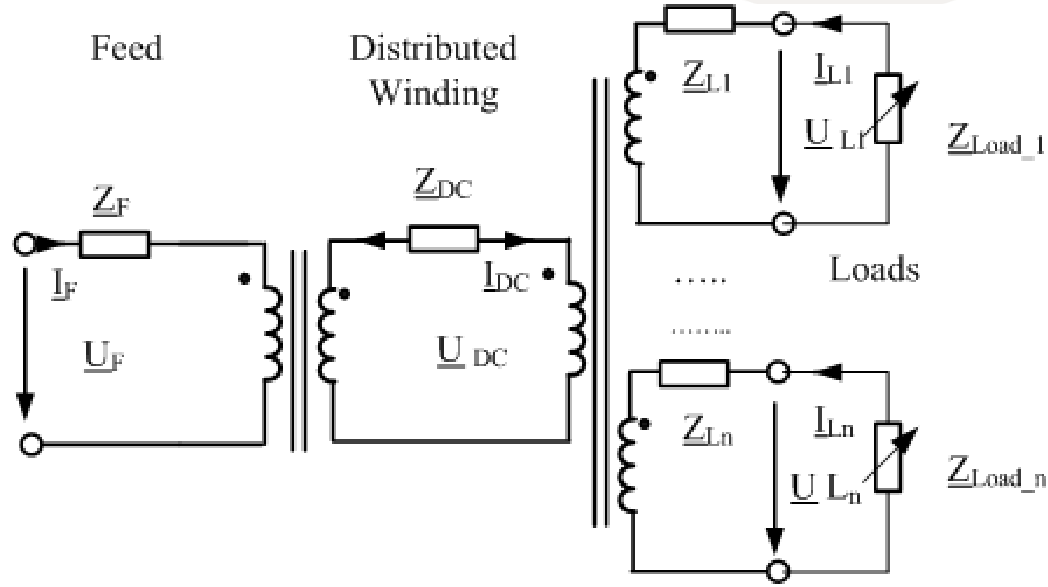
Objectives

Find Lumped Parameters





$$\underline{U}_F = \underline{Z}_F \cdot \underline{I}_F + j\omega M_{DWF} \cdot \underline{I}_{DC}$$

$$0 = \underline{Z}_{DW} \cdot \underline{I}_{DW} + j\omega \cdot M_{DwF} \cdot \underline{I}_F - j\omega \cdot \sum_{j=1}^{N_{load}} M_{DC\,Li} \cdot \underline{I}_{Li}$$

$$\underline{U}_{Li} = \underline{Z}_{Li} \cdot \underline{I}_{Li} + j\omega \cdot M_{DwLi} \cdot \underline{I}_{DW} + j\omega \cdot \sum_{\substack{j=1,\\ j\neq i}}^{N_{load}} M_{LiLj} \cdot \underline{I}_{Lj}$$

COMSOL Usage

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AC/DC Module

- Frequency domain
  - Linear transfer system: non saturation of ferrite E-cores
  - No-linear loads: input rectifier of inverters

- 2 D Studies
  - Air-gap influence, some geometry
  - Losses (skin and proximity of distributed winding)

- 3D Studies
  - Air gap check
  - Self and mutual inductances
  - Transfer behavior

Coupling to heat transfer for distributed winding

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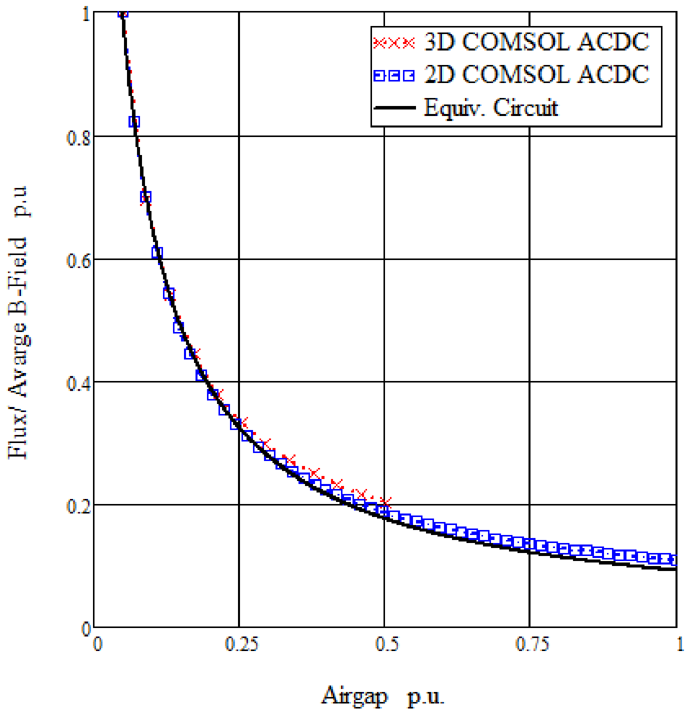
2D and 3D Air Gap Studies for one Coupler

