IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), April 2015.
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Numerical models of HTS coated conductors are now ready for realistic applications

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Motivation

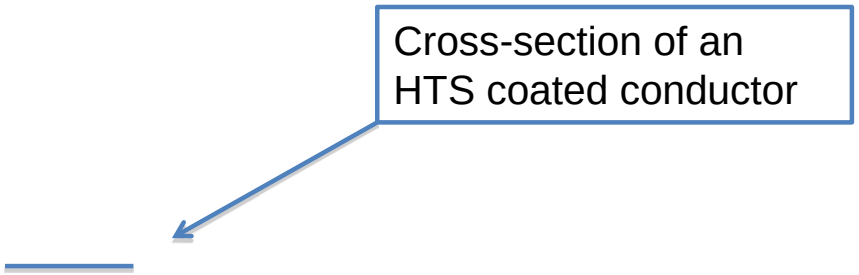
We want reliable and fast numerical models to simulate devices made of hundreds/thousands tapes (turns).

Simulating all the tapes is not an option.

We have developed two complementary approaches, both including the $J_c(B,\theta)$ dependence:

1. Multi-scale
2. Homogenization

Example: simulation of a stack 200 x 10



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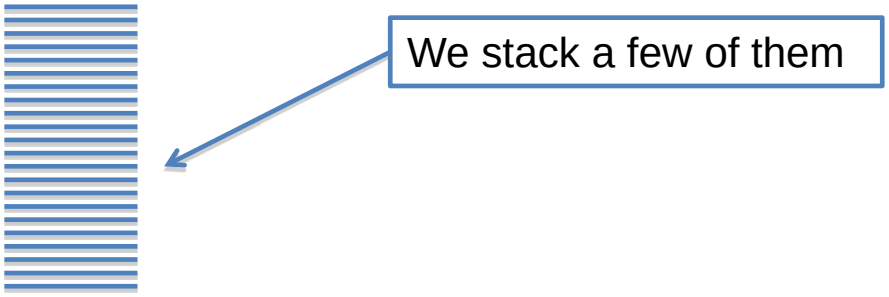

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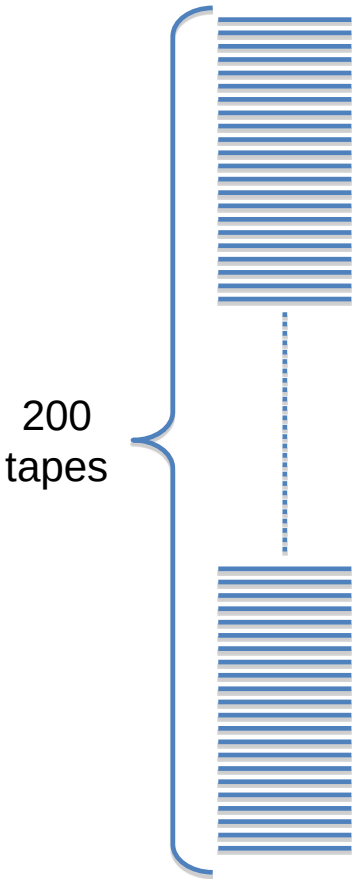

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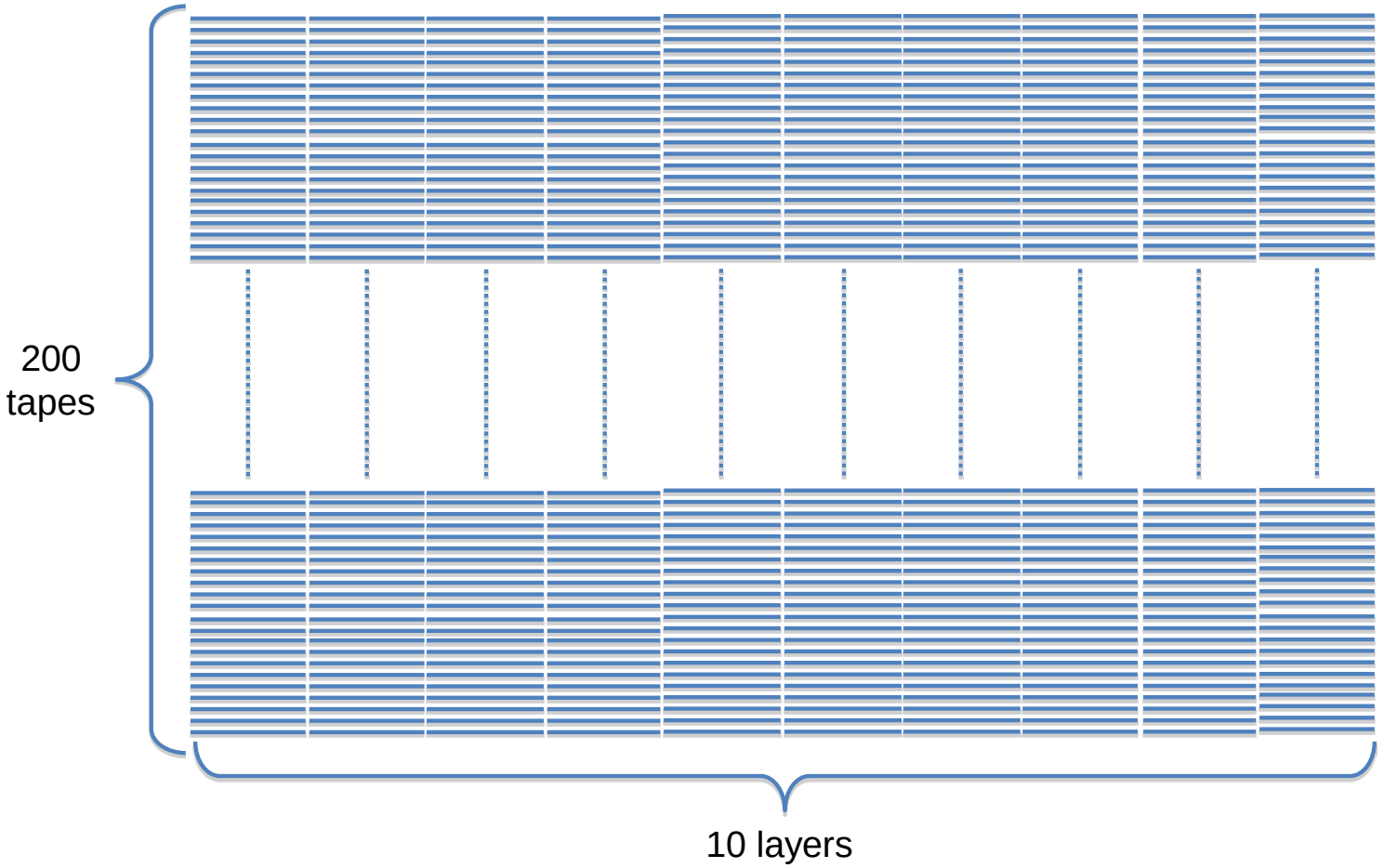

