Current Distribution in Heaters

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Motivation

- When designing heater geometries, do current distributions need to be considered for uniform heating?

- How magnetic fields and field variations affect the current distributions?

Physics

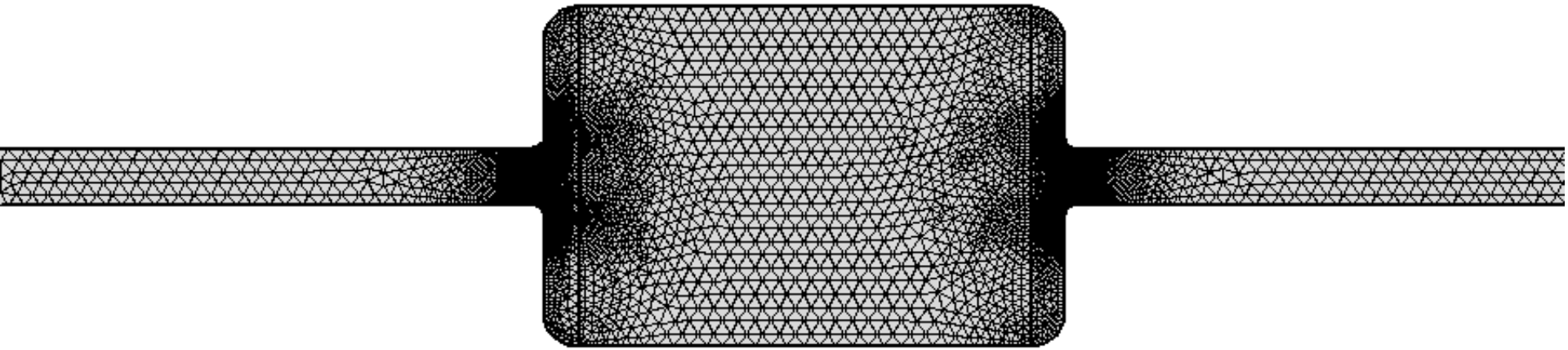
- Assuming stationary situation.
- Solve the following equations:

$$\nabla \cdot \vec{J} = 0$$
$$\vec{J} = \sigma \vec{E}$$
$$\vec{E} = -\nabla V$$

- Boundary conditions: fixed current density, zero normal current, fixed voltage, etc.

Calculations

- Complicated geometries → finite elements.
- COMSOL + Matlab.
- So far mainly 2D simulations (faster computations).

