Nonlinear Shielded Multipair Railway Cable Modeling with COMSOL Multiphysics®

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Introduction: Due to the electromagnetic disturbance of the railway environment, railway signaling and telecommunication cables can be subjected to high induced longitudinal electromotive force which can lead to the transmission of wrong information and a risk of electrocution of the railway staff. The objective of this work is to study the behaviour of these shielded multipair cables in different situations in order to design appropriate electromagnetic protection. A 2D model of a seven-pair shielded cable disturbed by an external interference current in the defined frequency is built in COMSOL's AC/DC Module to investigate the cable's shielding factor against the electromagnetic interference.

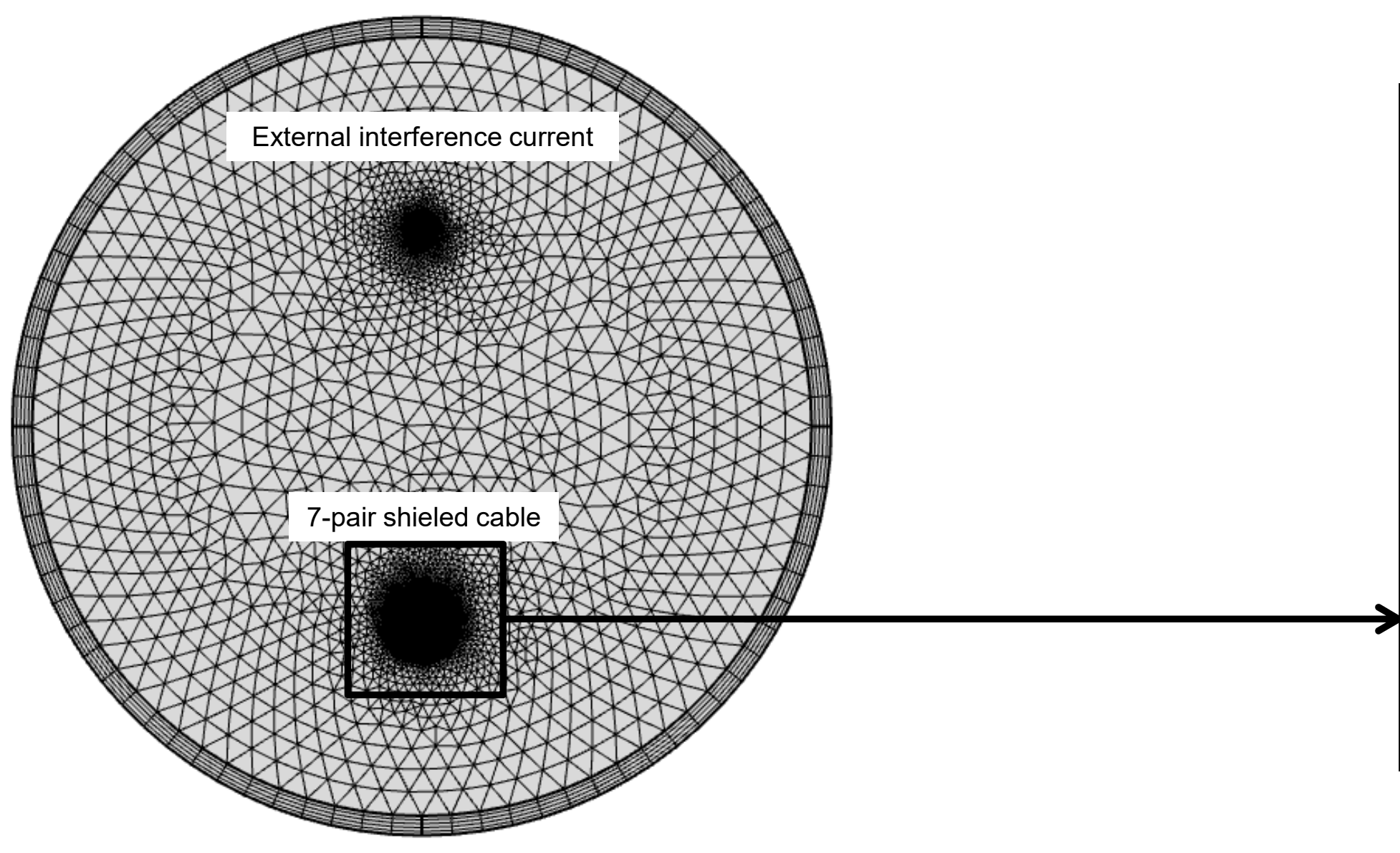

Figure 1. 2D COMSOL model of a seven-pair shielded cable disturbed by an external interference current

