Guide to Electromagnetic Compatibility Analysis Using Simulation (EMC)

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Schedule

1. Motivation: EMC/EMI problem
2. Electromagnetic fields in COMSOL Multiphysics
3. Inductive and capacitive phenomena
    - DEMO: Electromagnetic shielding tutorial
4. Wave radiation
    - DEMO: EMC/EMI of a circuit board

EMC/EMI Testing

- Electromagnetic compliance and interference testing is an integral part of device R&D process
- In critical components, the EMC/EMI is as important as the device primary function performance
  - Aerospace
  - Automotive
  - Biomedical devices
- Required for regulatory processes

A spacecraft undergoes EMC/EMI testing. Image by ESA-G Porter

Why Electromagnetic Shielding?

- Protect human life and ensure operation of technical systems?
- Reduce unwanted emission of EM fields
- Reduce susceptibility to interference
- Reduce fields to prevent breakdowns

Faraday cage made up of wires at the Sphinx Observatory in Switzerland

What Is Shielded?

- Power cables
- Transformers
- Medical and Lab devices like MRI
- Comm systems
- Superconducting circuits
- Passengers in aircraft
- Hard drives
- Microwave ovens
- Earth

Faraday cage made up of wires at the Sphinx Observatory in Switzerland

Types of Shielding

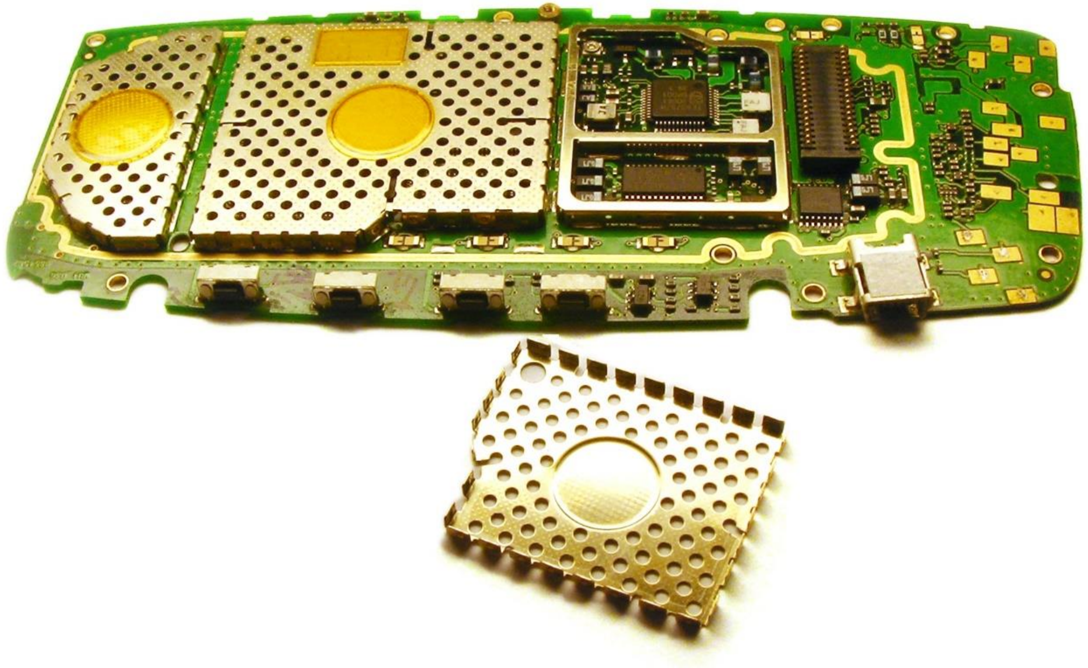
- Basic types of shielding in power systems
  - Electrostatic shielding (Faraday’s cage)
  - Magnetostatic shielding
  - Electromagnetic (inductive) shielding
- Other types of shielding
  - Frequency selective surfaces
  - Cloaking devices
  - Dielectric mirrors
  - Antireflective coatings

MRI RF shielding

Typical Shielding Materials

- Metal foils
- Metal screens
- Metal foams
- Metallic or semiconductive paints
- Mu-metal
- Permalloy

- **What they have in common?**

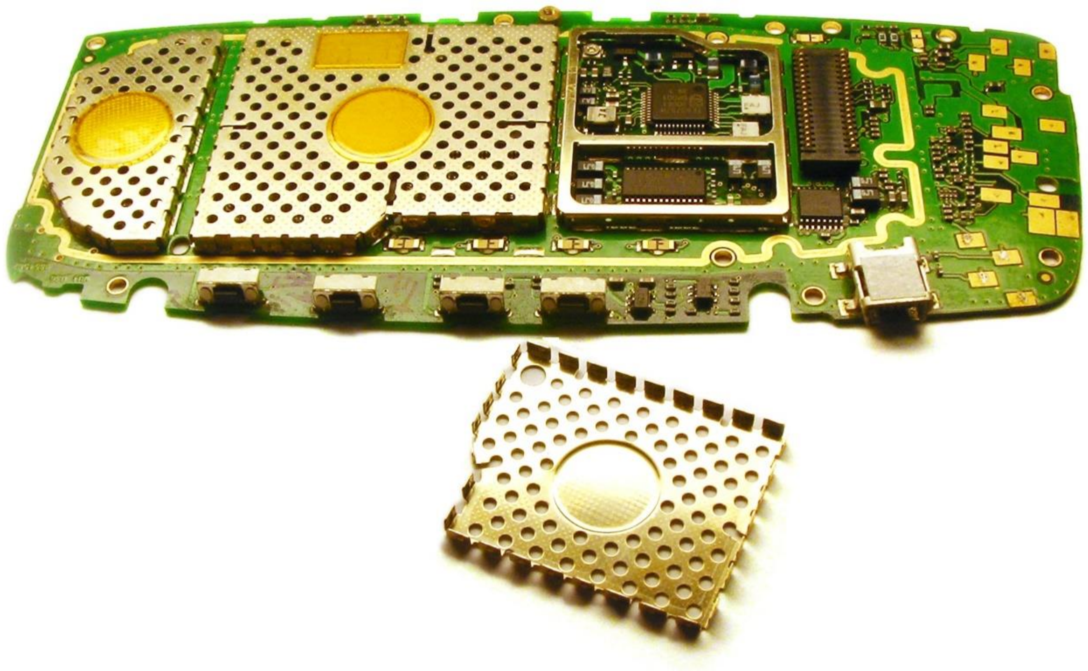


Electromagnetic shielding cages inside a disassembled mobile phone

Typical Shielding Materials

- Metal foils
- Metal screens
- Metal foams
- Metallic or semiconductive paints
- Mu-metal
- Permalloy