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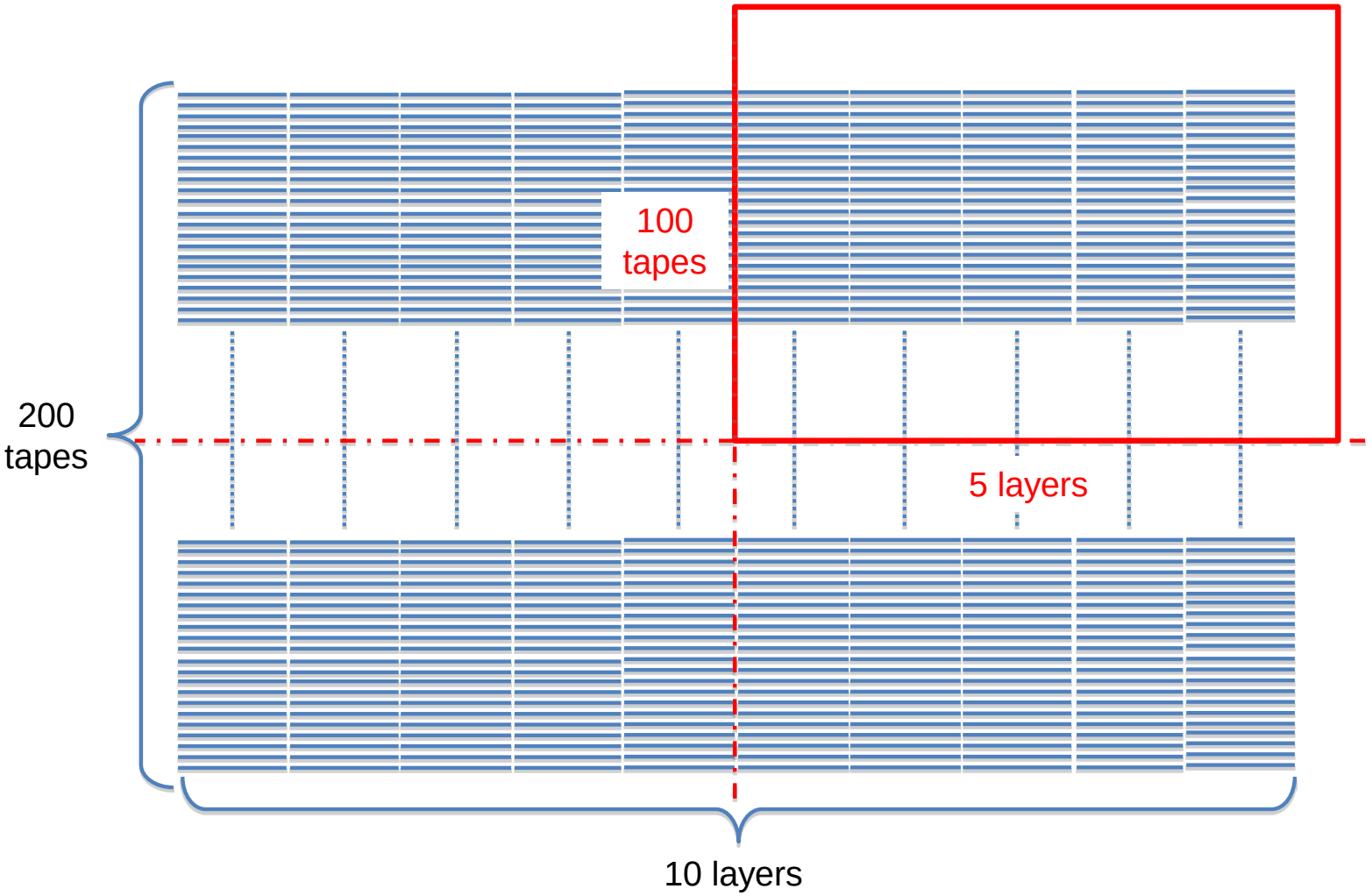
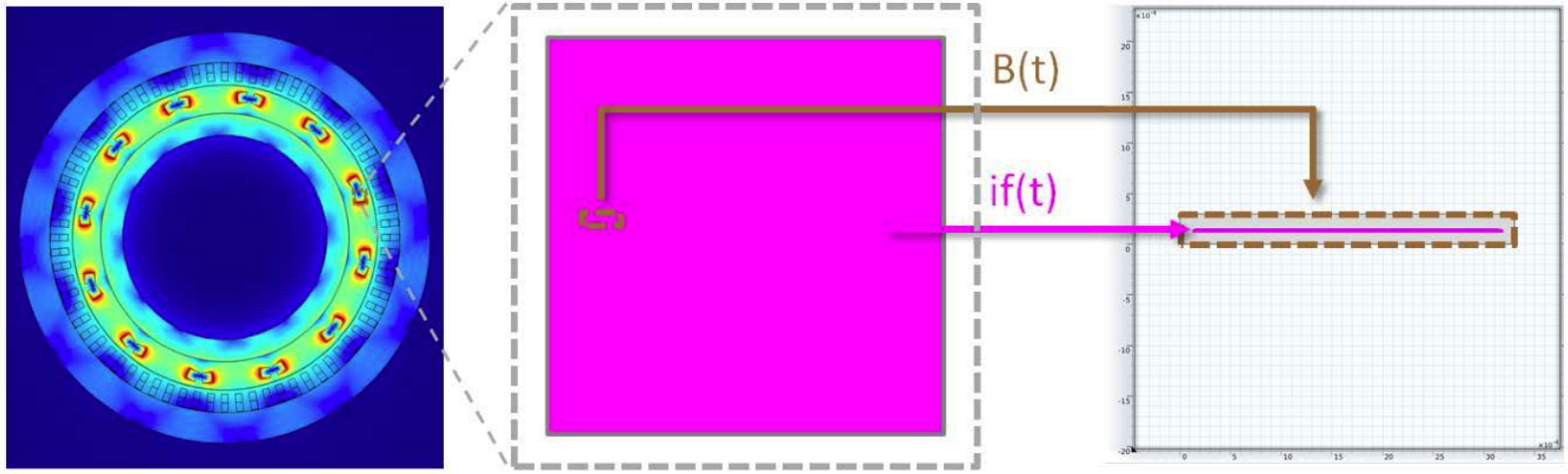


