From Surface Equivalence Principle to Modular Domain Decomposition

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T E M F

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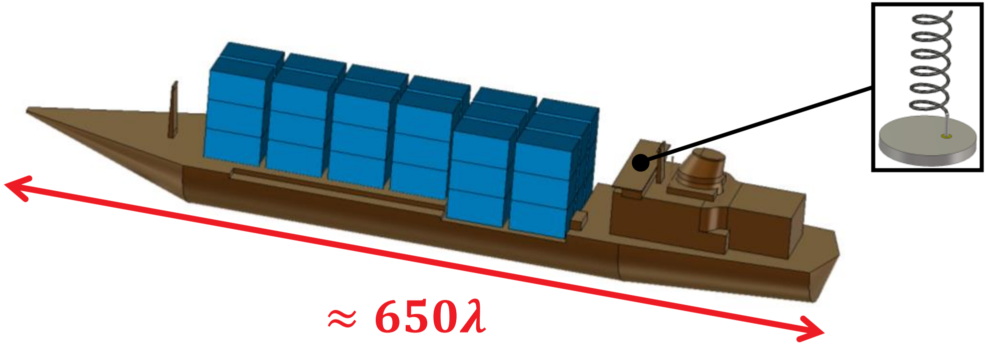
Motivation I

- Challenge: complex/large models
  - Multiple scales
  - Different electromagnetic properties
  - Full set of *MAXWELL*'s equations

$$\nabla \times \vec{E} = -j\omega\vec{B}$$
$$\nabla \times \vec{H} = j\omega\vec{D} + \vec{J}$$
$$\nabla \cdot \vec{D} = \rho$$
$$\nabla \cdot \vec{B} = 0$$



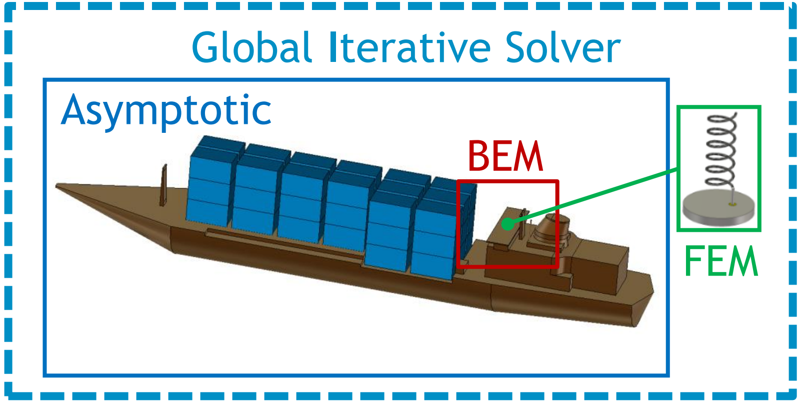
E.g.:
1.5 GHz GPS antenna

$\approx 650\lambda$

$\Rightarrow 10^{12}$ mesh cells (10 lines per wavelength)

Motivation II

- Approach: domain decomposition
  - Tightly coupled subdomains, full system solve necessary
    → global iterative solver
  - Couple existing solvers → modular, black box framework
    → arbitrary solvers
  - Coupling via surface currents
  - Integration in commercial software

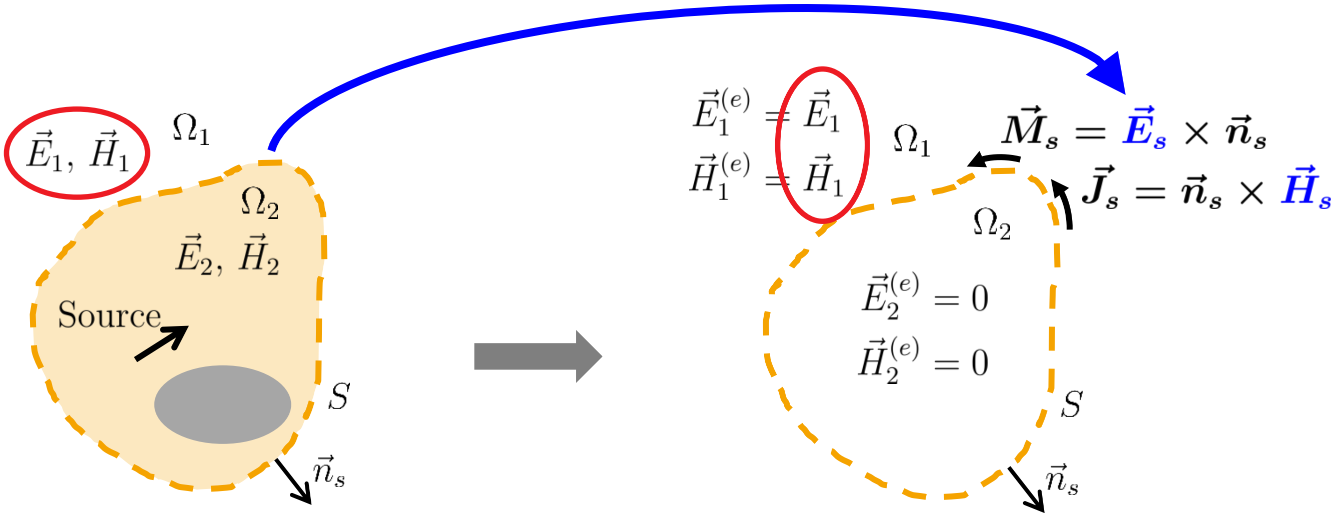


Outline

- Motivation
- Surface Equivalence Principle
- Iterative Domain Decomposition
- First Results
- Conclusion and Outlook

Surface Equivalence Principle I

- Sources and materials enclosed by surface S can be replaced by equivalent surface currents $\vec{J}_s$ and $\vec{M}_s$:

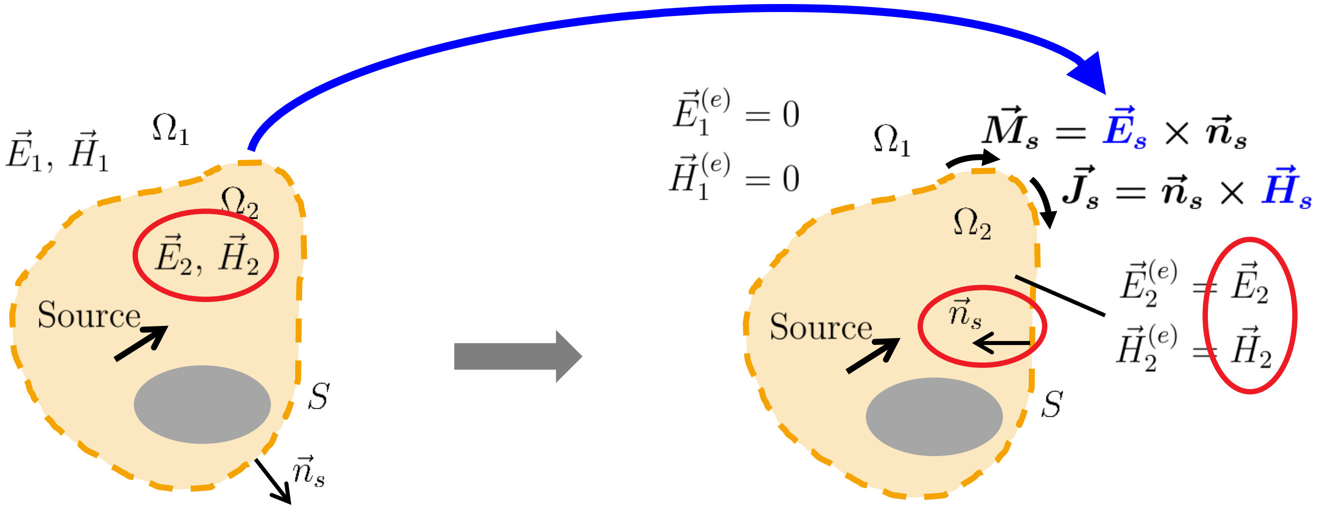


Full model

Equivalent model for outer domain

Surface Equivalence Principle I

- Sources and materials enclosed by surface S can be replaced by equivalent surface currents $\vec{J}_s$ and $\vec{M}_s$:

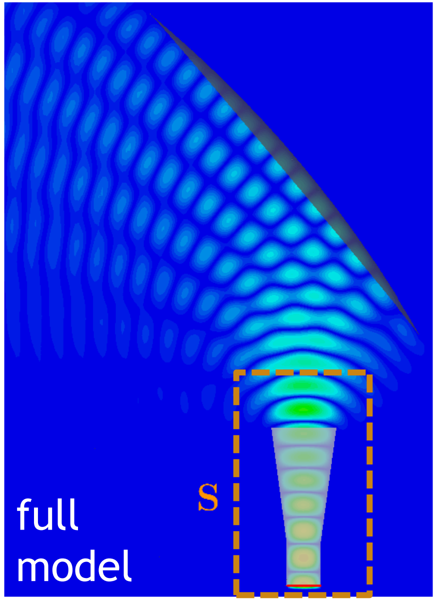


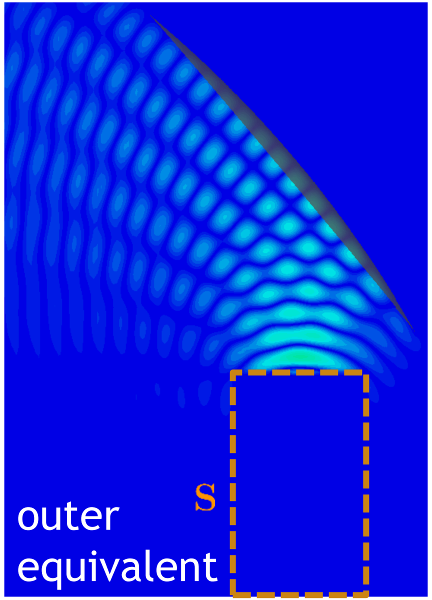
Full model

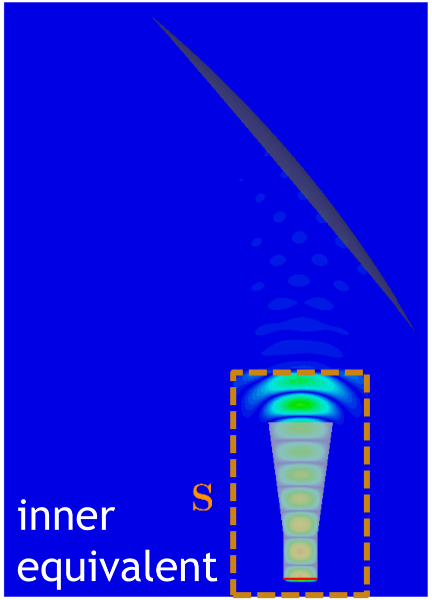
Equivalent model for inner domain

Surface Equivalence Principle I

- Sources and materials enclosed by surface S can be replaced by equivalent surface currents $\vec{J}_s$ and $\vec{M}_s$:







Surface Equivalence Principle II

- Will be utilized for black box DD approach
  - Coupling of subdomains via surface currents
  - Subdomains need to provide surface currents only
  - Resulting in an iterative DD method