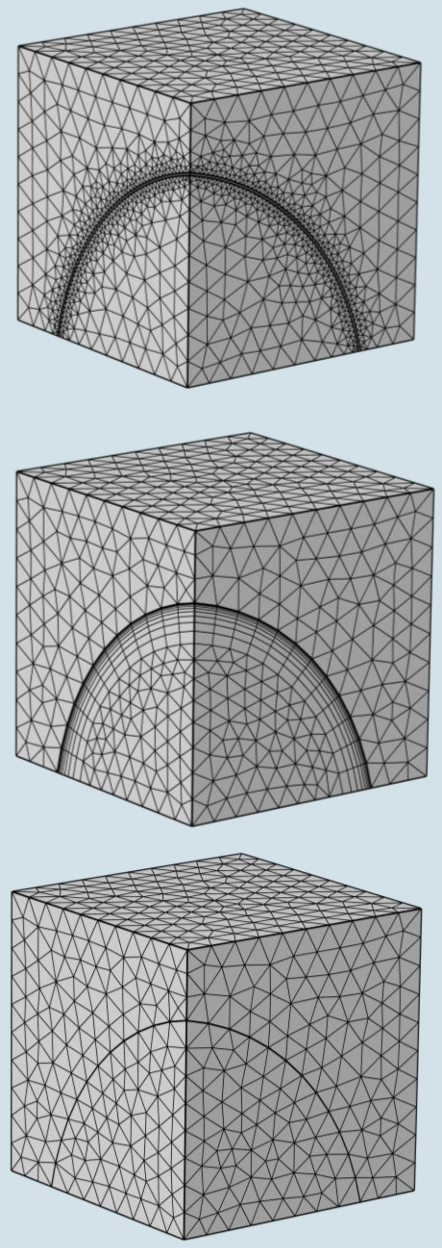
- **What they have in common?**
  - Thin layer coating a several orders larger area

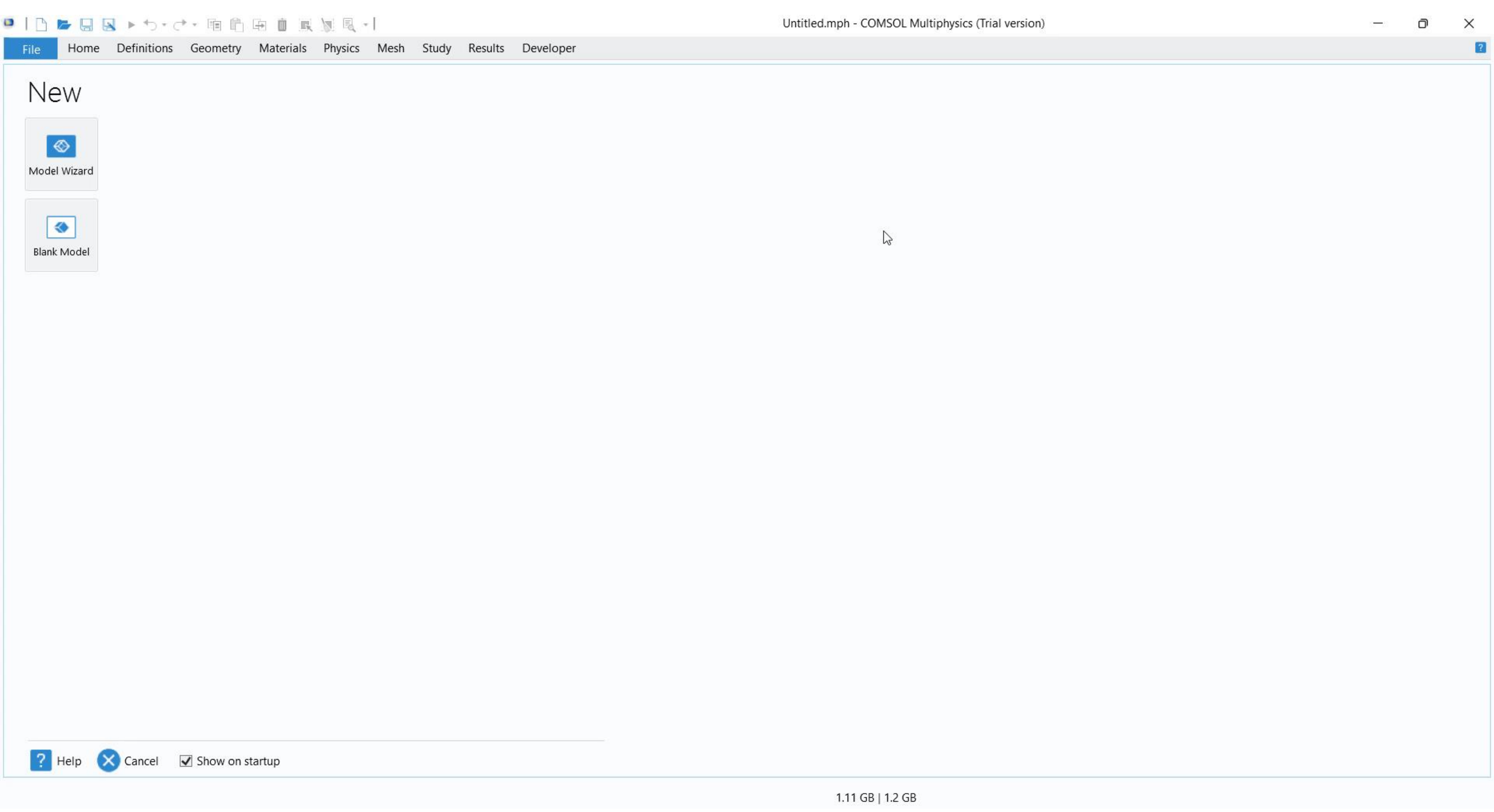


Electromagnetic shielding cages inside a disassembled mobile phone

Thin Layer Modelling in COMSOL

- Domain-based modelling
  - Swept and Boundary Layer mesh operations
- Impenetrable boundary conditions
  - Perfect Electric Conductor/Floating Potential
  - Electric/Magnetic Insulation
- Penetrable boundary conditions
  - Electric/Dielectric/Magnetic Shielding
  - Thin Low Permittivity/Permeability Gap
  - (Layered) Transition Boundary Condition
  - Contact Impedance