We use quite small air gaps so variations influence fluxes considerably

- 3D Model
  - Mesh and solutions issues due to unfavorable geometric ratios
- 2D
  - Much easier to solve

Eventually applied for 3D studies

- 3D Model
  - permittivity layer feature



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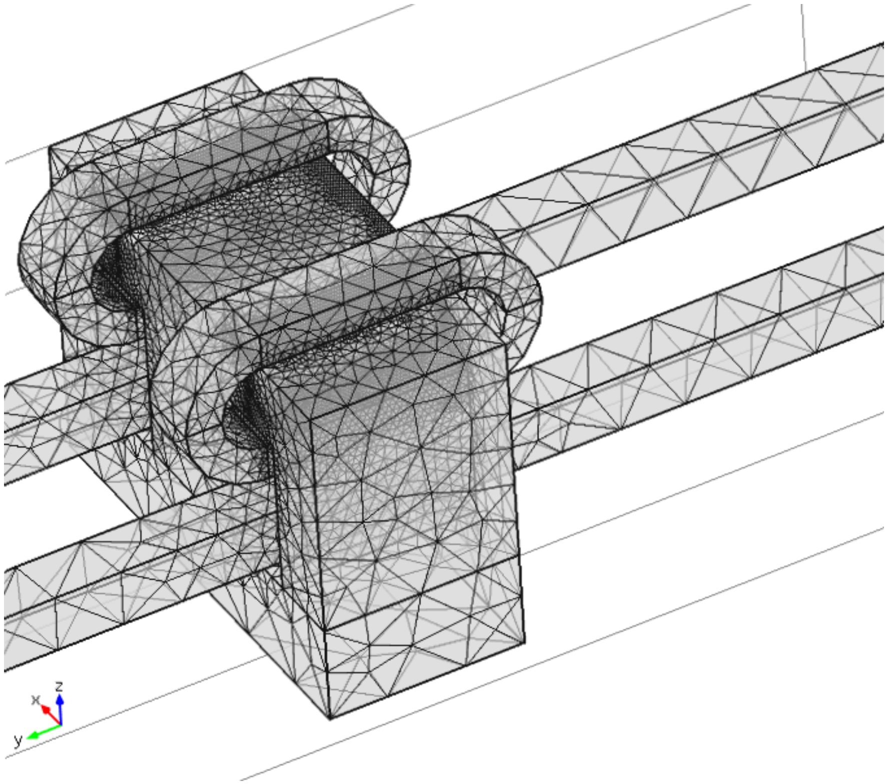
3D Studies