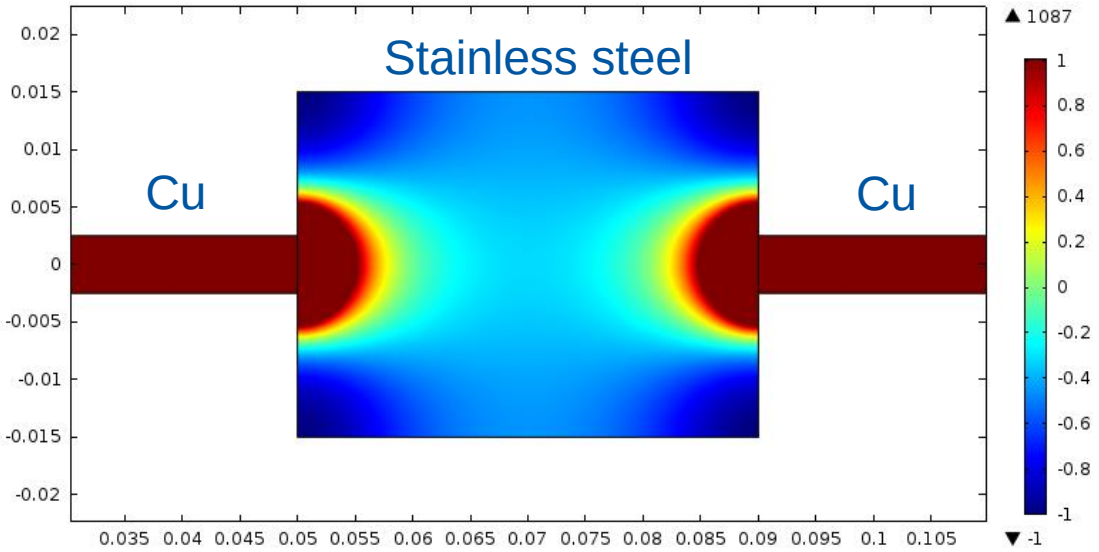


Heater geometry

±100 %

- Relative difference to the average current density squared:

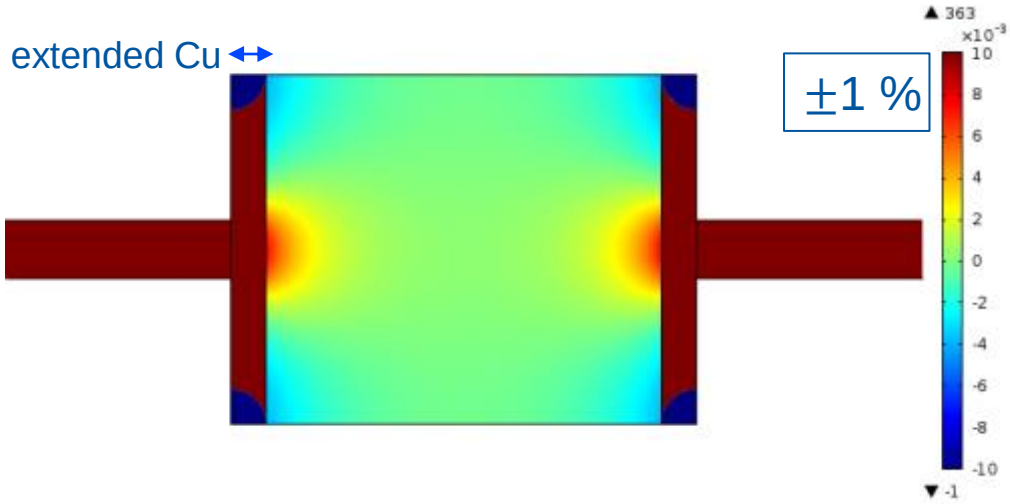
$$\delta = \frac{J(x,y)^2 - \langle J^2 \rangle}{\langle J^2 \rangle}$$



$$\sigma_{Ss} = 2 \cdot 10^6 \ \mathrm{S/m}$$
$$\sigma_{Cu} = 2 \cdot 10^9 \ \mathrm{S/m}$$