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Show on startup
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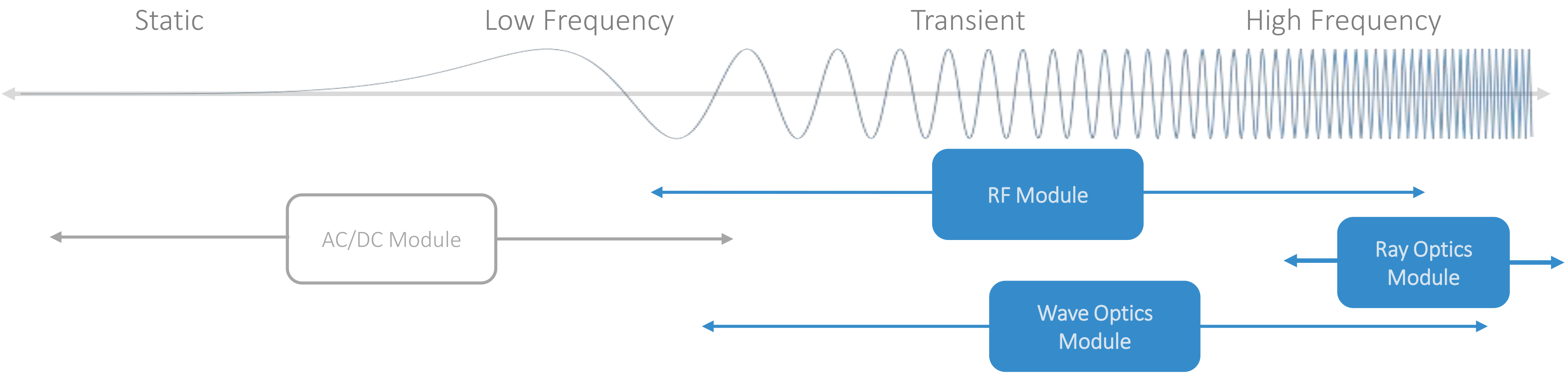
Electromagnetic Fields in COMSOL Multiphysics



$$\frac{\partial \mathbf{E}}{\partial t} = 0$$

Electric and magnetic fields do not vary in time.

$$\mathbf{E}\sin(\omega t)$$

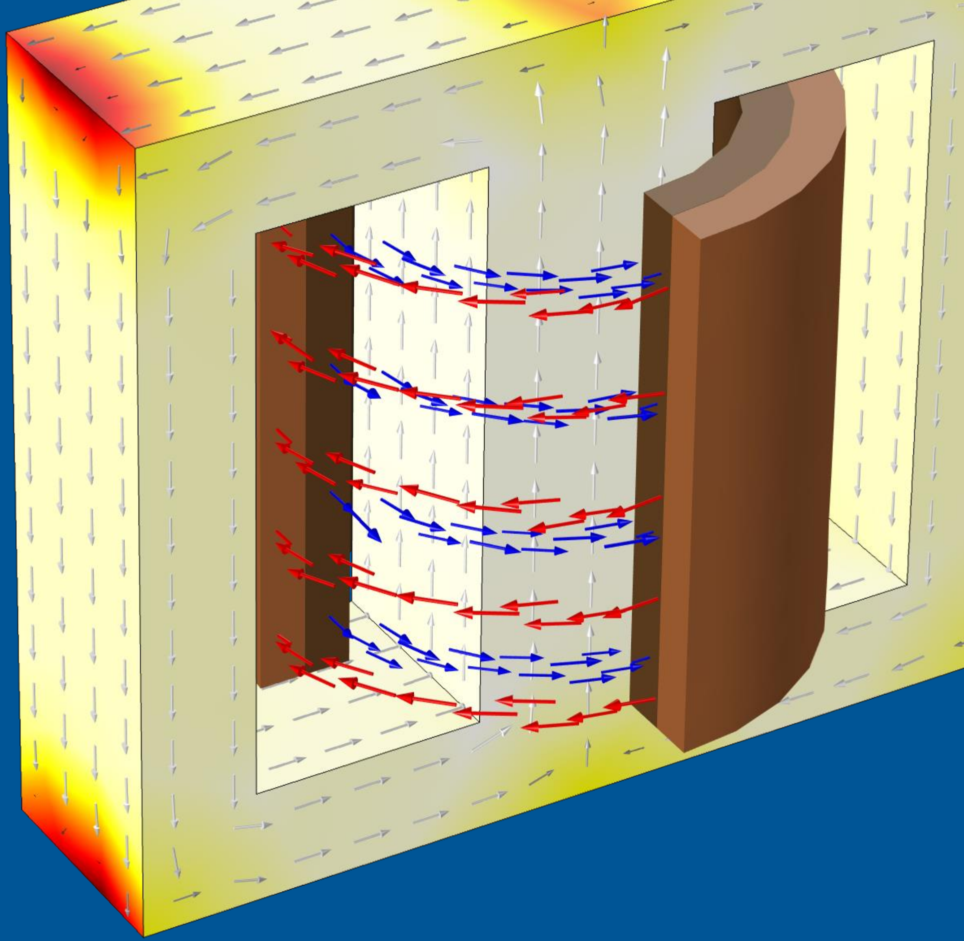
Fields vary sinusoidally in time, but there is negligible radiation.

$$\mathbf{E}(t)$$

Fields vary arbitrarily in time; radiation may or may not be significant. Objects can be moving.

$$\mathbf{E}\sin(\omega t)$$

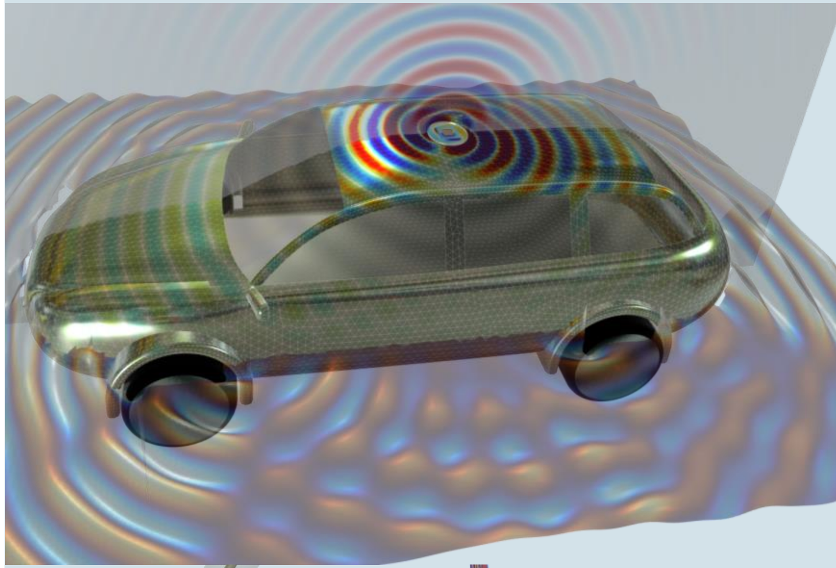
Fields vary sinusoidally in time; energy transfer is via radiation.