Multi-scale model: the main idea



Machine model

HTS tape model

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 23, NO. 3, JUNE 2013 5201905

AC Losses of a Grid-Connected Superconducting Wind Turbine Generator

Loïc Quéval and Hiroyuki Ohsaki, *Member, IEEE*

What is our strategy?

Step 1 H (H-formulation)

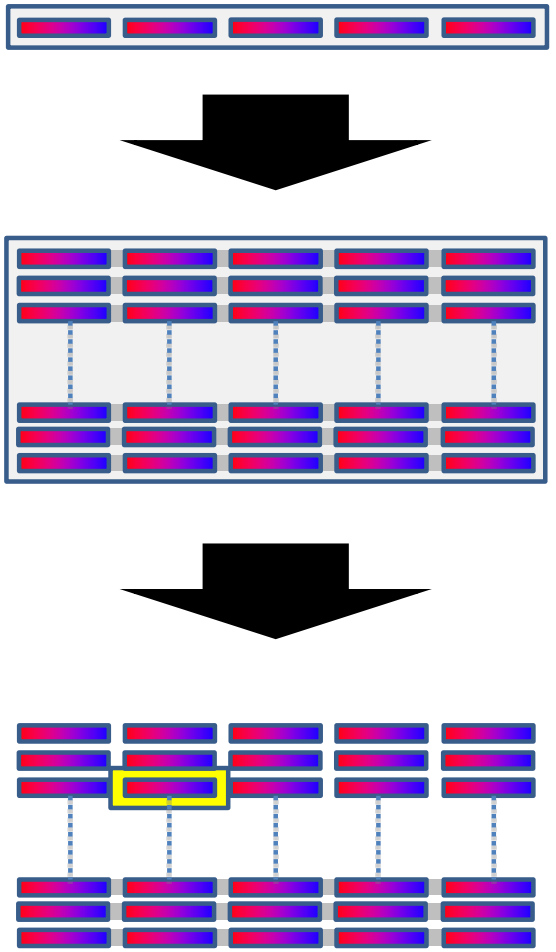
- Calculate *J* distribution in array of infinite stacks

Step 2 (A-formulation)

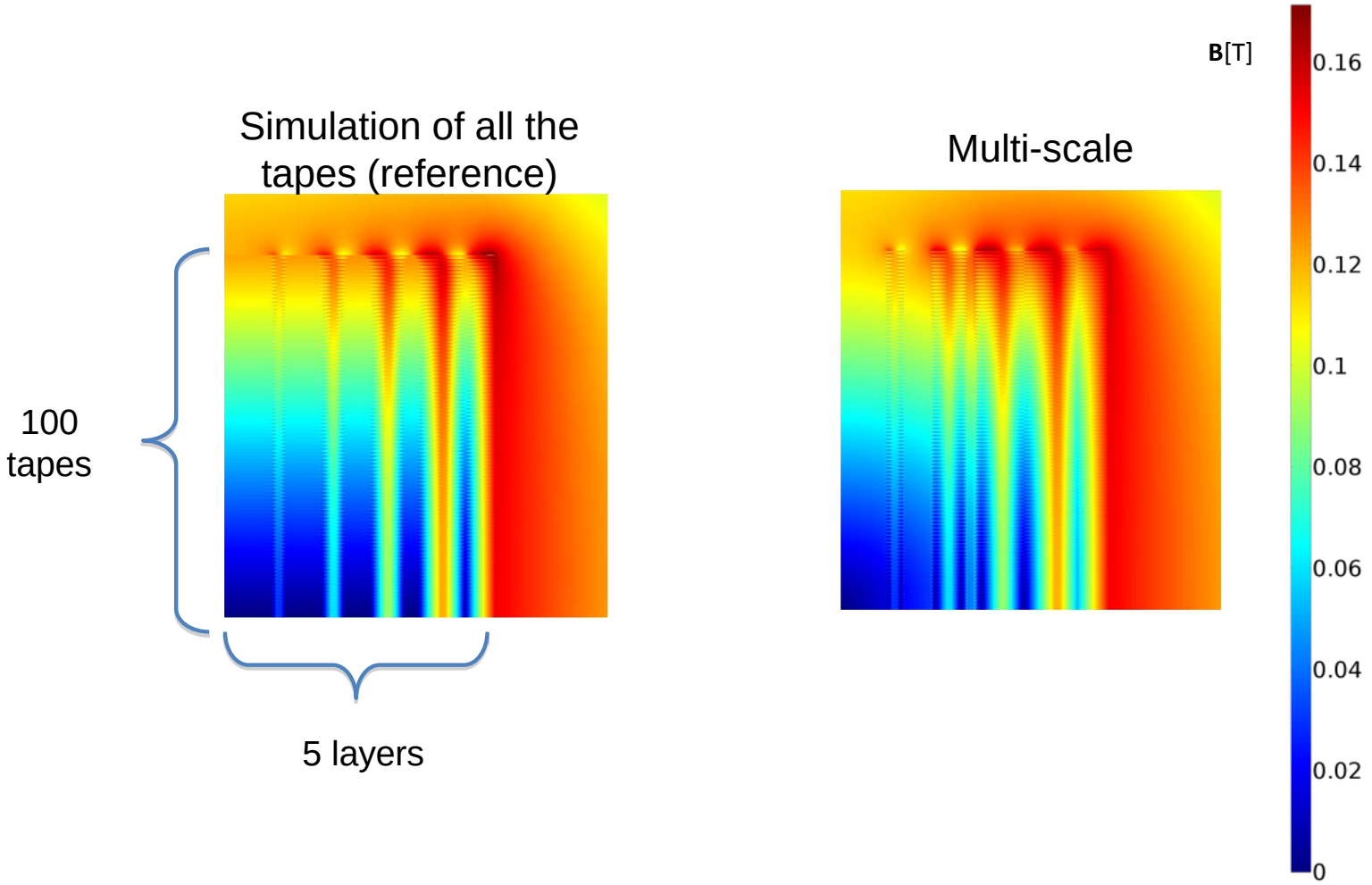
- *J* distribution from step 1
- Real geometric layout of device
- Time dependent (time is a parameter)
- Linear problem