3 mm extended Cu ↔

±1 %



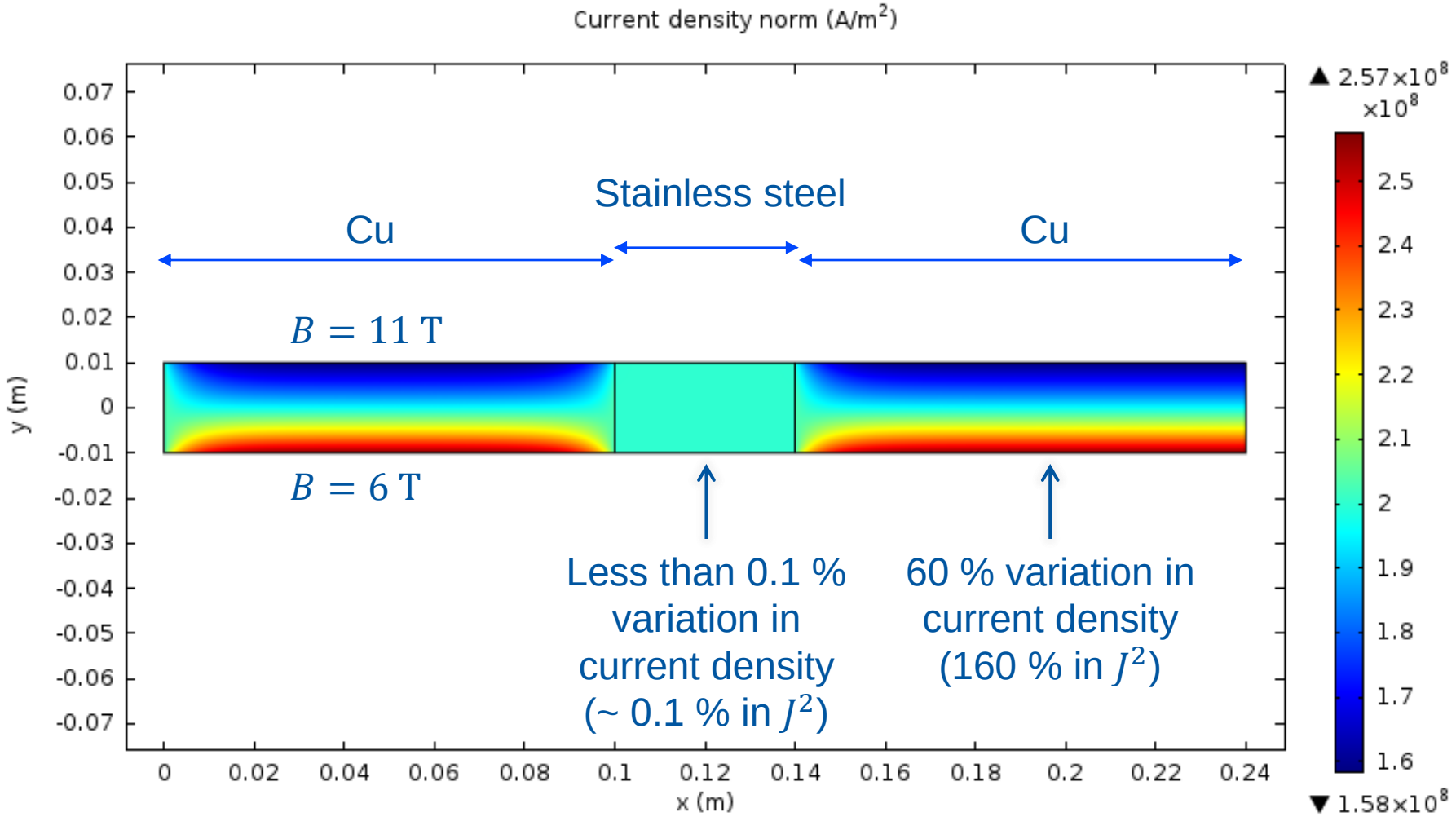
Magnetoresistance

- Two effects:
  - Isotropic magnetoresistance (scalar effects).
    - Simply set $\sigma = \sigma(T, B)$ in Cu.
  - Anisotropic magnetoresistance (Hall effect).
    - Simulated with a simple model with anisotropic conductivity.
    - Conductivity is a tensor:

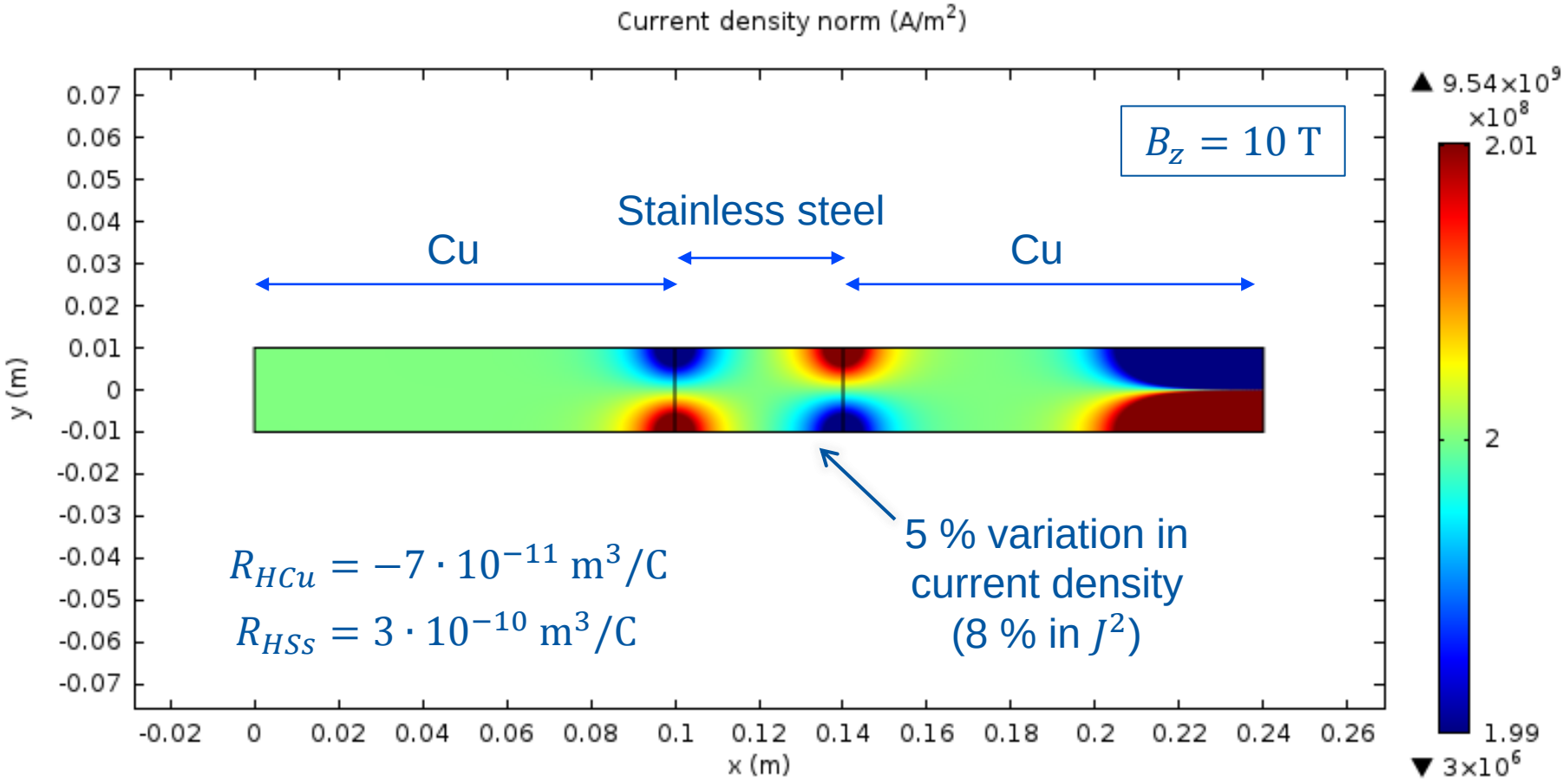
$$\sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{bmatrix}$$

Elements depend on B & $R_{H.}$

Scalar magnetoresistance



Hall effect


Current density norm (A/m²)
$B_z = 10$ T
Stainless steel
Cu
Cu
$R_{HCu} = -7 \cdot 10^{-11}$ m³/C
$R_{HSs} = 3 \cdot 10^{-10}$ m³/C
5 % variation in current density (8 % in J^2)
y (m)
x (m)
▲ 9.54×10⁹
×10⁸
2.01
2
1.99
▼ 3×10⁶

Conclusions

- Current distributions should be take into consideration in heaters (e.g. in copper cladding).
- Magnetic field variations in Cu do not pose any problems.
- Hall effect is larger, but still manageable (at most < 5 % variation from average heating).