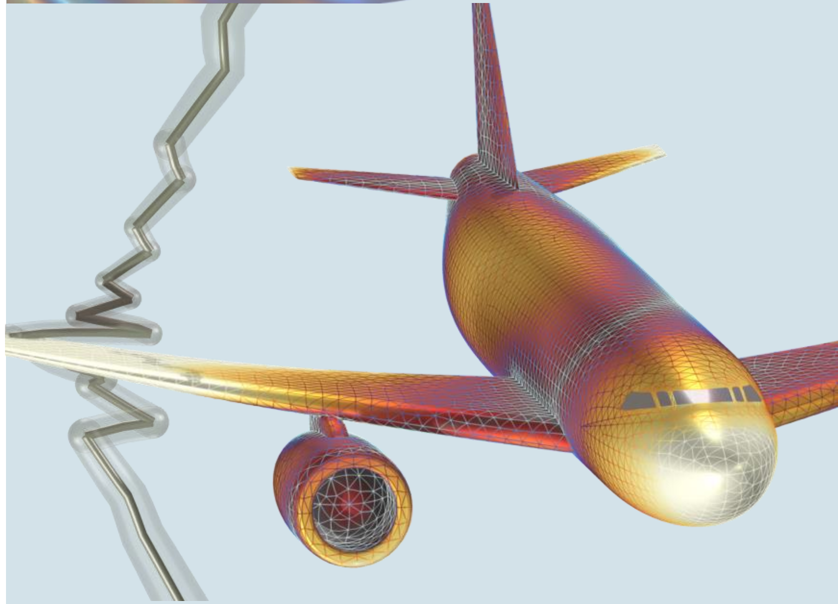


Low Frequency Fields:
Inductive and Capacitive Effects

Electrostatic Shielding: Faraday's Cage

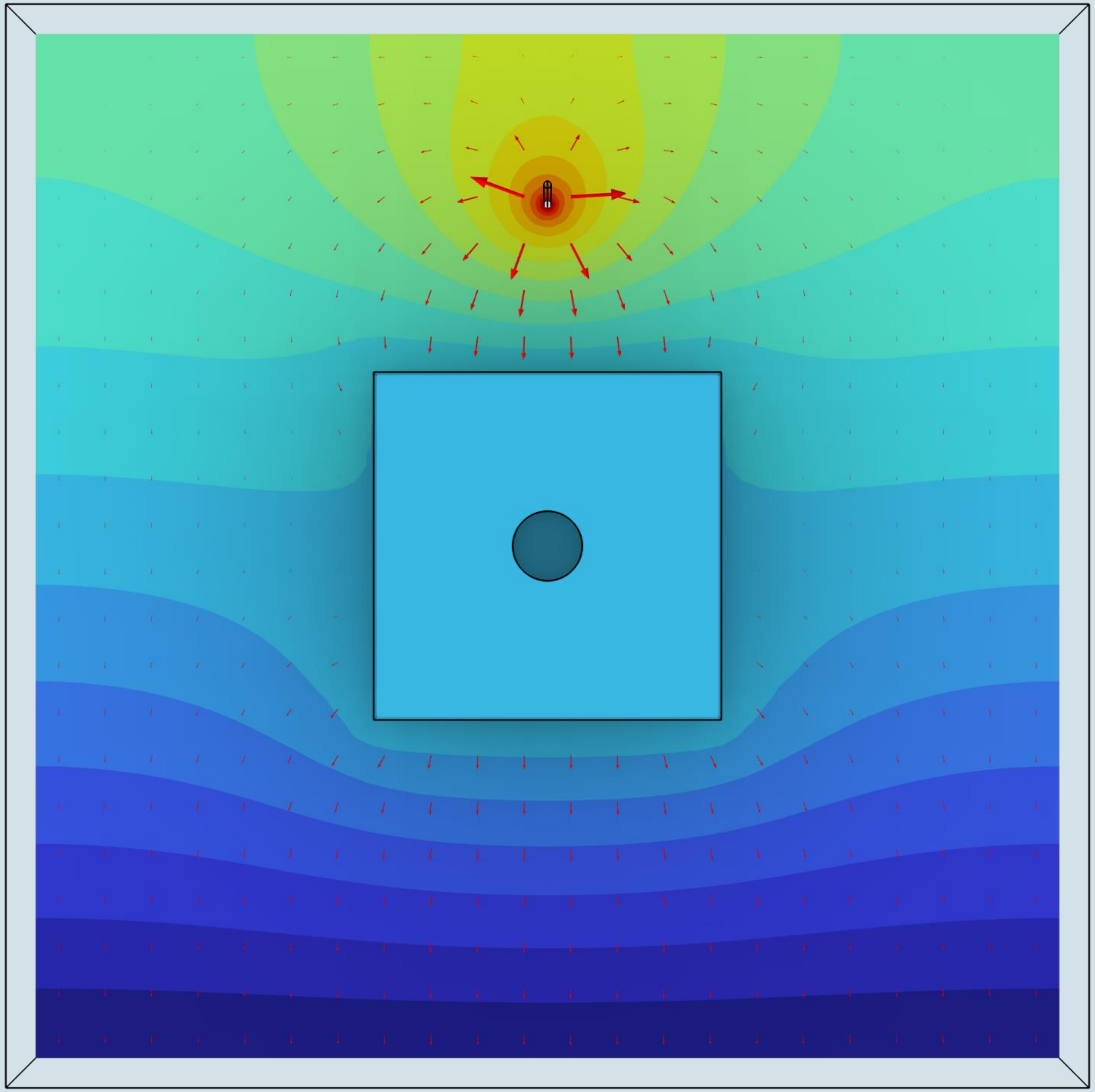
- External electric field influences surface charges, creating a compensating field
- Perfectly conducting materials can be simulated by Floating Potential boundary condition
- Highly conducting materials can be simulated by Electric Shielding boundary condition
- Highly resistive materials can be modeled with the Contact Impedance boundary condition