- Simple geometry,
  but relevant narrow region
  are to be resolved



- Flux contained quite well in
  E –I ferrite but not in
  distributed winding

Relative large element number

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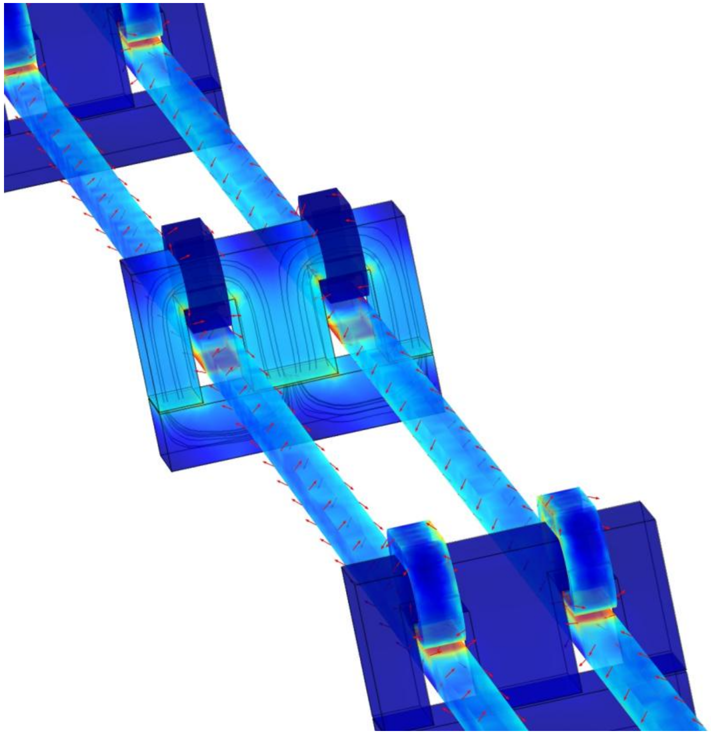
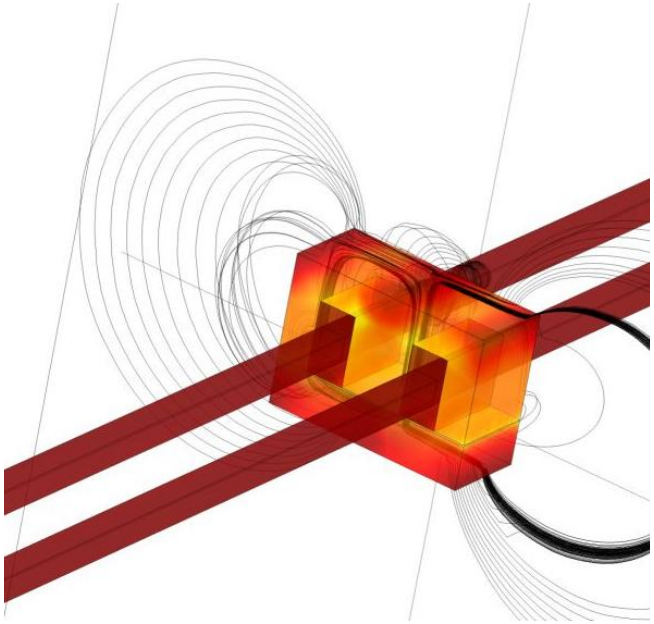
3D Studies AC/DC Module
Typical results





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Lumped Parameters Extraction

- Self inductances
  Energize only relevant winding while other windings are "disabled" and determine magnetic energy

- Mutual inductances
  Fluxes across appropriate faces , ratio of flux and currents (accounting for number of turns) yields mutual inductances

- Coupling with circuit also yields inductances

- Results are reasonable accurate for the application

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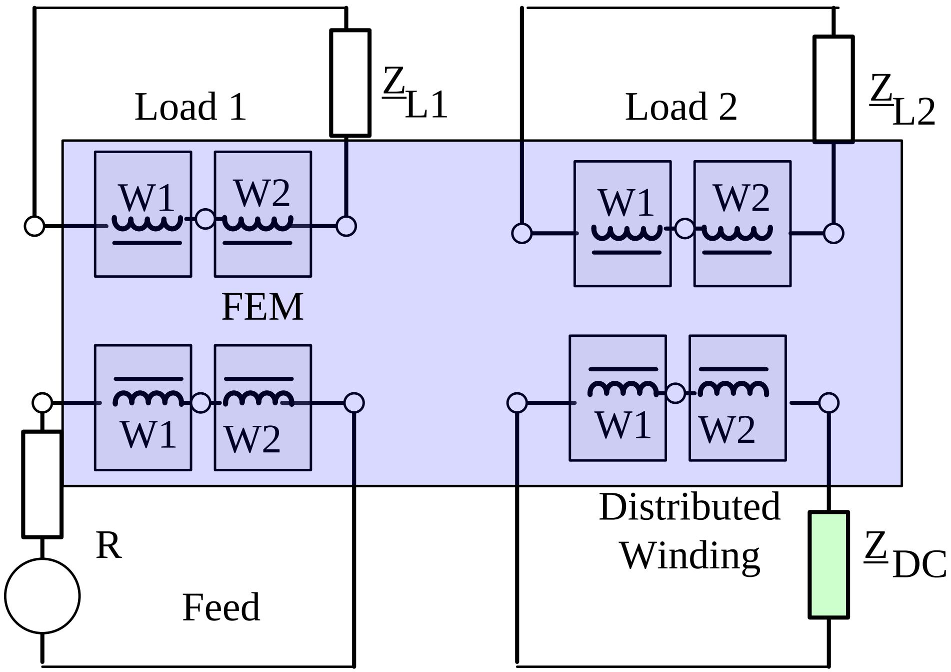
3D Studies AC/DC Module:

Magnetic Field and Circuit Calculation

- Distributed winding is divided
  - one small section (e.g. 1m / 3ft) part of FEM
  - the large section (e.g. 100m/300ft) is modeled via an impedance within the circuit