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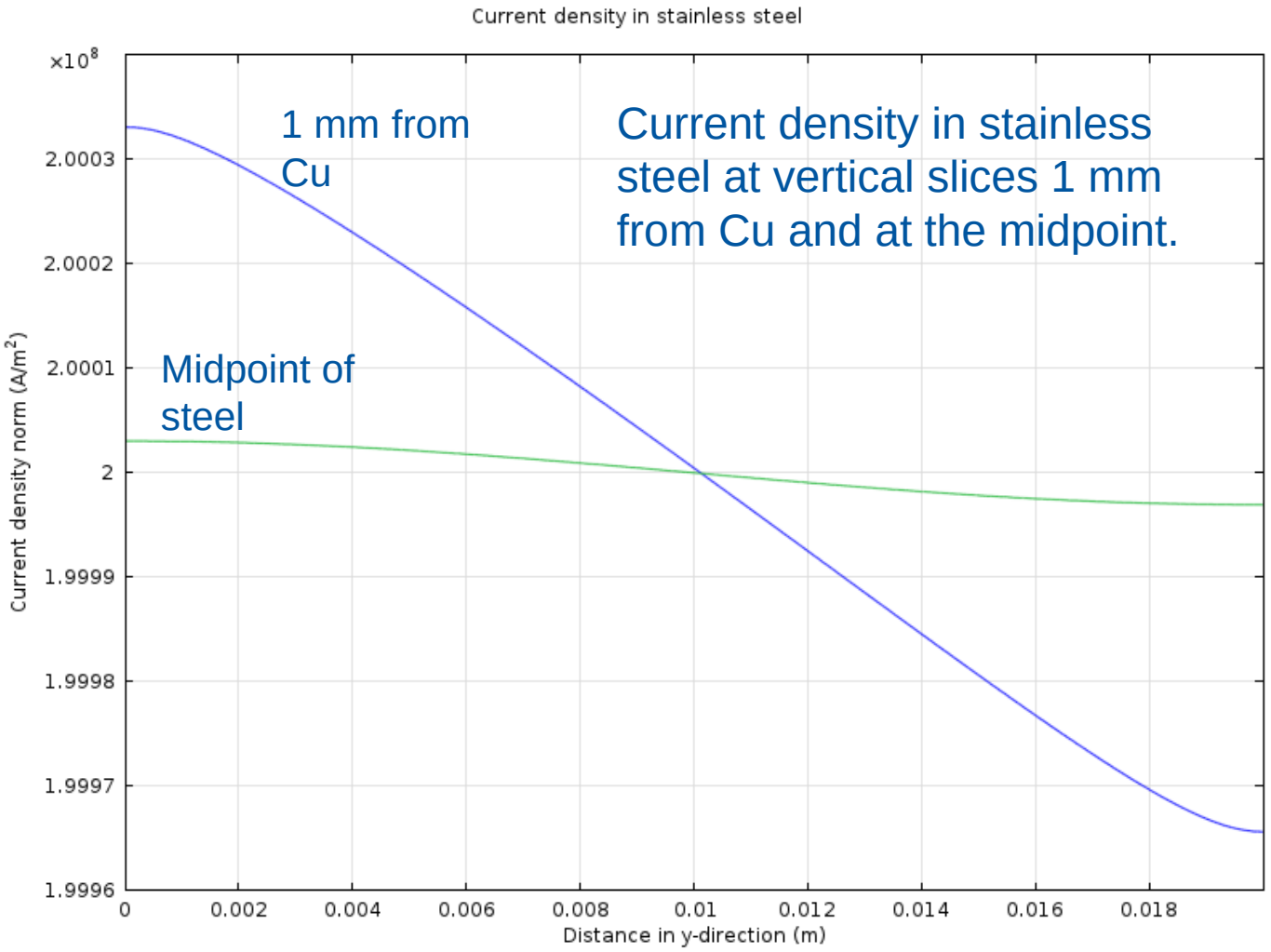
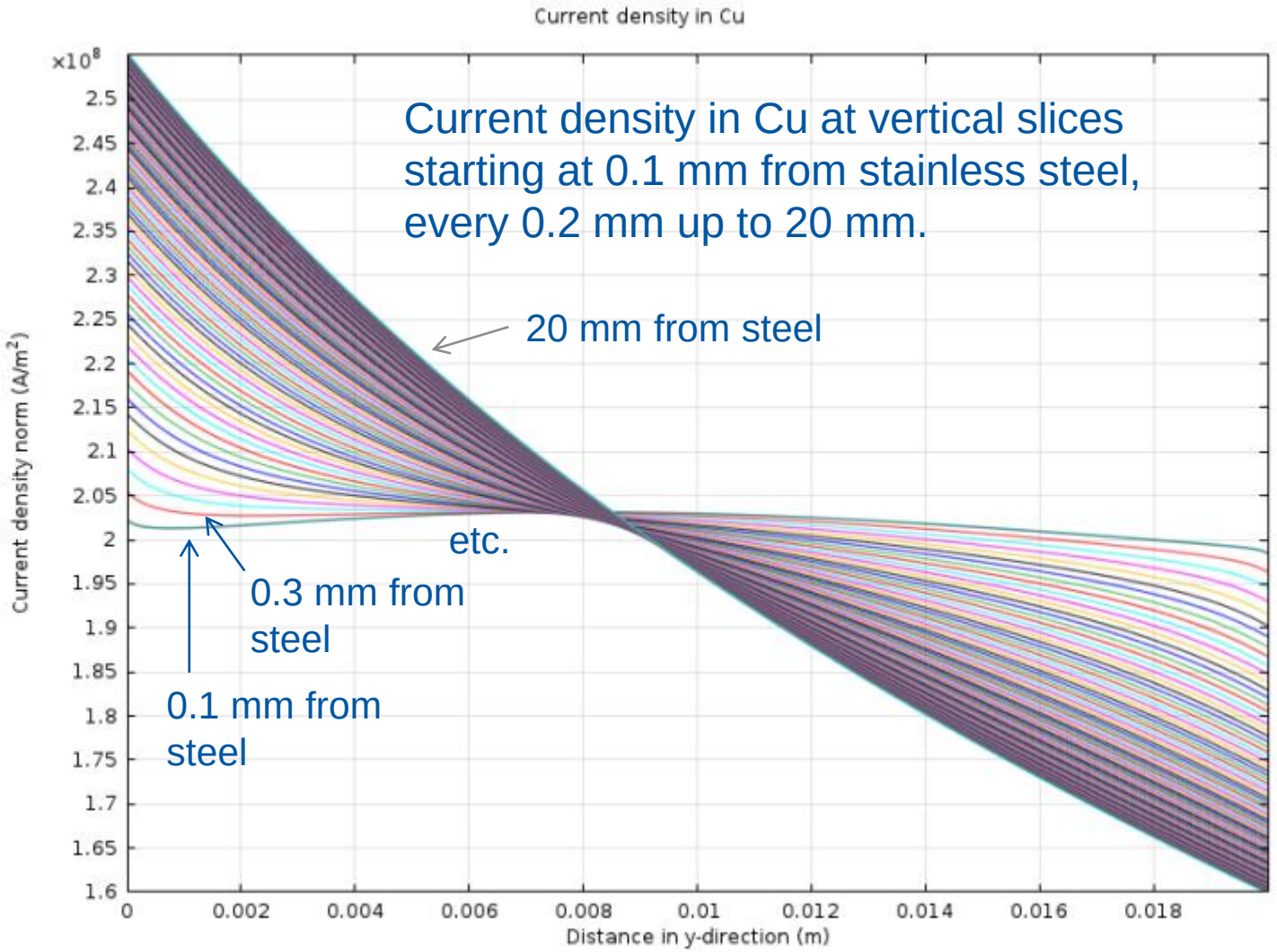
Extra slides

(Scalar magnetoresistance)



Extra slides

(Scalar magnetoresistance)



Extra slides

(Hall effect)