Step 3 (H-formulation)

- Uses field from step 2 as a boundary condition
- Rapid implementation (only one tape)
- Every tape can be simulated in parallel



The results of the multi-scale approach are very similar to those obtained by simulating all the tapes.



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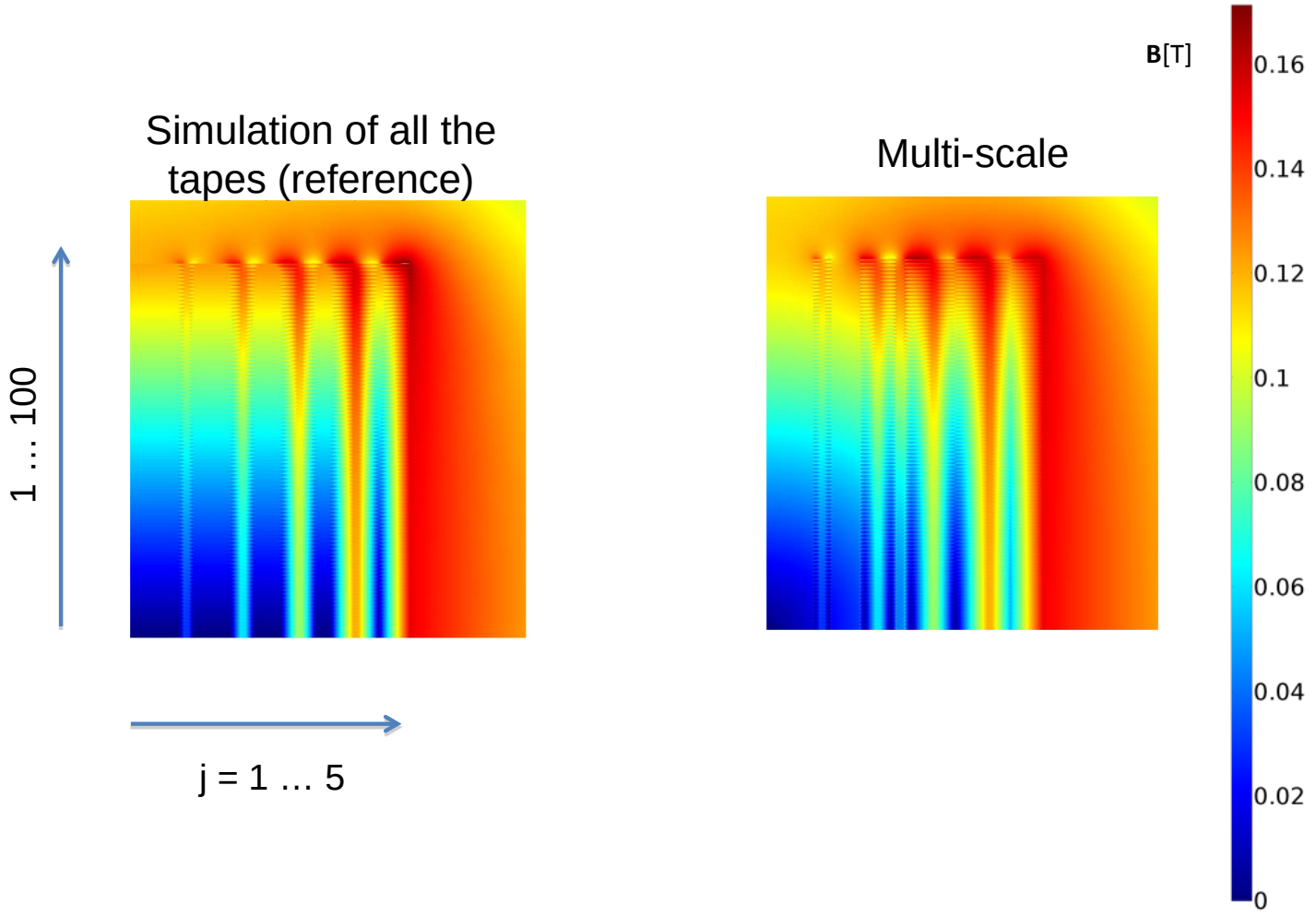
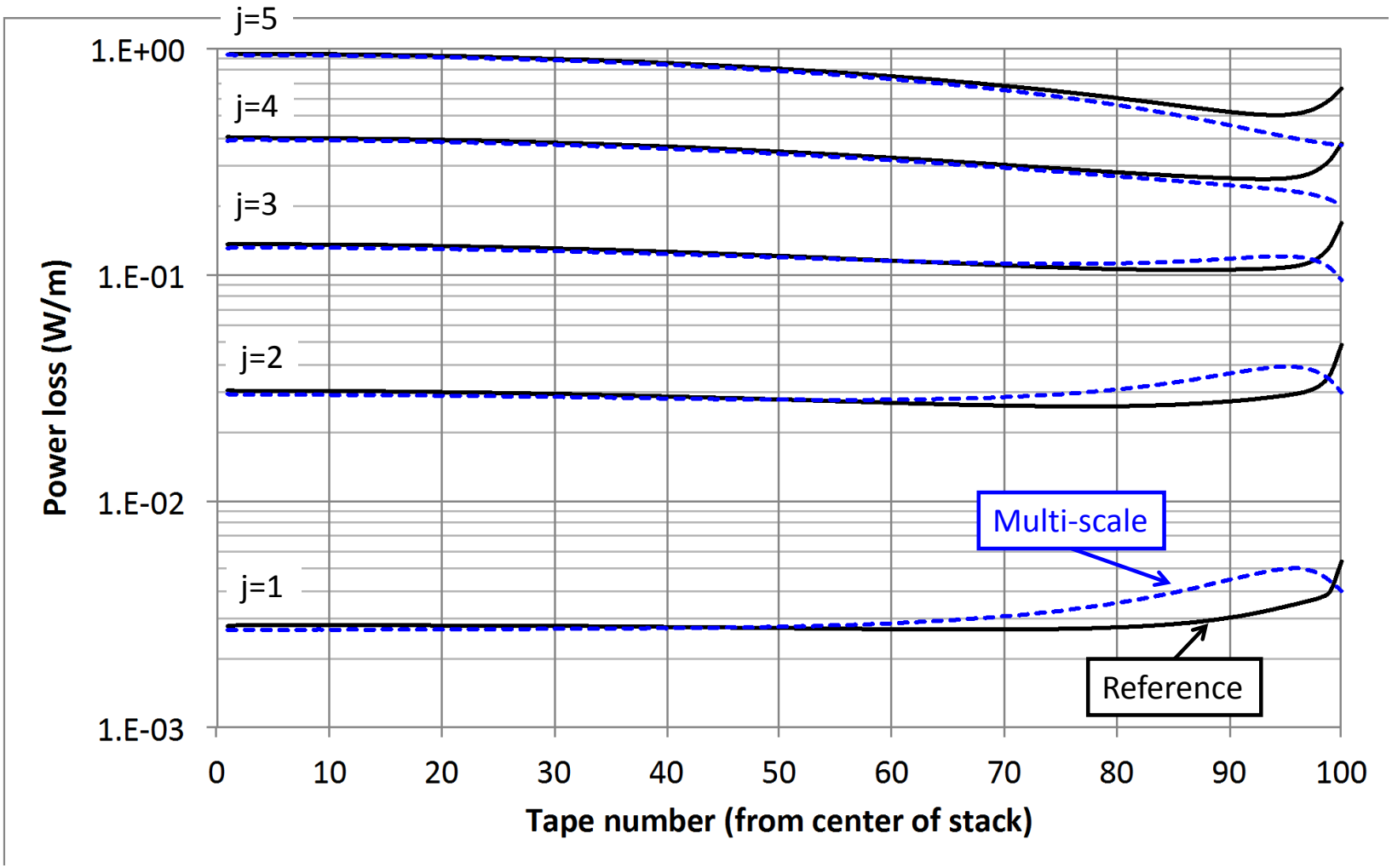
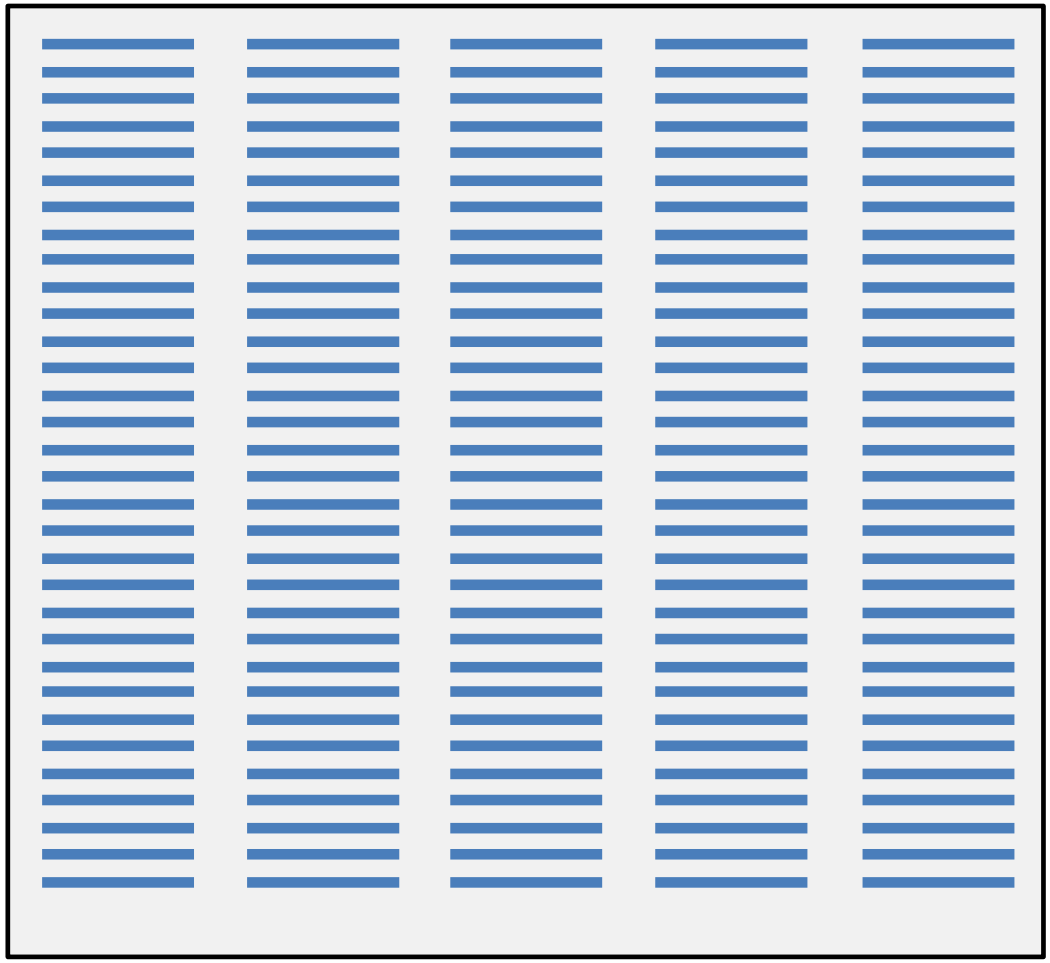