Experimental Set Up

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Test Stand

- Five adjustable speed drives
- Feed laboratory H-bridge with full control and access
- Distributed winding (app. 65 m / 200ft) is housed in a conduit which meanders along a wooden base plate.
- Distributed winding for data is attached to it
- Field and load couplers use standard E-Cores, bobbins are tailor made

Experimental Set Up

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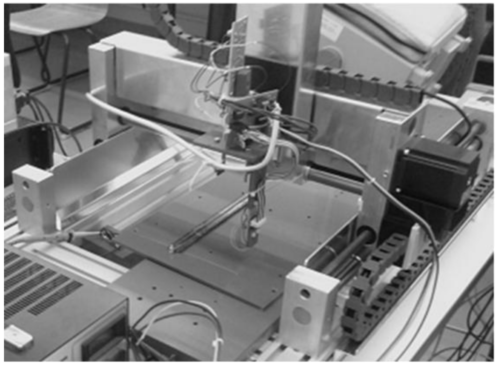
Measurement

Lumped parameters
- Precision impedance meter
- Frequency synthesizer and power amplifier
- Current sensor DC to 5Mhz

System behaviour
- Voltage and current sensors

Field
- Scanning device
- 3 perpendicular hall sensors
- DC- 300kHz



X, Y,Z positioning

sensor head

Results and Conclusion

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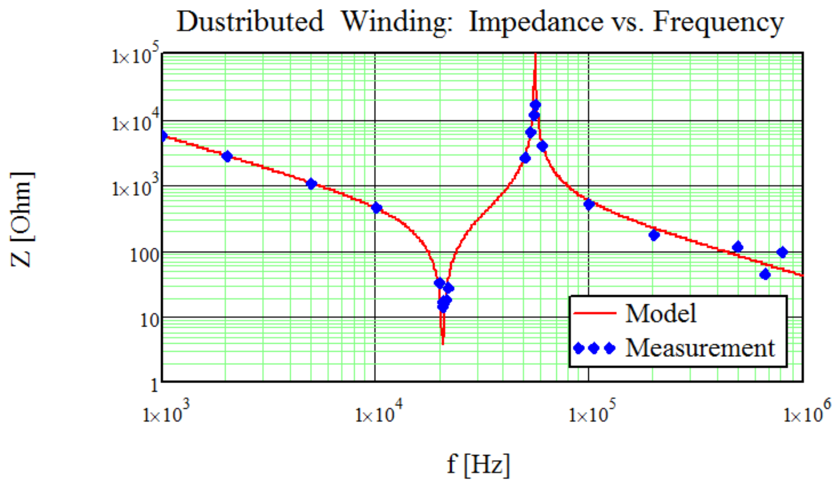
Results

Lumped parameter

- Results are reasonable accurate to 10 % within the measurements

- Field levels (only one coupler) Results are reasonable accurate



Transfer behavior

- No and light load voltage transfer ok also within 10 %
- Heavy load conditions have to be re considered

Heating

- Temperature elevation reproduced with adjusted heat transfer coefficients

Results and Conclusion

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Conclusion

- As expected results are quite sensitive to air gap spacing
- The presented work is on go-ing and first results have been presented.
- This first results helped to build a **working test stand** in finding appropriate pa-rameters.
  We have operated inverter driven motors, where power and data have been supplied contactless.

Next steps

- Heavy load conditions
- Transient behaviour.

Thank you

for your attention!

Contents

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- Introduction
- Objectives
- COMSOL Usage
- Experimental Set UP
- Results and Conclusion