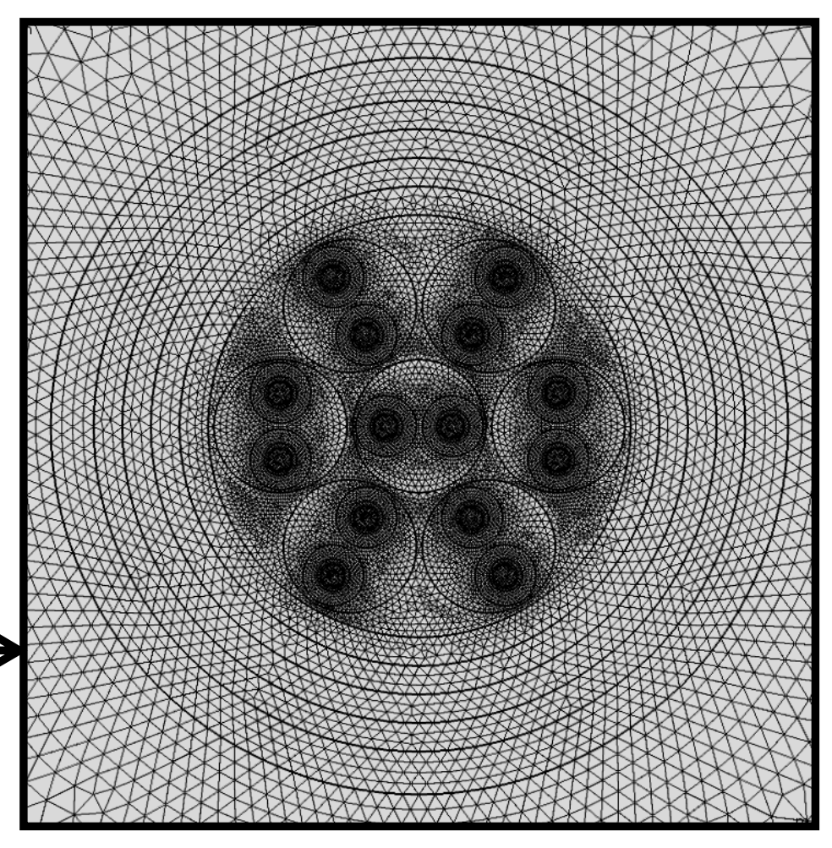

Figure 2. 7-pair shielded cable geometry

Computational Methods

- The nonlinear magnetic **B-H** curve of the ferromagnetic material steel in the cable's shielding is shown in figure 3.