Power loss in the different positions of the stack

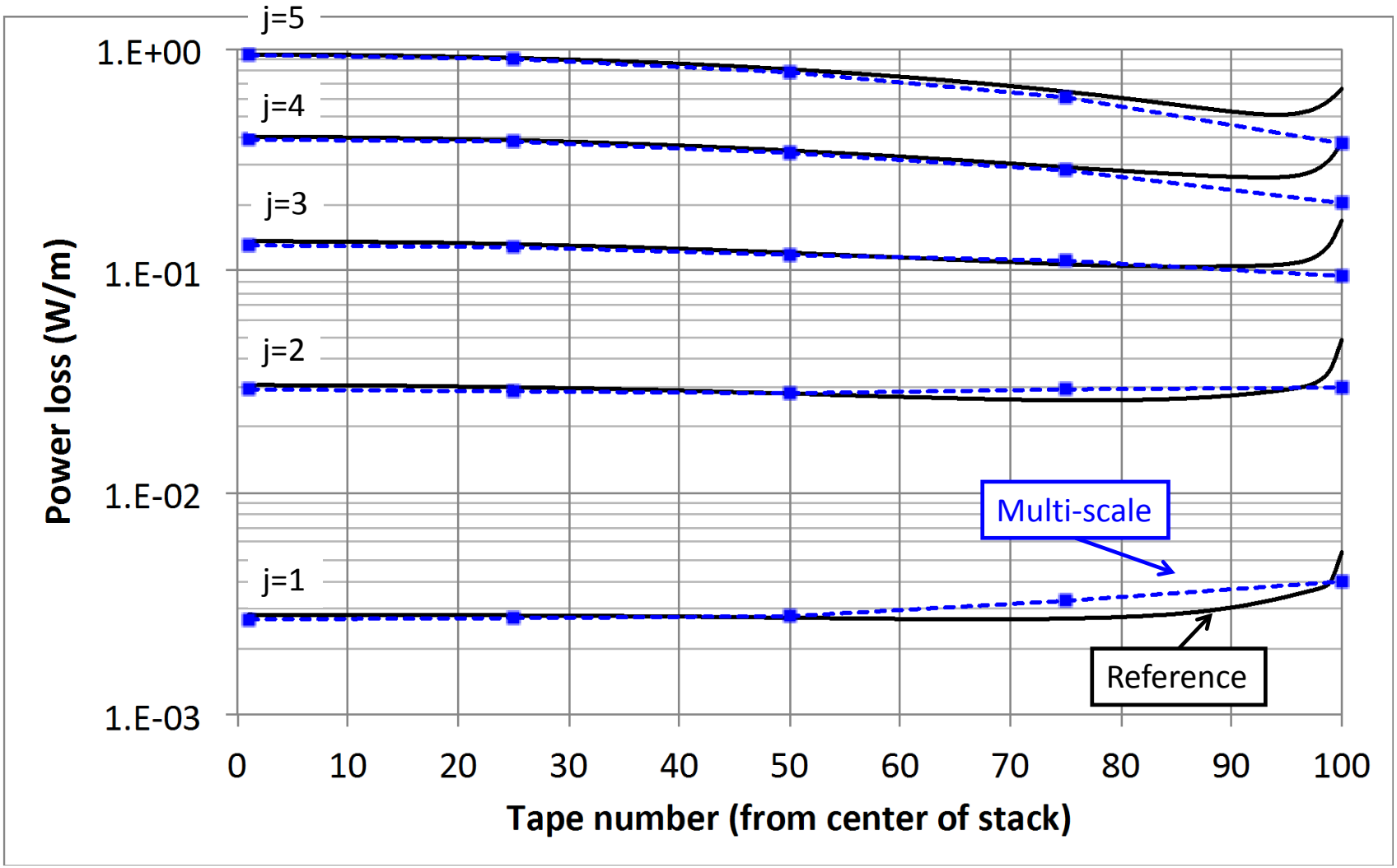


Do we need to simulate all the tapes?



No, we don't!

Using only 25 tapes still gives a good estimate



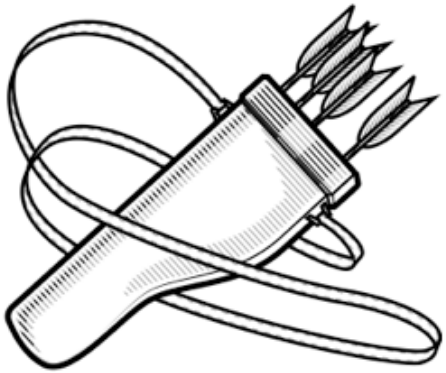
What about the computation time?

Model	Loss value (% of reference)	Computing time (hours)
Reference	100 %	50
Multi-scale (all 500 tapes)	96 %	34*
Multi-scale (25 tapes)	94 %	2.3*

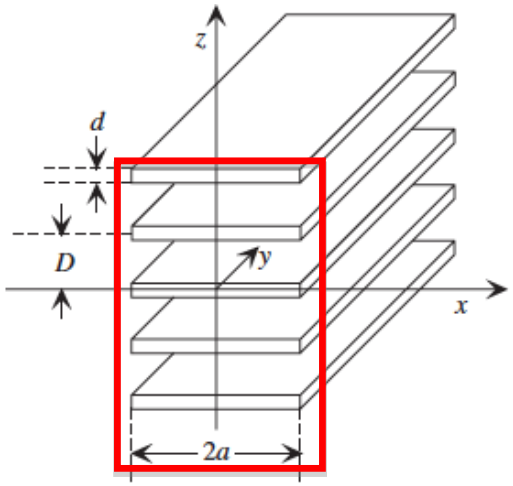
*Speed-up with parallelization:

- With 25 cores (1 core per tape) → 46 minutes
- With 5 cores (e.g. desktop workstation) → 1 hr

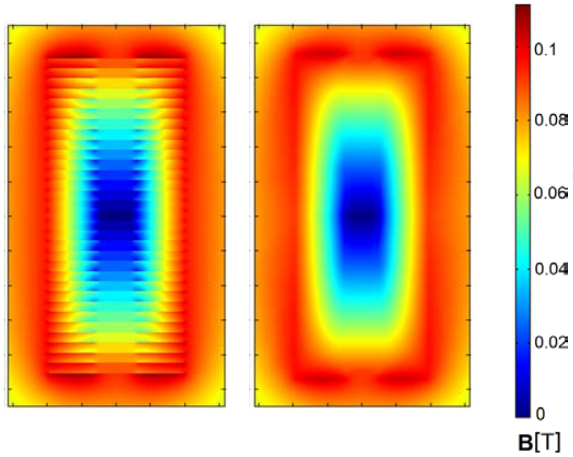
Multi-scale is not the only arrow in our quiver, though!



Modelling HTS stacks with homogenization



Clem et al., SUST **20** (2007) 1130
Yuan et al., SUST **23** (2010) 085011
Prigozhin et al., SUST **24** (2011) 075012

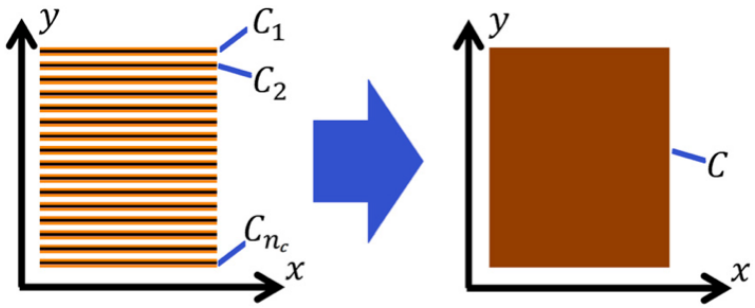


JOURNAL OF APPLIED PHYSICS **114**, 173901 (2013)

Calculation of alternating current losses in stacks and coils made of second generation high temperature superconducting tapes for large scale applications

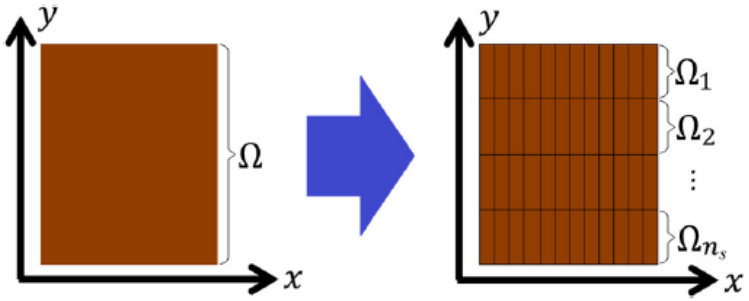
Victor M. R. Zermeno,[1,2,a)] Asger B. Abrahamsen,[3] Nenad Mijatovic,[4] Bogi B. Jensen,[4] and Mads P. Sørensen[2]