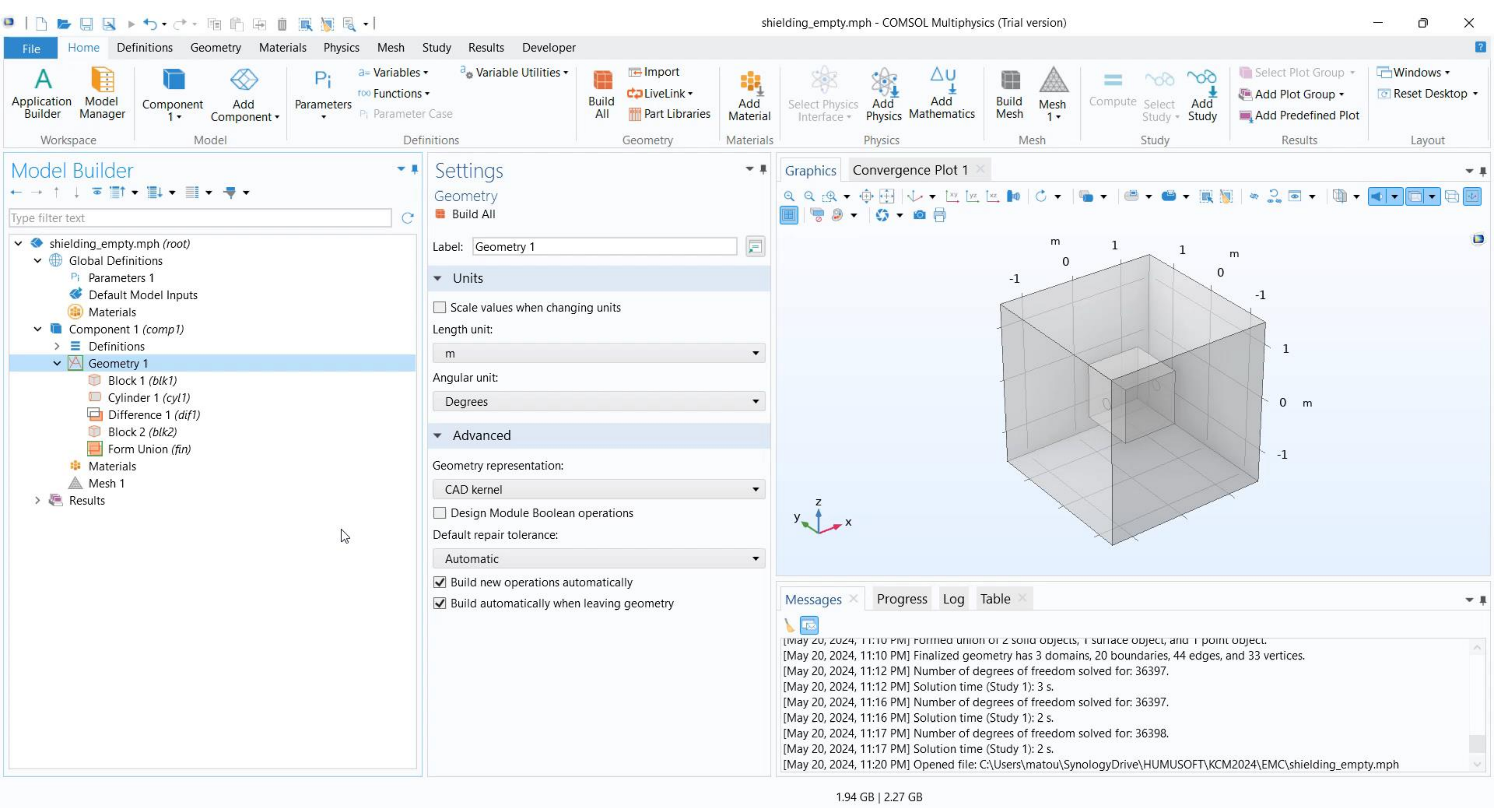




DEMO:
Electrostatic Shielding

- Shielding the box interior from 1 [kV] static potential
- (Im)penetrable boundary condition
  - Floating potential vs Electric shielding