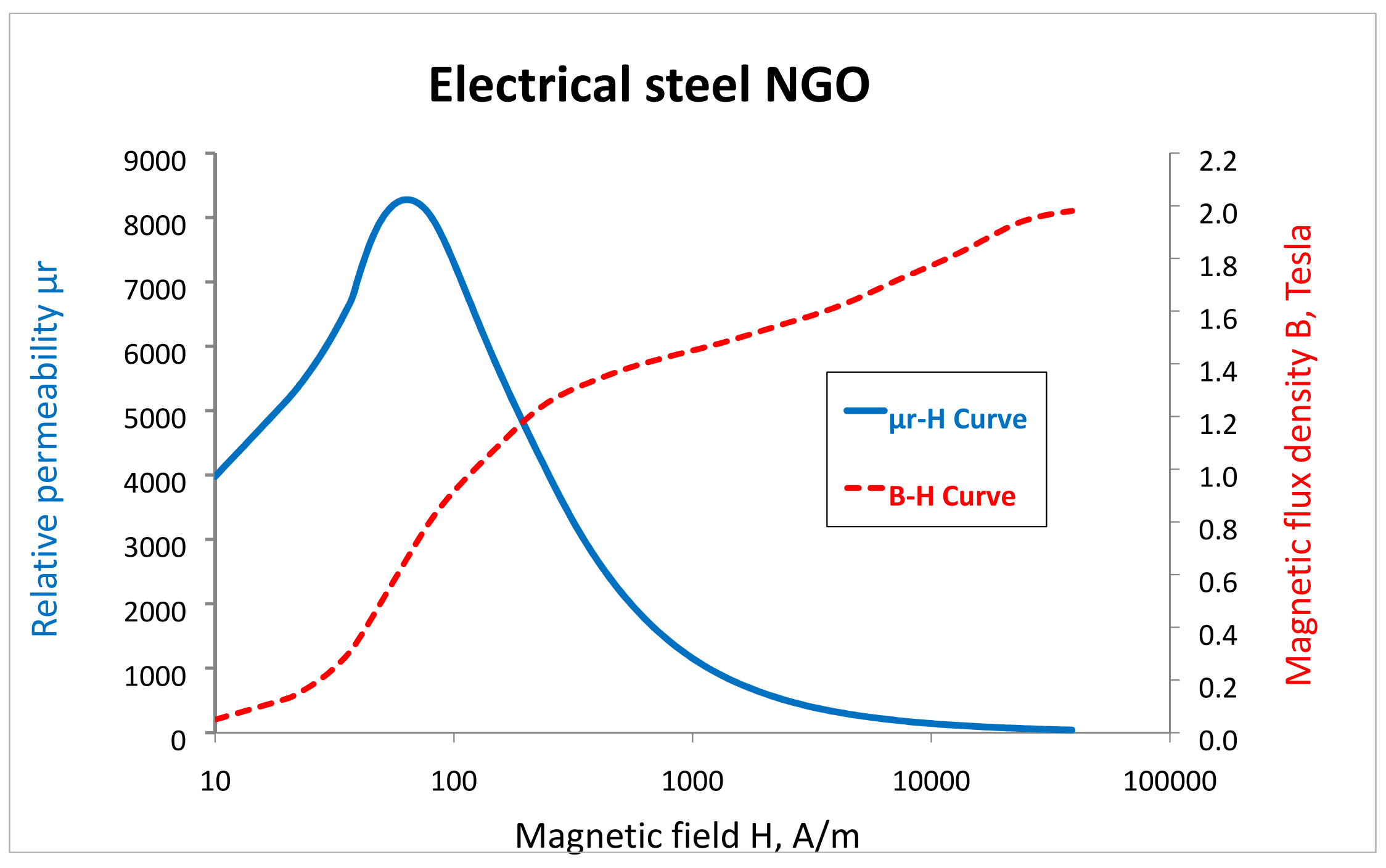

Figure 3. Magnetic saturation of the electrical steel NGO

$$\boldsymbol{B} = \mu_0(\boldsymbol{H} + \boldsymbol{M})$$

$$\mu_r = 1 + \frac{\boldsymbol{M}}{\boldsymbol{H}}$$

$\boldsymbol{M}$: Magnetization of the material

$$\boldsymbol{M} = \boldsymbol{M}_{sat}\ \left[\coth\left(\frac{\boldsymbol{m}\mu_0(\boldsymbol{H} + \alpha\boldsymbol{M})}{kT}\right) - \frac{kT}{\boldsymbol{m}\mu_0(\boldsymbol{H} + \alpha\boldsymbol{M})}\right]$$

- The reduction factor k that represents cable's shielding efficiency is calculated as follows:

$$k = \frac{e}{E}$$

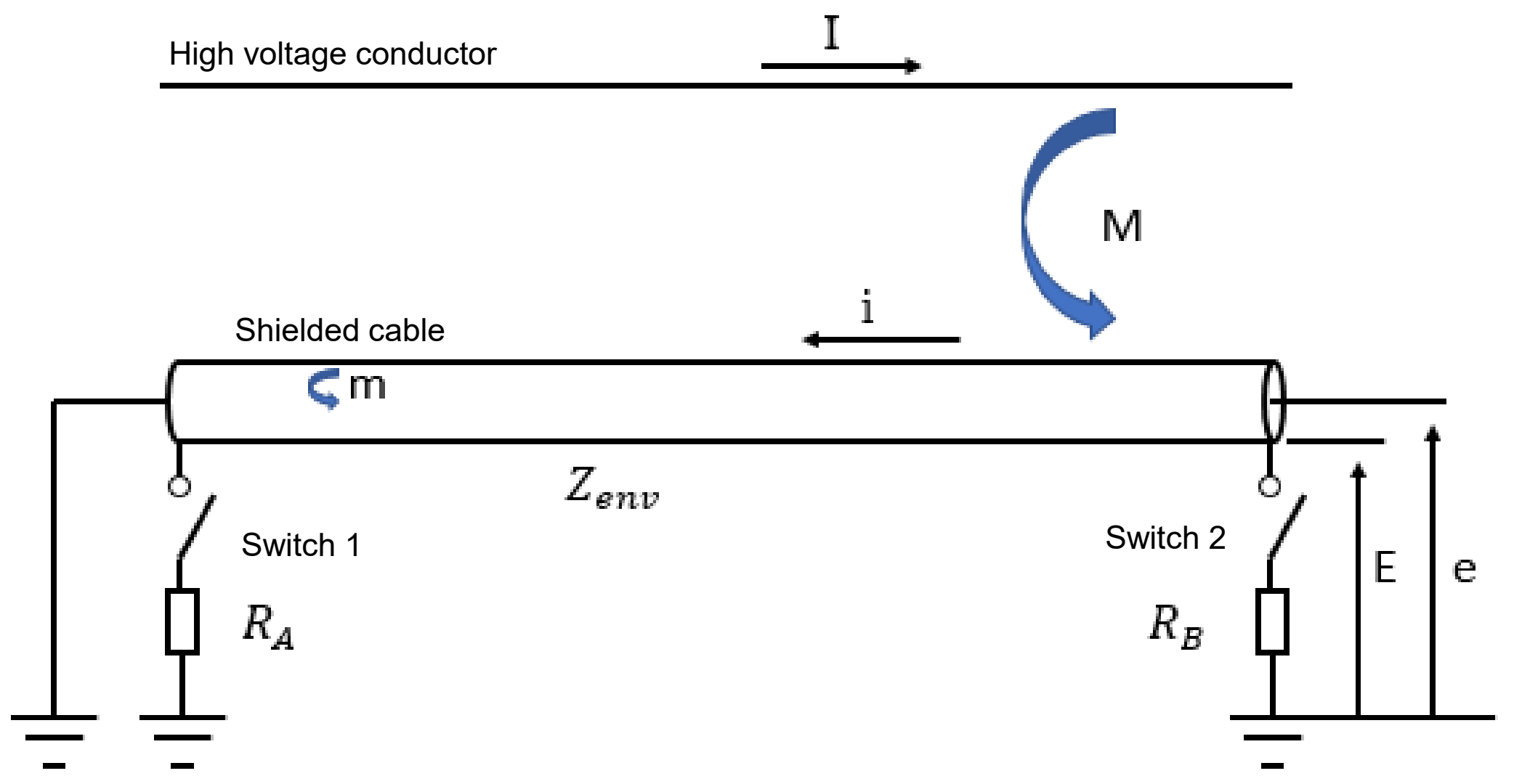

***Figure 4.** Experimental bench for measurement of the reduction factor at SNCF*

e, E: Induced voltages over the conductor pairs of the cable core respectively with and without the presence of the shielding.

- Without shielding:
  $$\mathrm{E} = \mathrm{M}I\omega\mathrm{j}$$
- With shielding:
  $$i = \frac{-E}{Z_{env}+R_A+R_B}$$
  $$e = E + mi\omega j$$

The induced electromotive force can be obtained by the Faraday's law of electromagnetic induction :

$$V = -\frac{d\Phi}{dt} = \frac{\iint_S \boldsymbol{B}\cdot d\boldsymbol{S}}{dt}$$

Results: The simulation shows:

- Convergence of the mean magnetic field in the space in terms of mesh size.
- Reduction of the magnetic field in the cable core brought by the electromagnetic shielding.
- Concentration of the magnetic field lines in the steel armor as a result of its high magnetic permeability.
- Reduction effect in terms of external interference intensity and frequency, relating to the magnetization saturation of the steel in the shielding.