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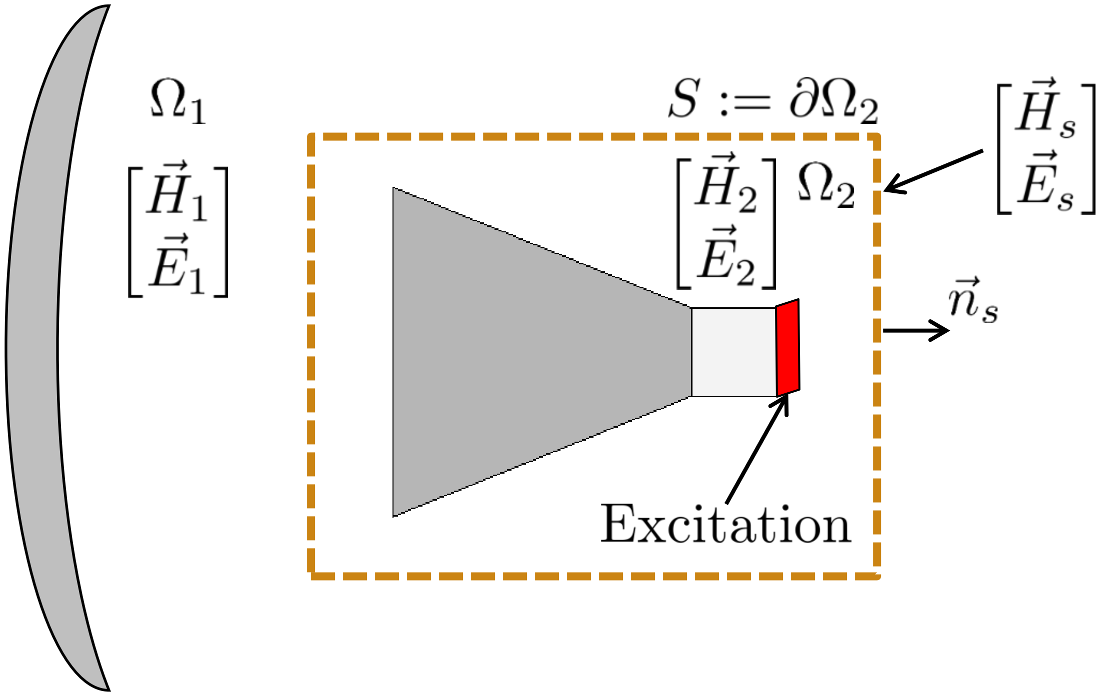
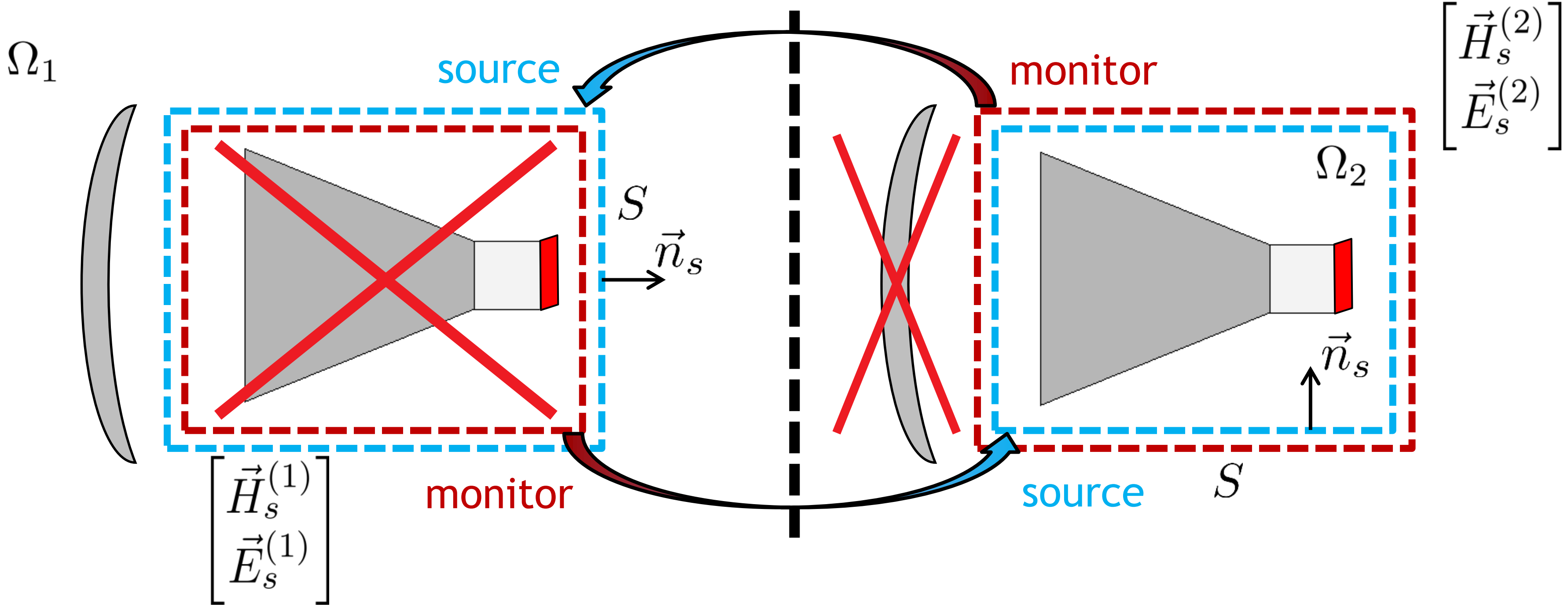
Iterative Domain Decomposition