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Application Builder
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Component 1
Add Component
Model
Parameters
Variables
Functions
Parameter Case
Variable Utilities
Definitions
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Add Physics
Add Mathematics
Physics
Build Mesh
Mesh 1
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Add Study
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Add Plot Group
Add Predefined Plot
Results
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Reset Desktop
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Global Definitions
Parameters 1
Default Model Inputs
Materials
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Block 1 (blk1)
Cylinder 1 (cyl1)
Difference 1 (dif1)
Block 2 (blk2)
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Label: Geometry 1
Units
Scale values when changing units
Length unit:
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Angular unit:
Degrees
Advanced
Geometry representation:
CAD kernel
Design Module Boolean operations
Default repair tolerance:
Automatic
Build new operations automatically
Build automatically when leaving geometry
Graphics
Convergence Plot 1
Messages
Progress
Log
Table
[May 20, 2024, 11:10 PM] Formed union of 2 solid objects, 1 surface object, and 1 point object.
[May 20, 2024, 11:10 PM] Finalized geometry has 3 domains, 20 boundaries, 44 edges, and 33 vertices.
[May 20, 2024, 11:12 PM] Number of degrees of freedom solved for: 36397.
[May 20, 2024, 11:12 PM] Solution time (Study 1): 3 s.
[May 20, 2024, 11:16 PM] Number of degrees of freedom solved for: 36397.
[May 20, 2024, 11:16 PM] Solution time (Study 1): 2 s.
[May 20, 2024, 11:17 PM] Number of degrees of freedom solved for: 36398.
[May 20, 2024, 11:17 PM] Solution time (Study 1): 2 s.
[May 20, 2024, 11:20 PM] Opened file: C:\Users\matou\SynologyDrive\HUMUSOFT\KCM2024\EMC\shielding_empty.mph
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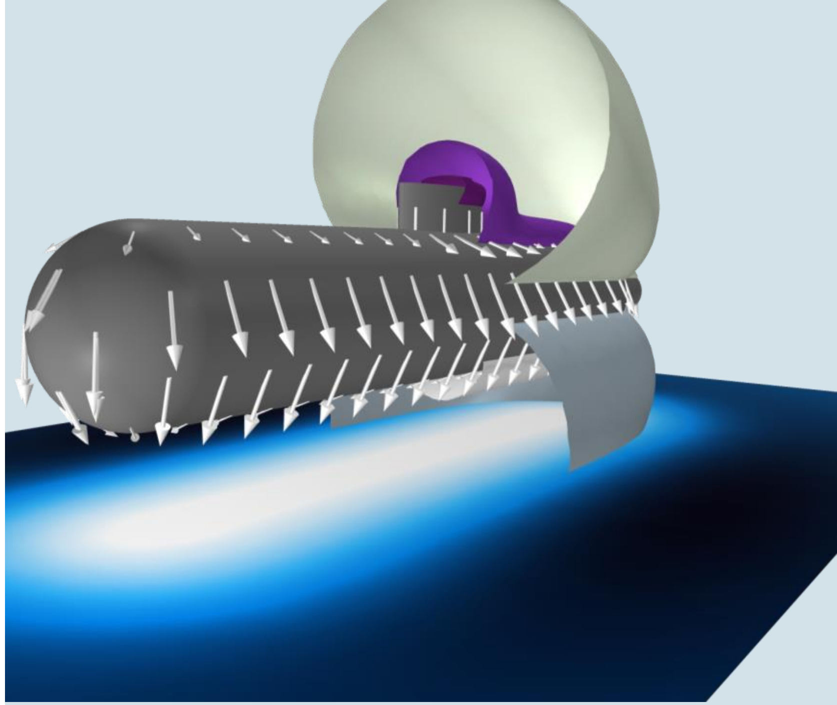
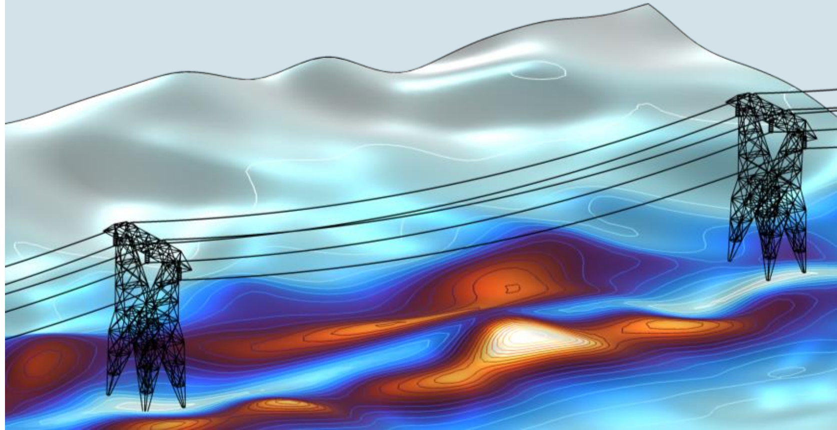
Magnetostatic Shielding

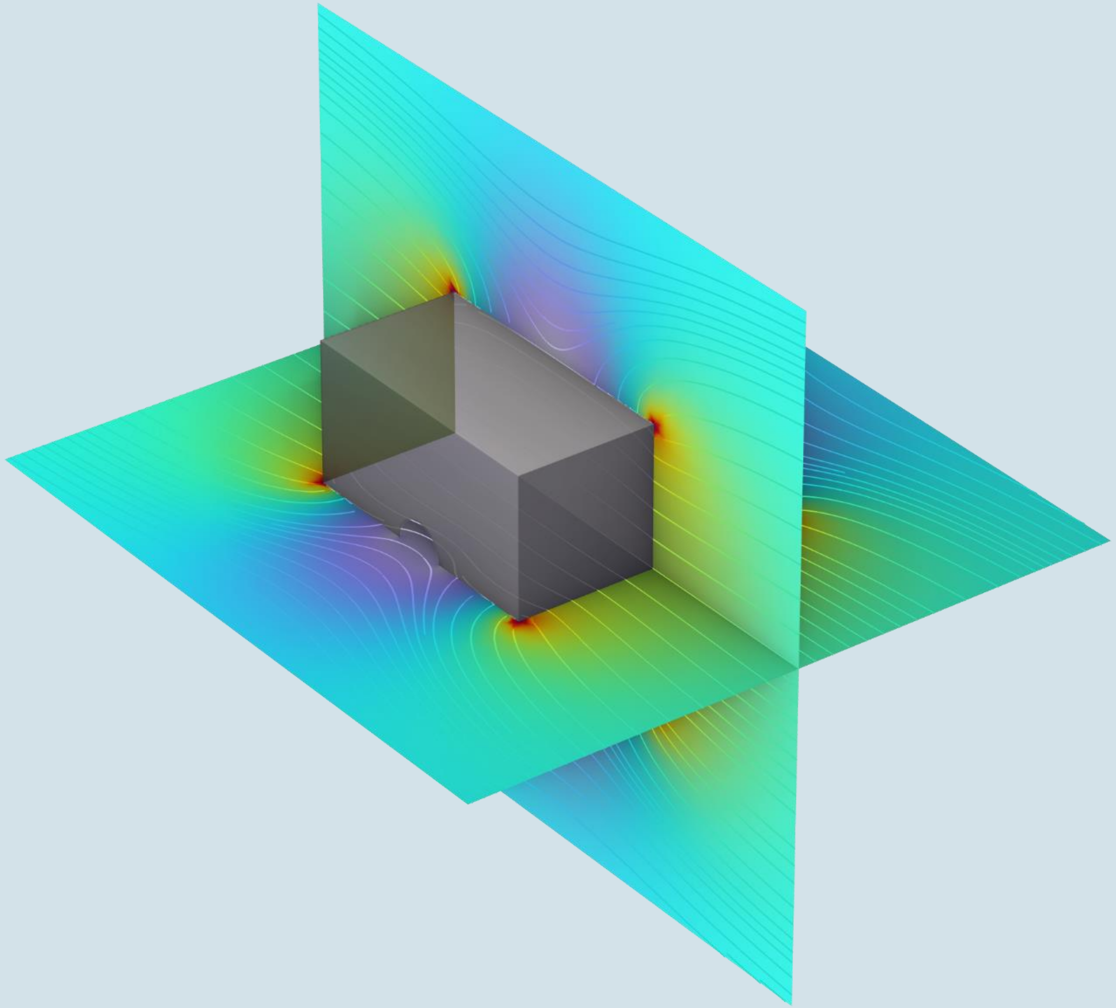
- Materials with a very high magnetic permeability provide a low reluctance path so that the flux can be channeled around the objects
- Dedicated boundary conditions
  - Magnetic Shielding
  - Thin Low Permeability Gap
- Sources of the magnetic field can be:
  - Background field (Earth's magnetic field)
  - Permanent magnet
  - Ideal dipoles
  - Current-carrying conductors