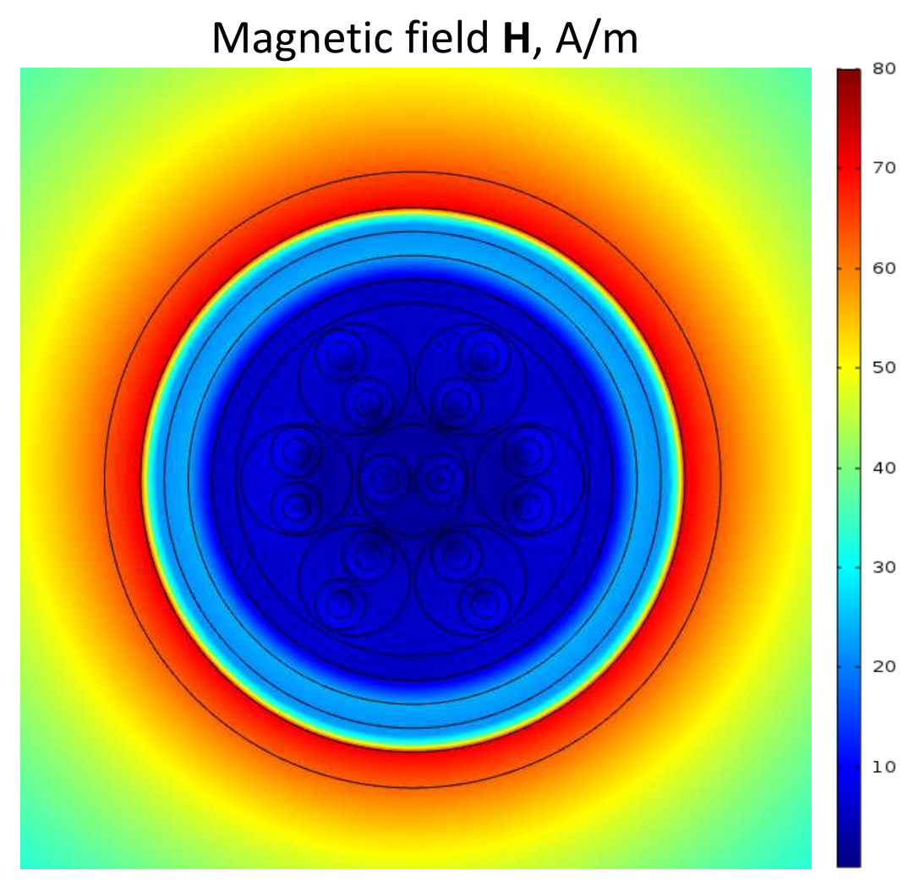

Figure 5. Magnetic field **H** in the shielded cable disturbed by an external interference at 50 Hz

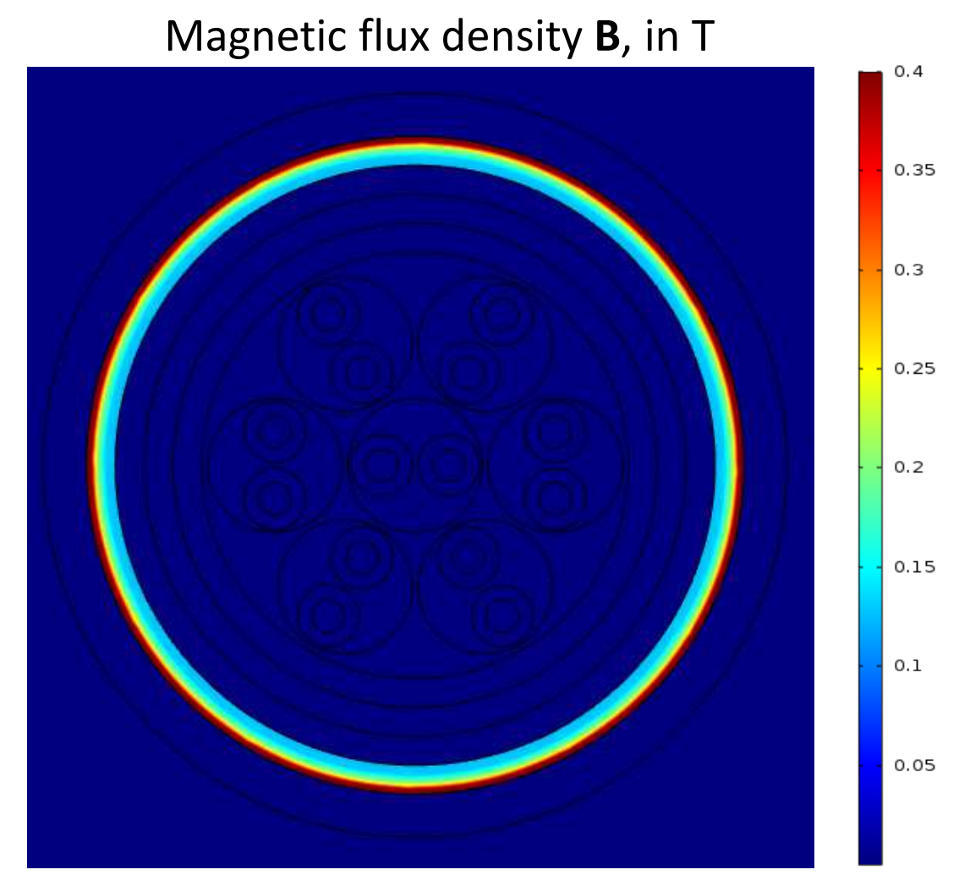

Figure 6. Magnetic flux density **B** in the shielded cable disturbed by an external interference at 50 Hz