Introduction

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Contactless Power Transfer

“Battery” Charging

Source: Conductix-Wampfler,

Source: Wire less Consotrium

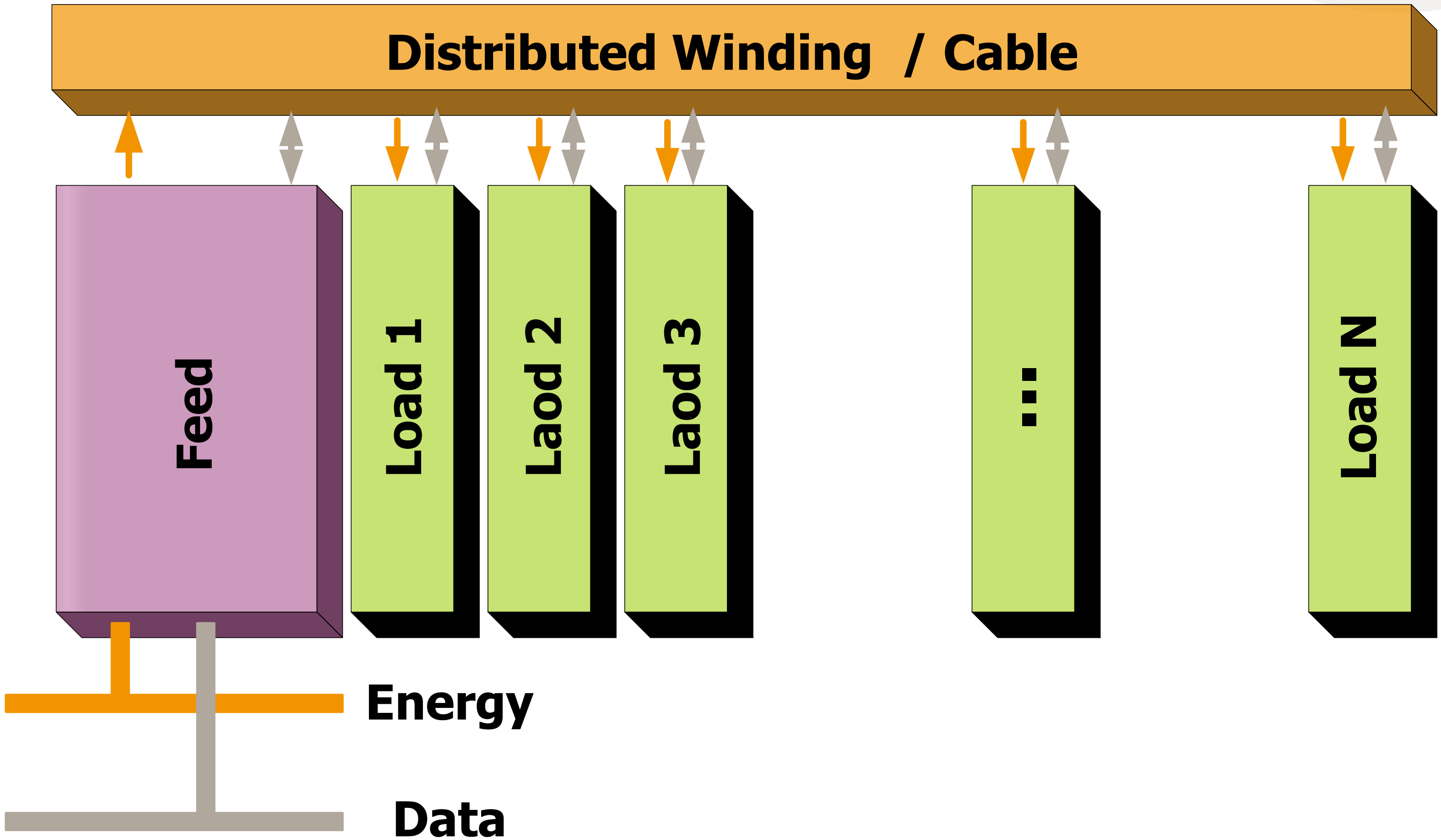
EMS – electric monorail systems

AGV – automated guided vehicles

Source: Vahle

Introduction

System Configuration



COMSOL Usage

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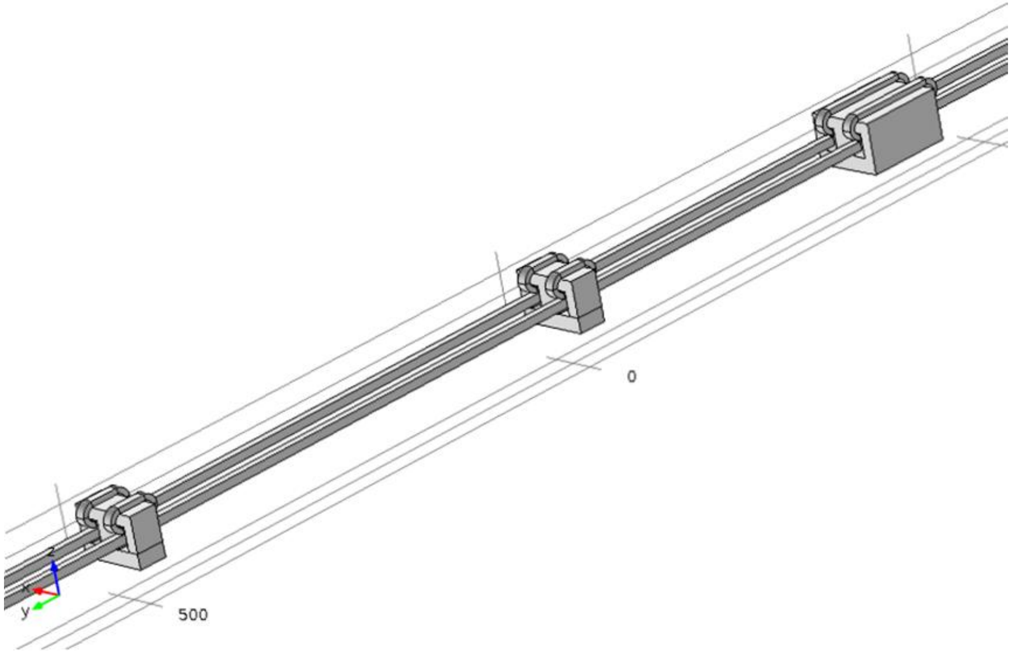
3D Studies