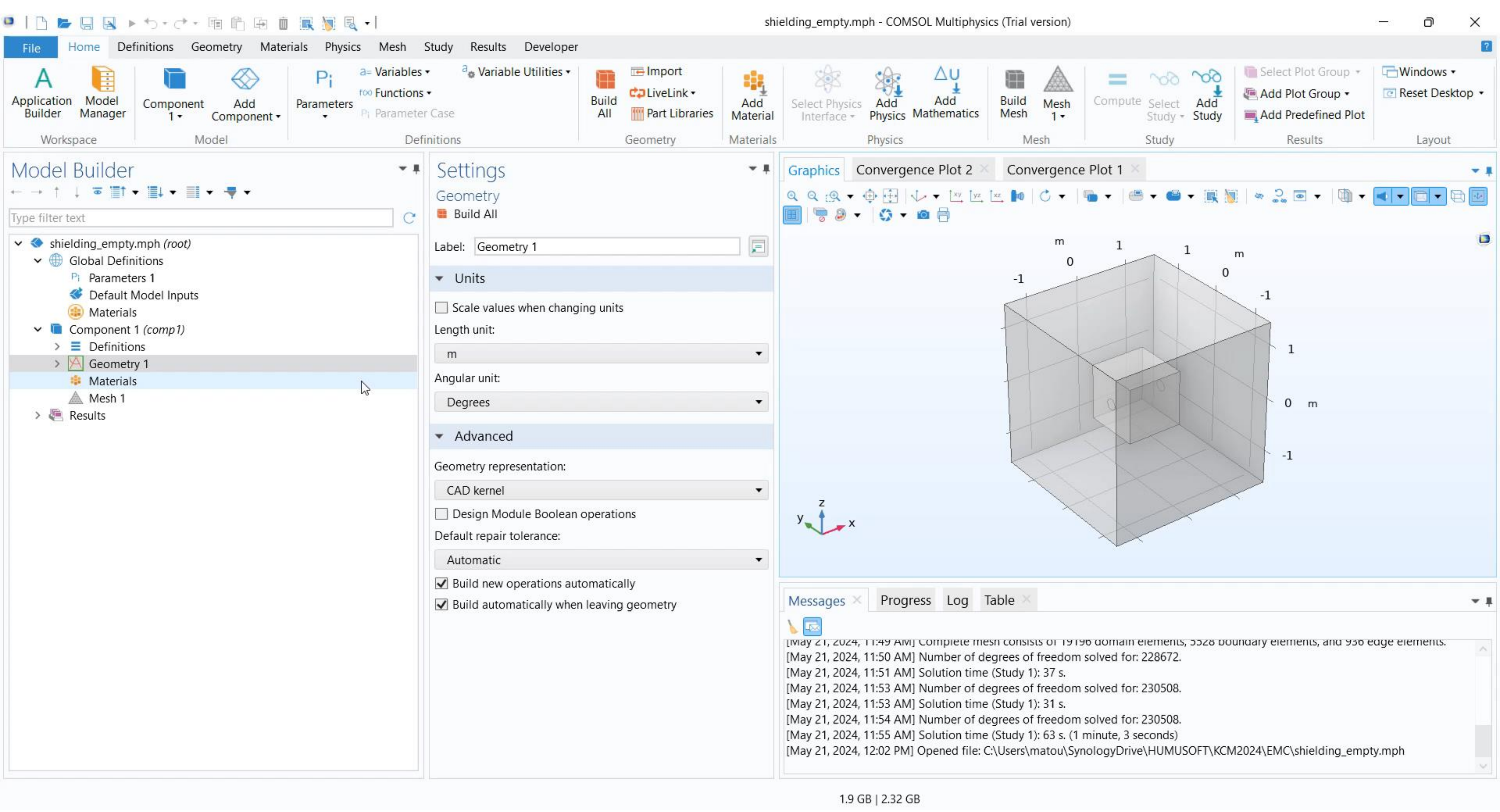




DEMO: Magnetostatic Shielding

- Background Earth’s magnetic field
  - Reduced field formulation
  - 50 µT
- Magnetic Shielding boundary condition for stationary fields only
- Linear vs. nonlinear magnetic shielding material