Typical Coupled System



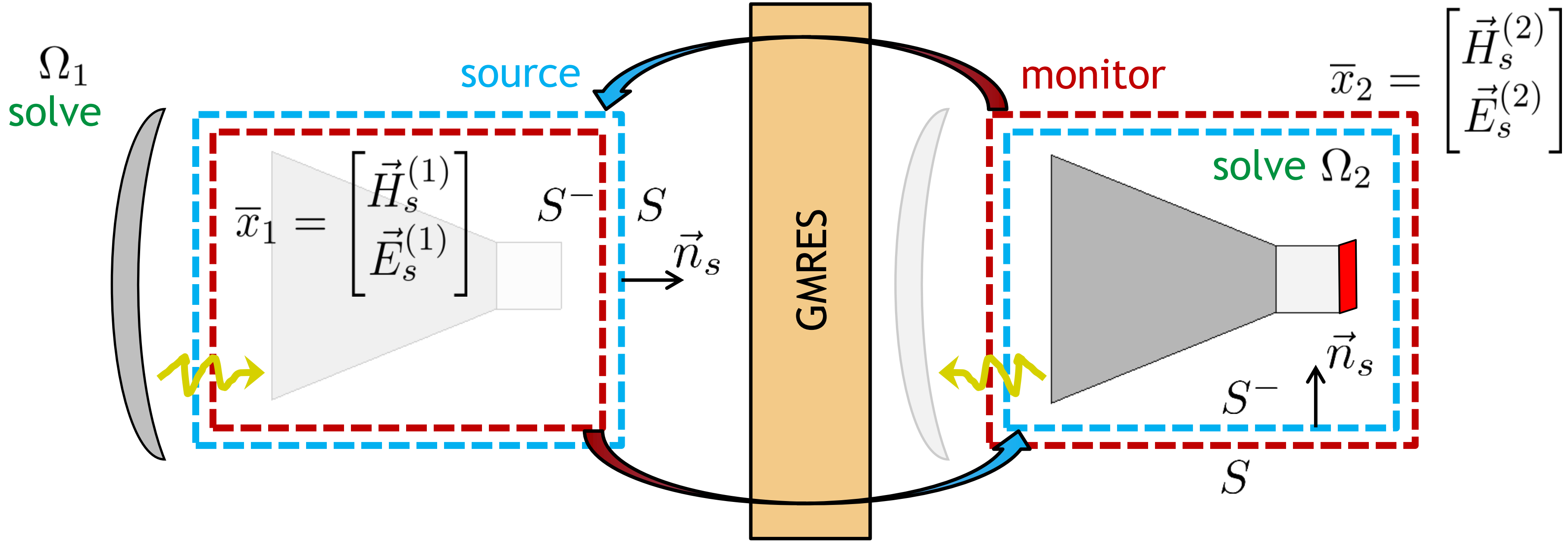
Iterative Domain Decomposition

Coupled System + Surface Equivalence Principle



Iterative Domain Decomposition

Equivalence Principle Motivated Approach



Resulting system solved for surface quantities $\bar{x}_1$ and $\bar{x}_2$, e.g. by fixpoint iteration or accelerated by GMRES

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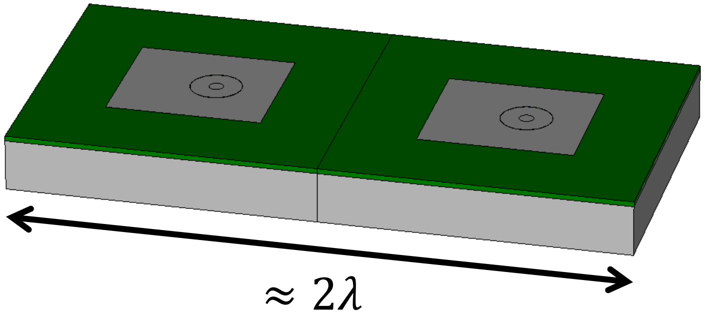
First Results

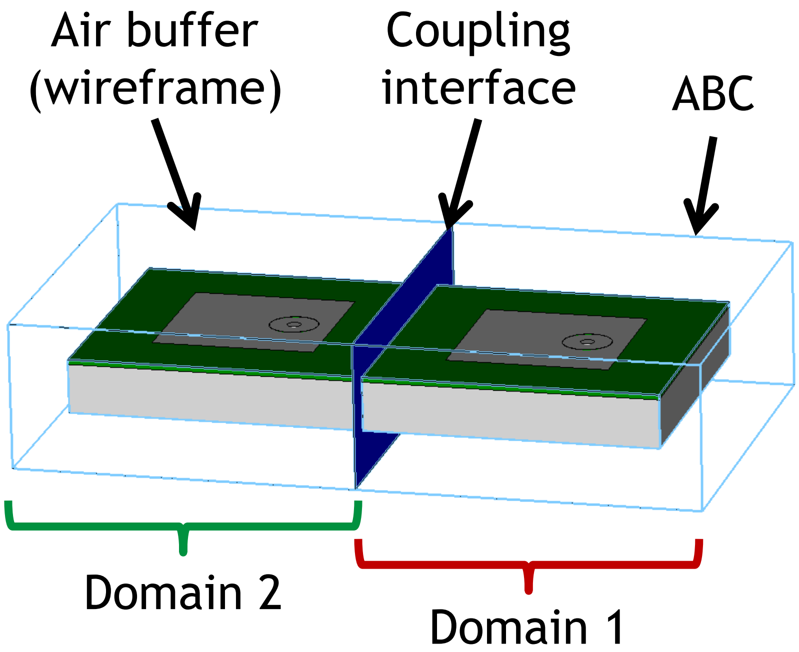
- Area of application of this project
  - Small number of user-defined, coupled subdomains
  - Priority not on scalability, but flexibility
  - E.g. antenna placement

- Model: 1x2 patch antenna array
  - Academic example
  - For investigation purposes