Paint circuit relative simple geomatry

Results

+ MCAD



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Loss Considerations

Losses are assed via analytical approximations:

- Skin effect

$$\frac{R}{R_{DC}} = \mathrm{Re}\left\{ \frac{r_w}{2} \sqrt{-j \cdot 2\pi \cdot f \cdot \mu \cdot \sigma} \frac{J_o(\sqrt{-j \cdot 2\pi \cdot f \cdot \mu \cdot \sigma} \cdot r_w)}{J_1(\sqrt{-j \cdot 2\pi \cdot f \cdot \mu \cdot \sigma} \cdot r_w)} \right\}$$

- Proximity effect as given by Nan and Sullivan,

$$P_{vProximity} = G(r, f, ws, ls) \frac{\overline{H}^2}{\sigma} \qquad \overline{H}^2 = \frac{1}{3} \frac{N^2 \cdot I^2}{b_w^2} \left(1 - \frac{1}{4m^2}\right)$$

- Core losses via a Steinmetz formula

$$P_V = K \cdot f^{ef} B^{eb}$$

- Eddy current losses of a thin back plate

$$P_V = \frac{1}{2} B_{av}^2 \cdot \pi^{3/2} \cdot f^{3/2} \cdot \sqrt{\frac{\sigma}{\mu \cdot}} \cdot \frac{\sinh(X) - \sin(X)}{\cosh(X) - \cos(X)}; \quad X = \frac{d}{\delta} = \sqrt{\pi \cdot f \cdot \mu \cdot \sigma} \cdot d$$

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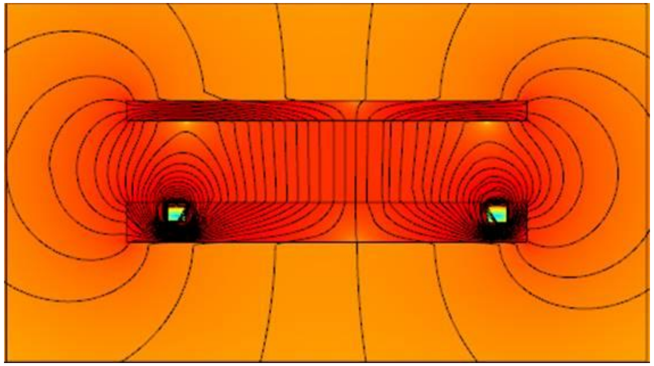
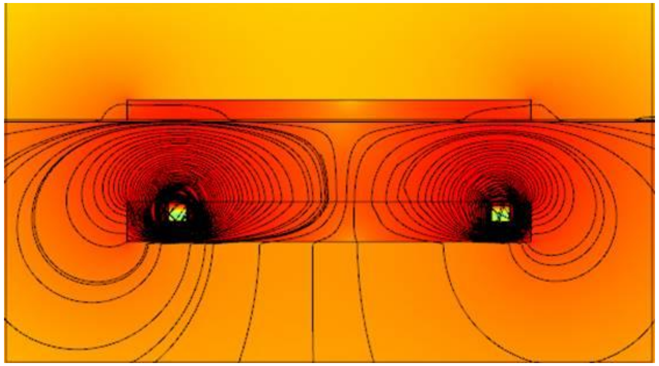
Shielding

Opera 3D Electra and 2D COMSOL
- Diffusion equation for the quasi static case and the harmonic Ansatz.





- Design of shield geometries for given damping requirements
- Minimizing incurred eddy current losses by altering conductivities, distances and thicknesses