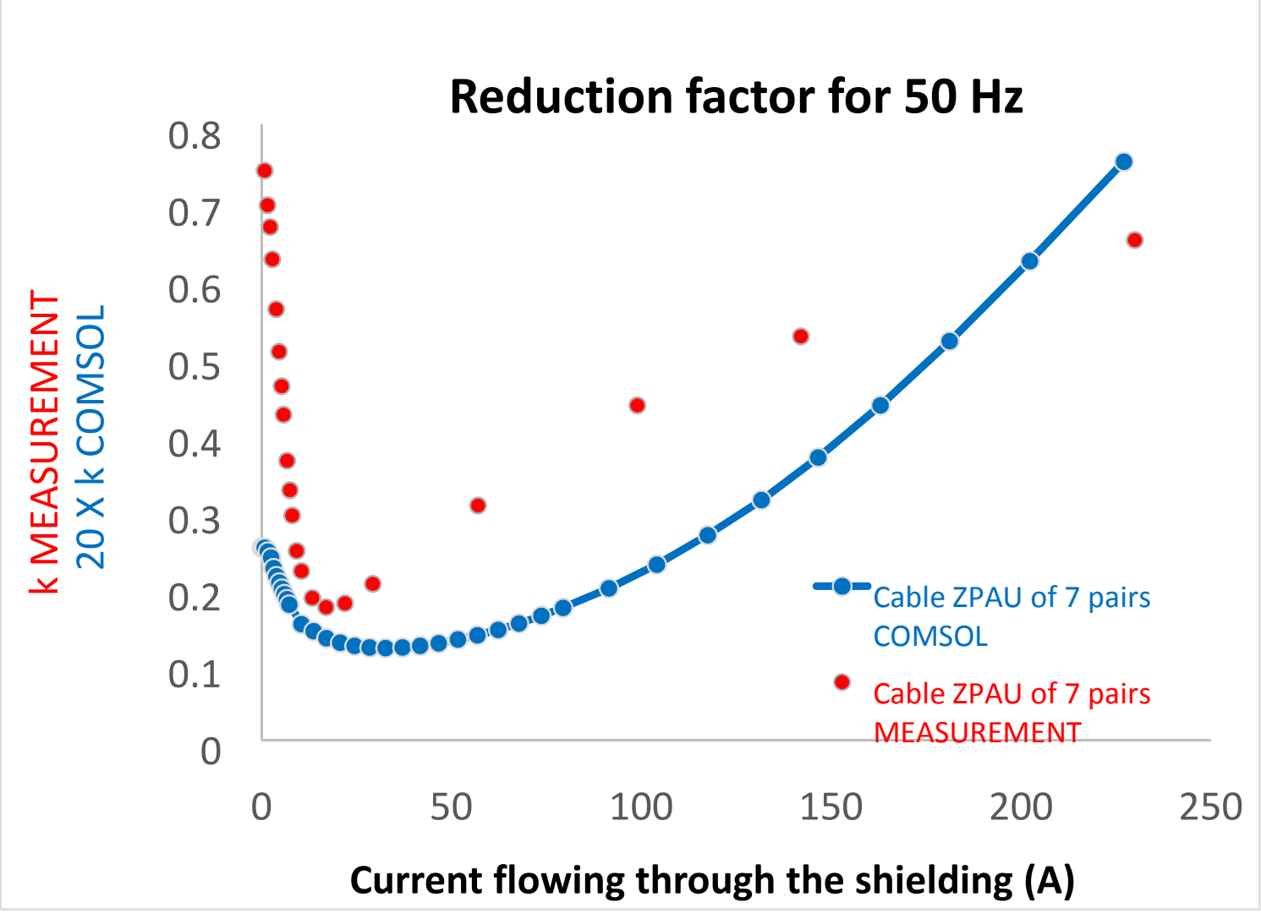

Figure 7. Comparison between the simulation results and measurement results for the 7-pair cable