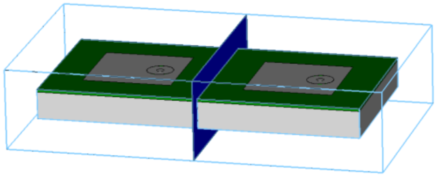


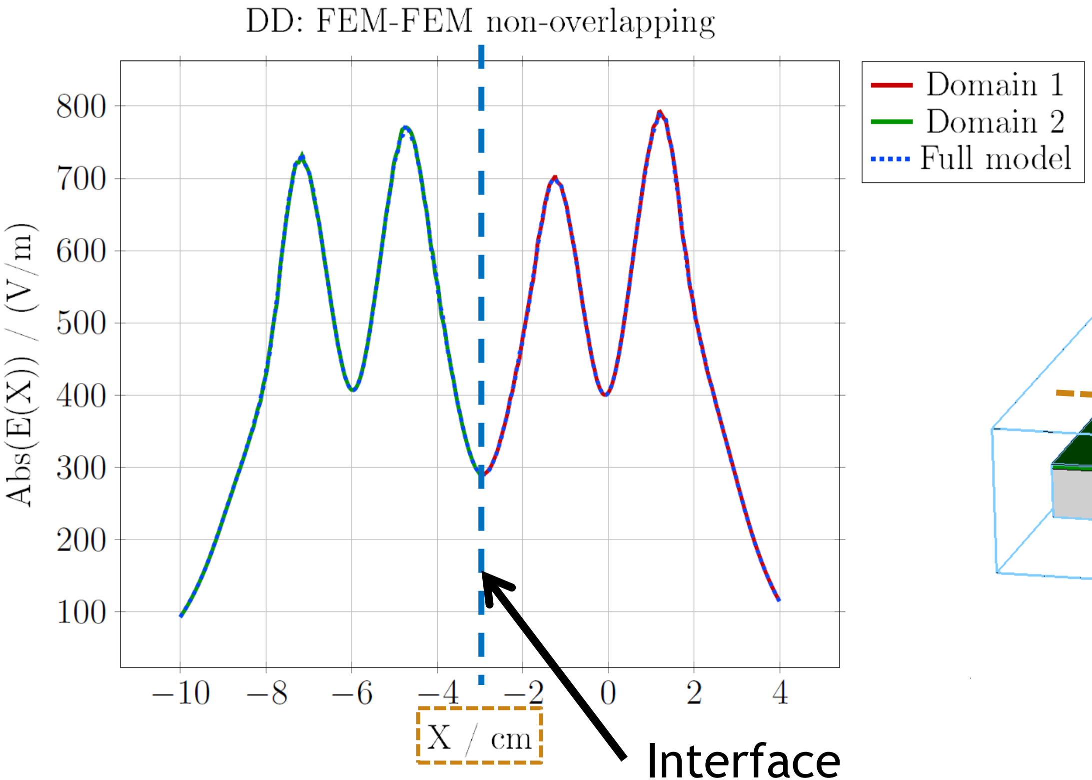
First Results
Setup

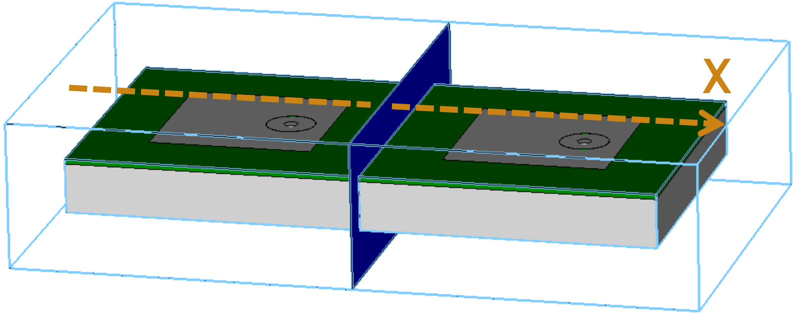
- FEM-FEM coupling
- Non-overlapping subdomains
- **A**bsorbing **B**oundary **C**ondition
- Broadside radiation
- Non-conforming mesh at interface