Modelling HTS stacks with homogenization



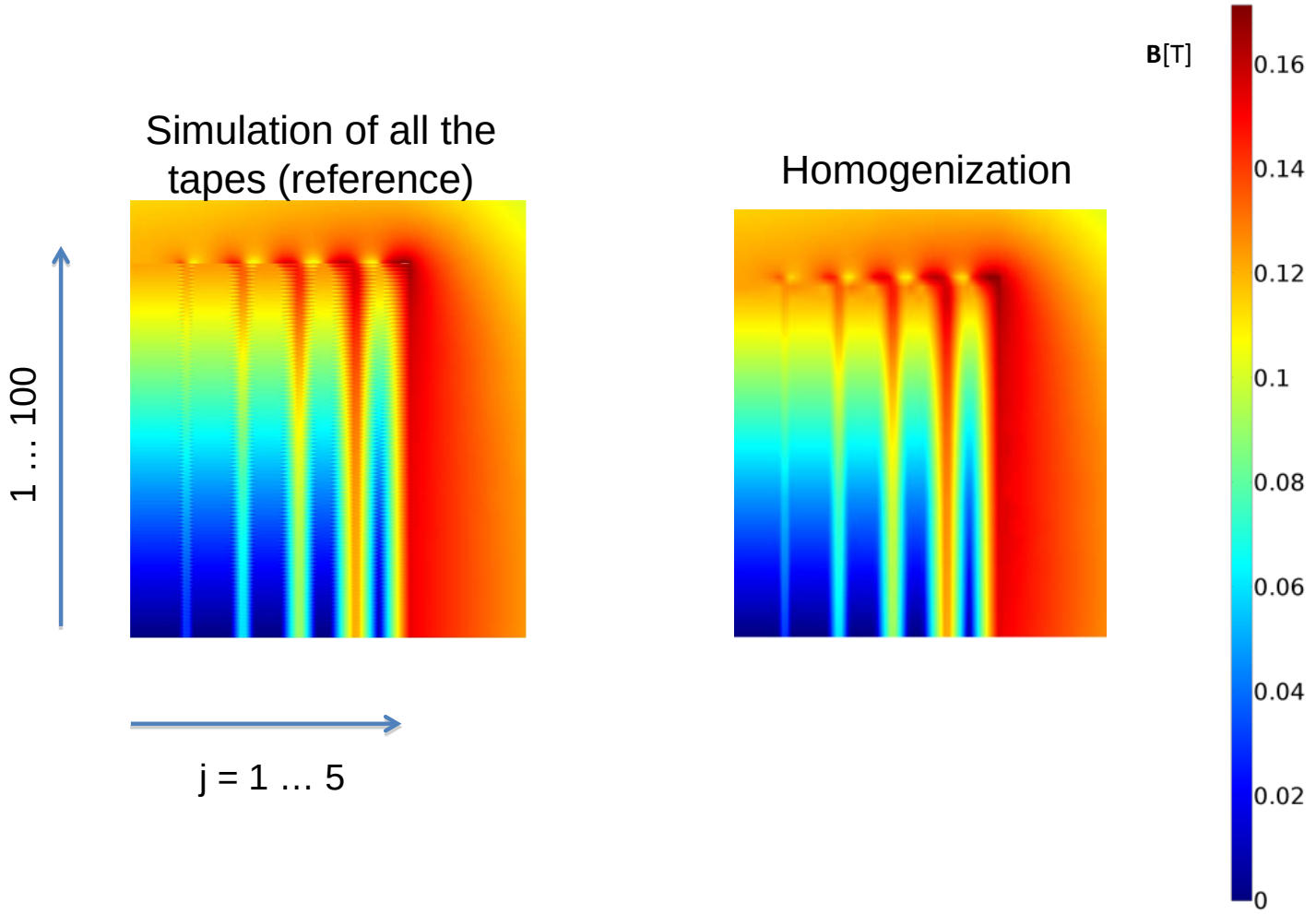
$$K(y,t) = \int_C J(x,y,t)dx$$

The fact that each tape carries the same current (coil) is imposed by means of a current constraint, which is independent of *y*

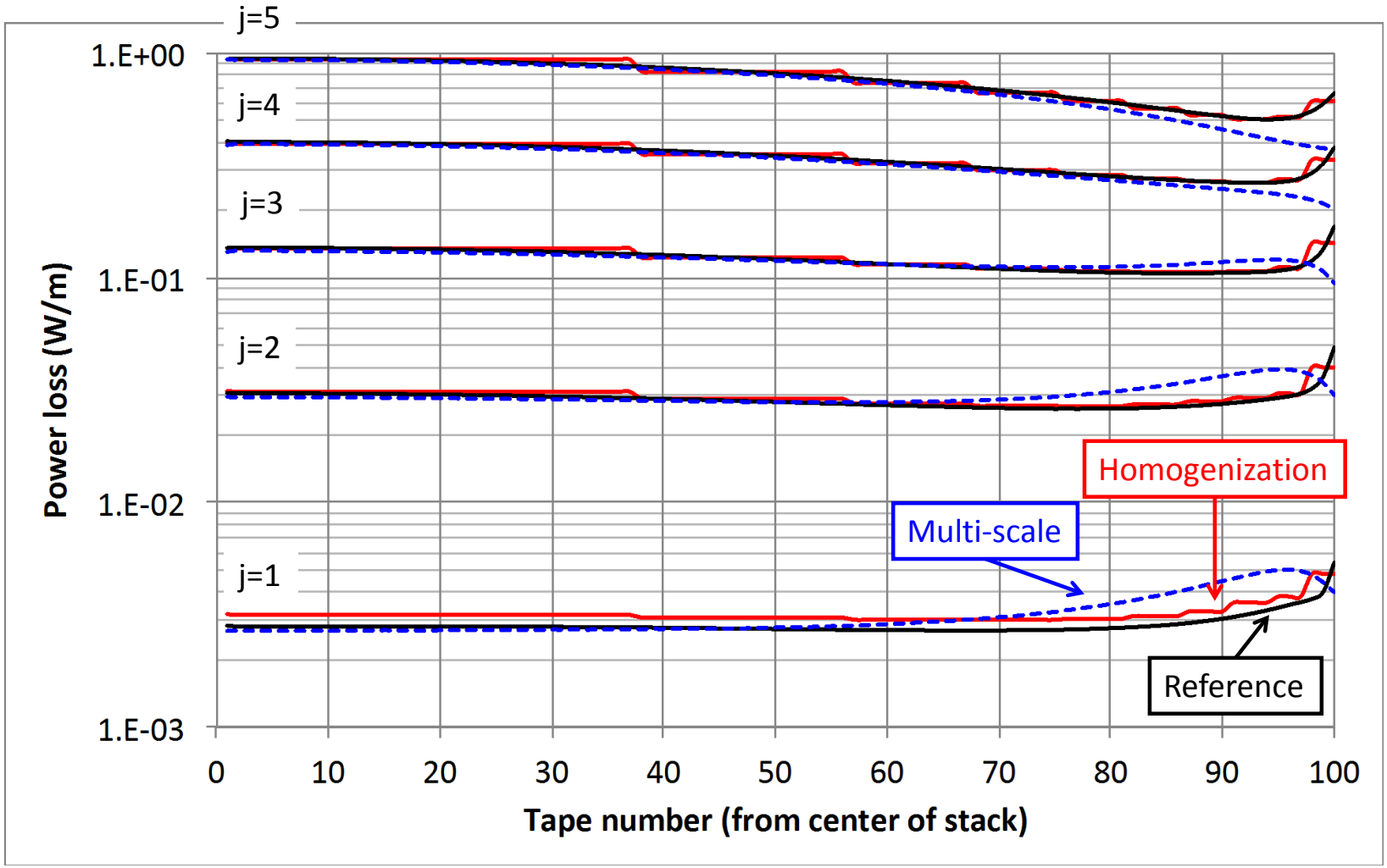


The mesh of the homogenized conductor is coarse
→ Drastic reduction of computation times

The results of the homogenization too are very similar to those obtained by simulating all the tapes.



How does multi-scale compare to homogenization?



What about the computation time?

Model	Loss value (% of reference)	Computing time (hours)
Reference	100 %	50
Multi-scale (all 500 tapes)	96 %	34*
Multi-scale (25 tapes)	94 %	2.3*
Homogenization	100.7 %	0.5

*Speed-up with parallelization:

- With 25 cores (1 core per tape) → 46 minutes
- With 5 cores (e.g. desktop workstation) → 1 hr

Summary

- Two complementary approaches to simulate devices composed of a large number of tapes (turns)
- AC losses within 5% of those calculated simulating the entire device
- 25-100 times faster
- Multi-scale can take full advantage of parallelization
- Homogenization faster, but not always usable