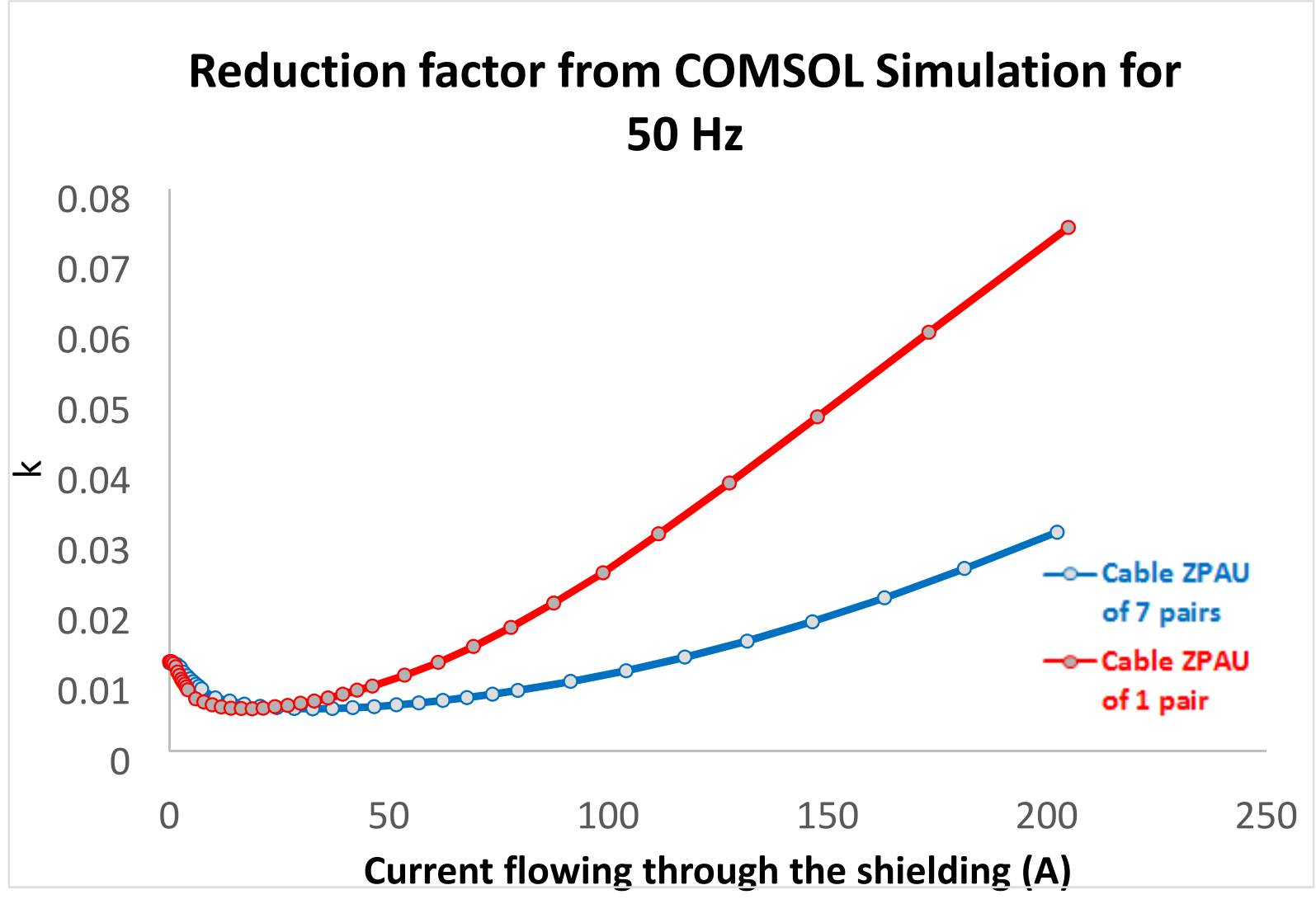

Figure 8. Comparison between the 1-pair cable and the 7-pair cable in terms of interference intensity