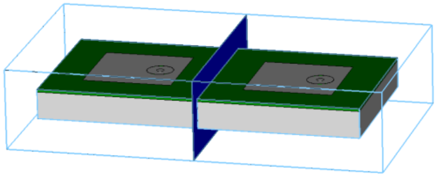
First Results
E-Field on 1D-Curve



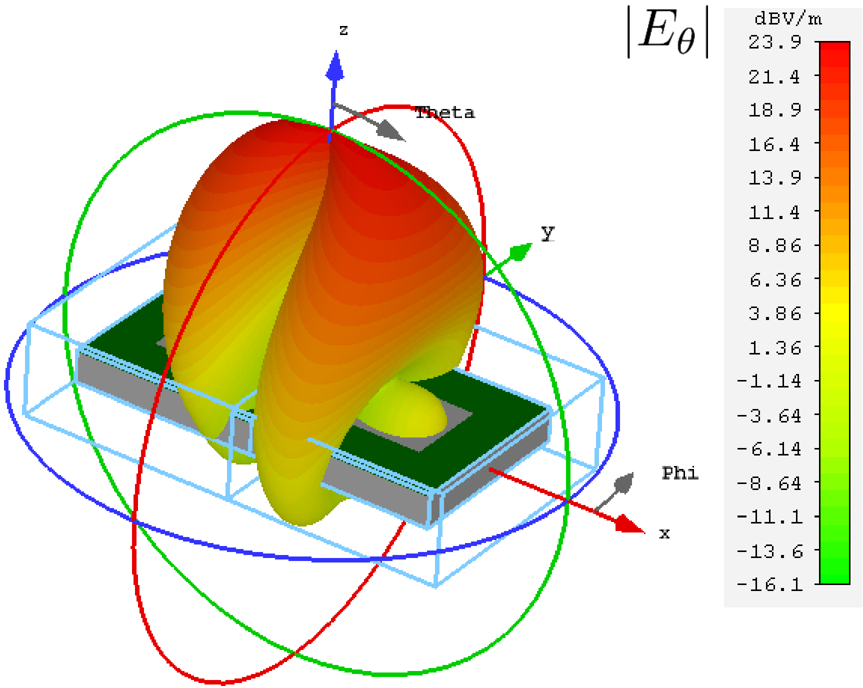




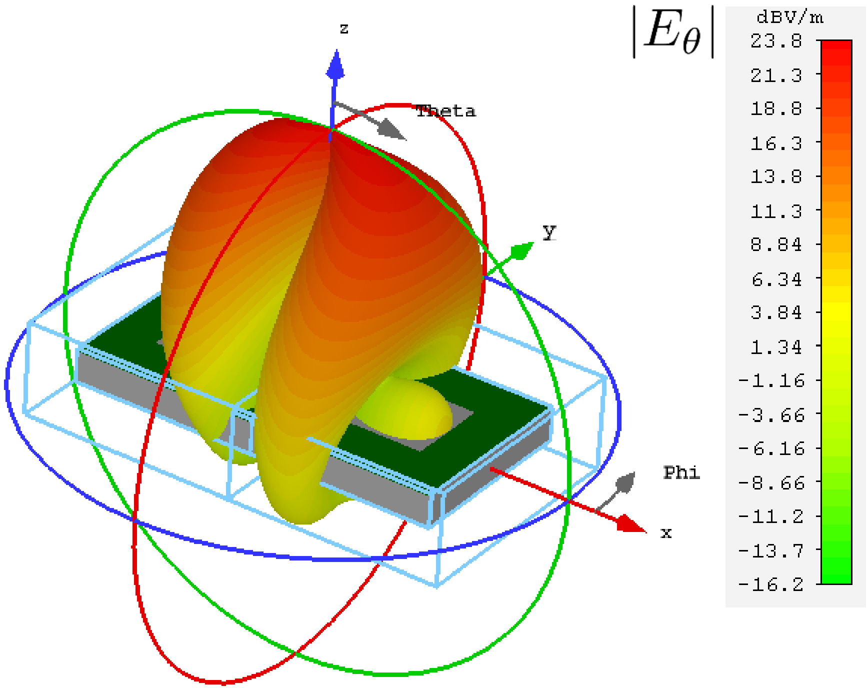
First Results
Far Field



Full model:

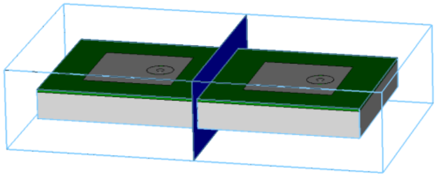


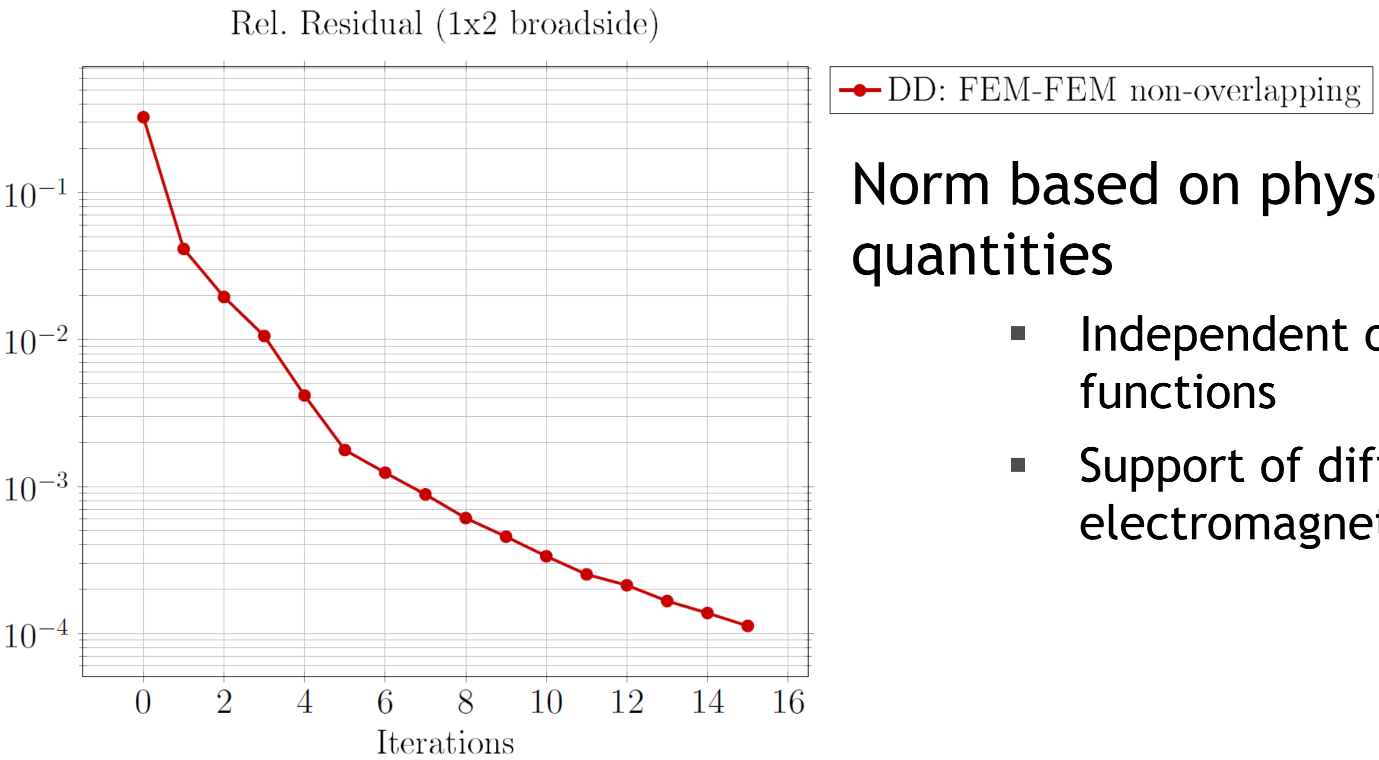
DD approach:



First Results

GMRES Residual Convergence



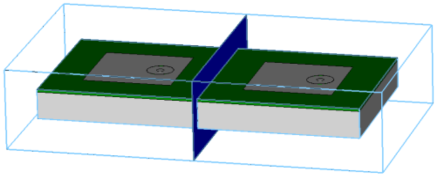


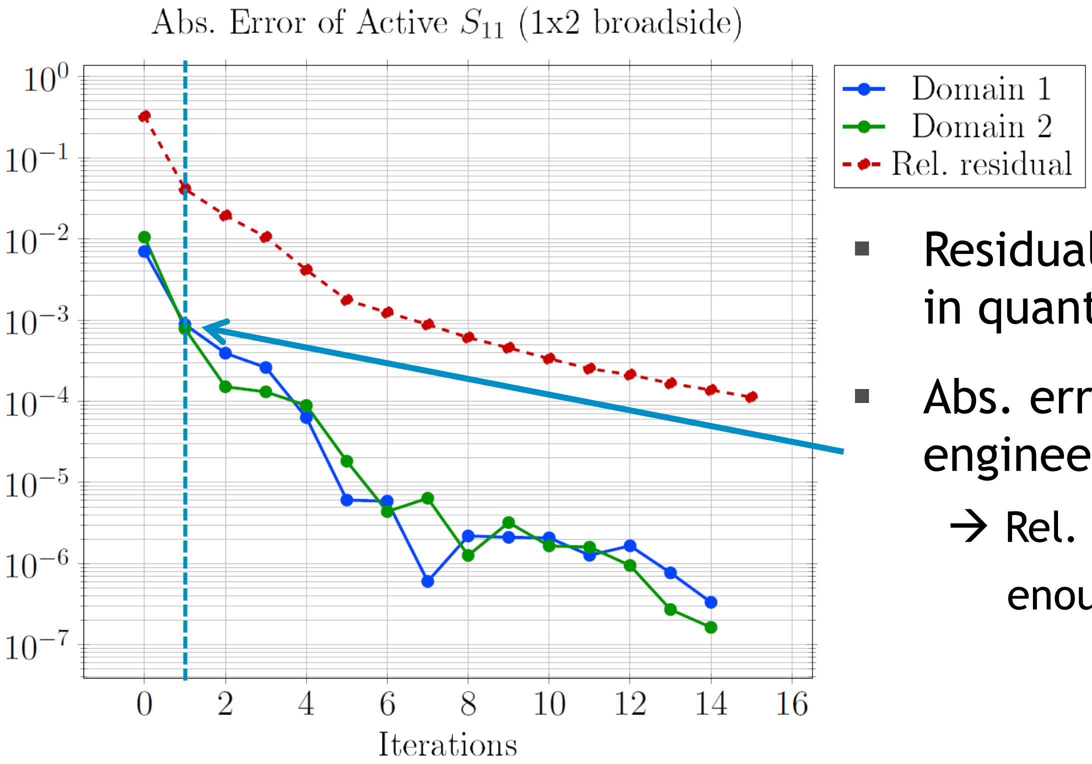
Norm based on physical quantities

- Independent of basis functions
- Support of different types of electromagnetic solvers

First Results

S-Parameter Convergence



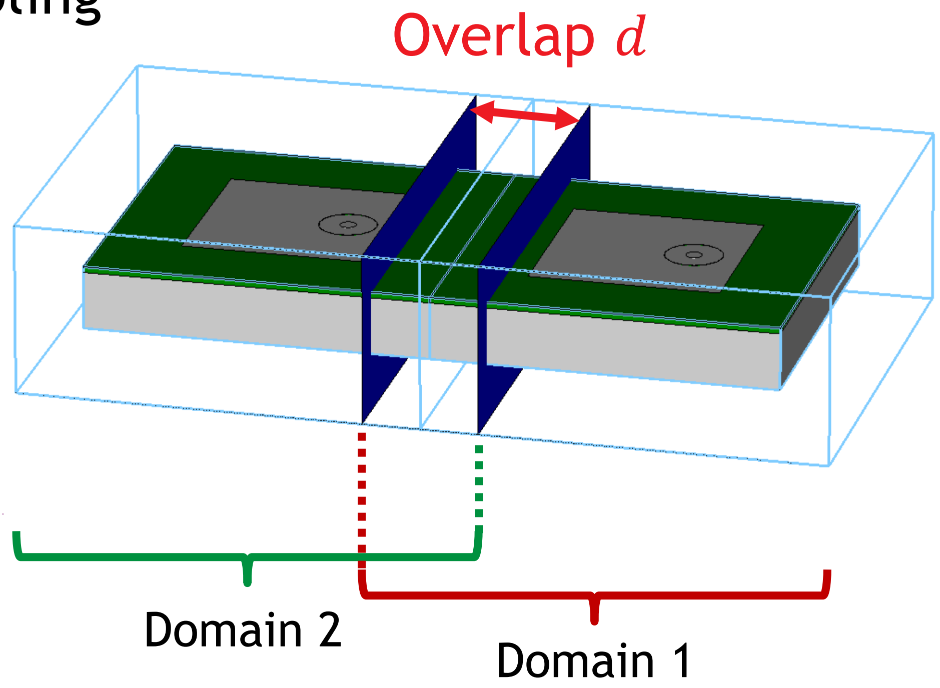


- Residual in surface quantities ↔ errors in quantities of interest?
- Abs. error < 10^{-3} sufficient for typical engineering applications
  → Rel. residual < $4 \cdot 10^{-2}$ already enough!?

First Results

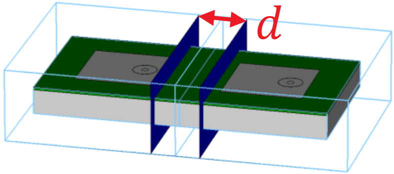
Overlap Parameter Study I

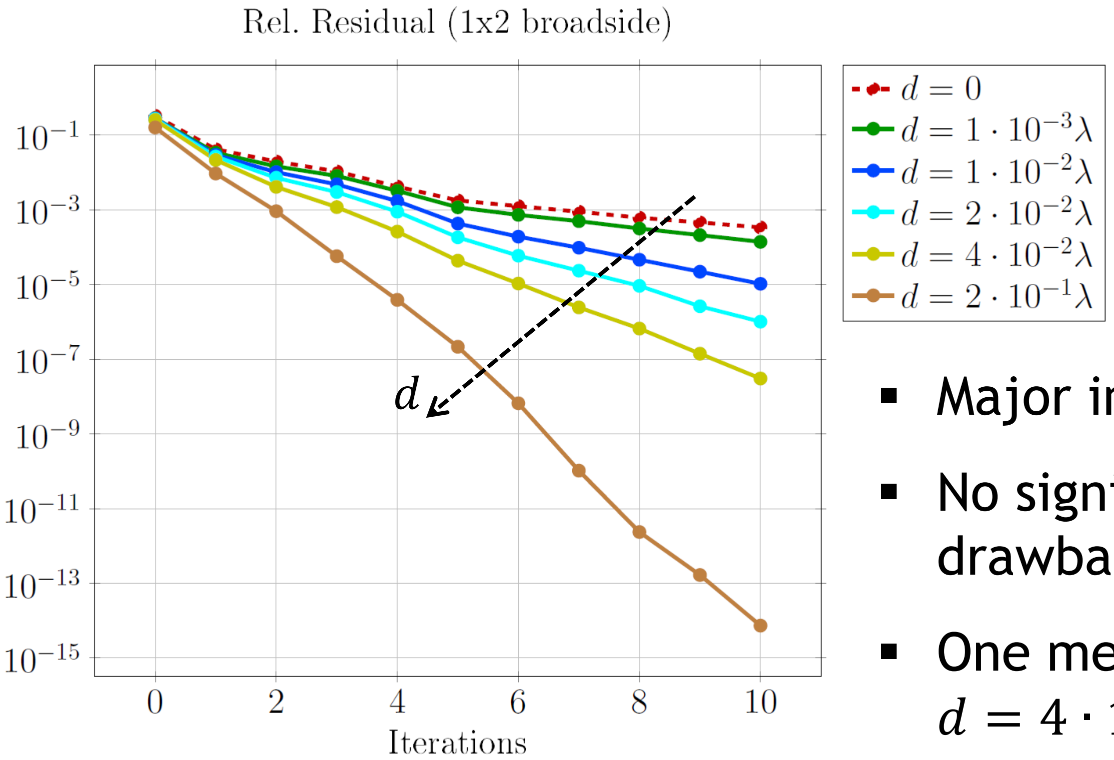
- DD approach features high flexibility in defining coupling surfaces
- Overlaps can be easily introduced



First Results

Overlap Parameter Study II





- Major improvement in convergence
- No significant performance drawback!
- One mesh cell layer overlap: $d = 4 \cdot 10^{-2}\lambda$

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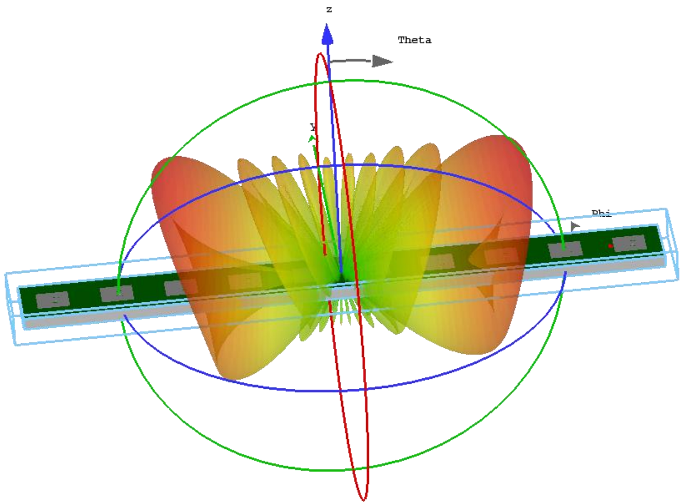
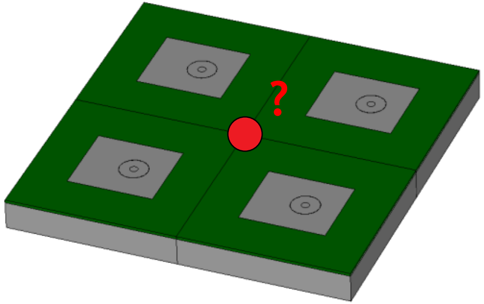
Conclusion

- DD approach suitable for large and complex setups
- Modular, black box framework → arbitrary solvers
- Equivalence principle motivated coupling via surface currents
- High flexibility in defining coupling surfaces
- Promising first results, accelerated convergence due to introduced overlap

Outlook

- Proper definition of the norm
- Residual ↔ errors in the quantities of interest
- Dependency of convergence on coupling strength of subdomains
- Treatment of cross-points





Thank You For Your Attention!

Any Questions?