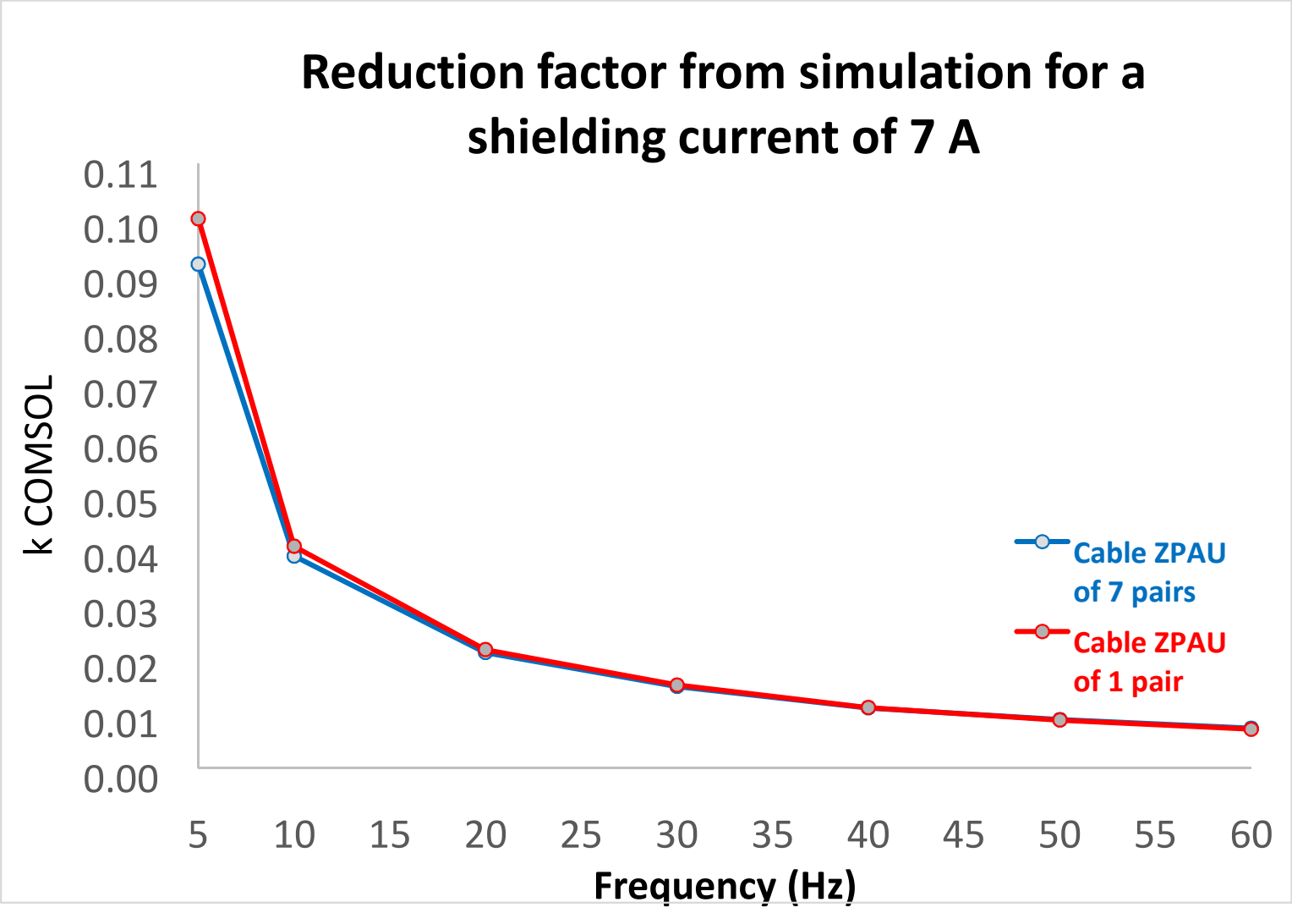

Figure 9. Comparison between the 1-pair cable and the 7-pair cable in terms of frequency

Conclusions: The nonlinearity of the cable's behaviour is simulated in COMSOL Multiphysics by varying the external interference current and the frequency. Through the comparison with the reduction factor obtained from measurements, the simulation results are well verified. Thus, the COMSOL model can be used to investigate the cable's shielding behaviour in wide intensity and frequency exposition which is currently limited by measurements. Future work may focus on the different cable configuration.

References:

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2. M. Alejandra MORA RIVEROS, Contribution to the EMC modeling in the railway environment: the influence of infrastructure, Lab-STICC, 2010.
3. N. Paudel, Model Magnetic Materials in the Frequency Domain with an APP, COMSOL BLOG, 2016.

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