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Add Component
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Parameter Case
Variable Utilities
Build All
Import
LiveLink
Part Libraries
Add Material
Select Physics Interface
Add Physics
Add Mathematics
Build Mesh
Mesh 1
Compute
Select Study
Add Study
Select Plot Group
Add Plot Group
Add Predefined Plot
Windows
Reset Desktop
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Definitions
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Physics
Mesh
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Results
Layout
Model Builder
Type filter text
shielding_empty.mph (root)
Global Definitions
Parameters 1
Default Model Inputs
Materials
Component 1 (comp1)
Definitions
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Mesh 1
Results
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Label: Geometry 1
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Geometry representation:
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Build automatically when leaving geometry
Graphics
Convergence Plot 2
Convergence Plot 1
Messages
Progress
Log
Table
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[May 21, 2024, 11:50 AM] Number of degrees of freedom solved for: 228672.
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[May 21, 2024, 11:53 AM] Solution time (Study 1): 31 s.
[May 21, 2024, 11:54 AM] Number of degrees of freedom solved for: 230508.
[May 21, 2024, 11:55 AM] Solution time (Study 1): 63 s. (1 minute, 3 seconds)
[May 21, 2024, 12:02 PM] Opened file: C:\Users\matou\SynologyDrive\HUMUSOFT\KCM2024\EMC\shielding_empty.mph
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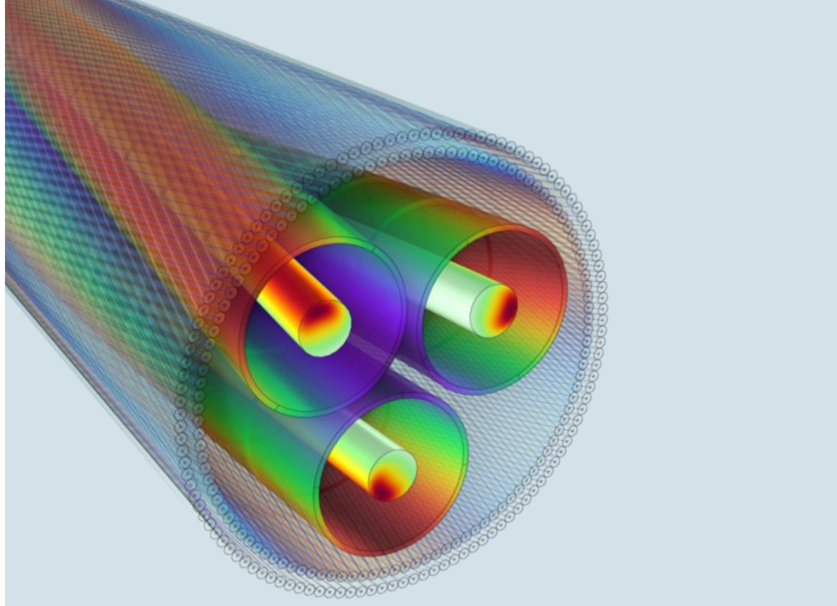
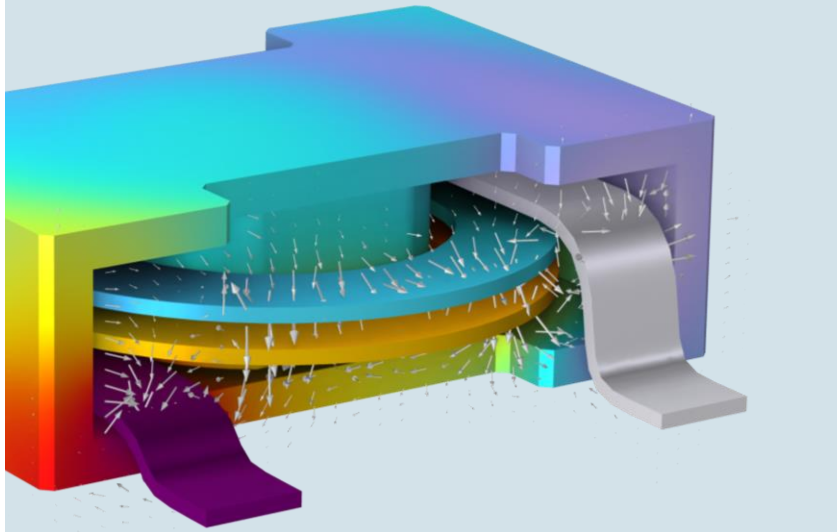
Electromagnetic Shielding

- The magnetic field variation generates eddy currents in conductive layers that act to reduce the applied field
  - The shielding efficiency of conductors is frequency dependent and related to the skin depth
- **Transition boundary condition**: lossy, skin-depth-dependent penetration
- **Impedance boundary condition**: lossy, impenetrable
- **Perfect electric conductor (PEC)**: lossless, impenetrable

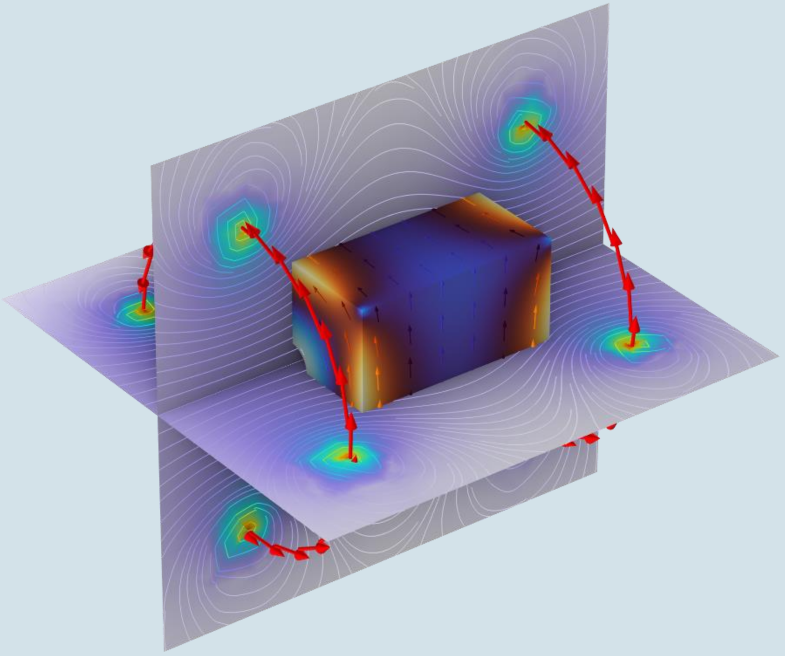


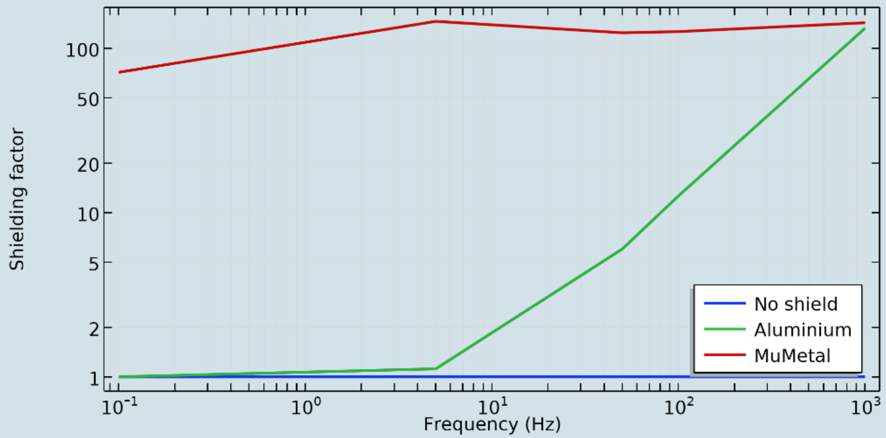


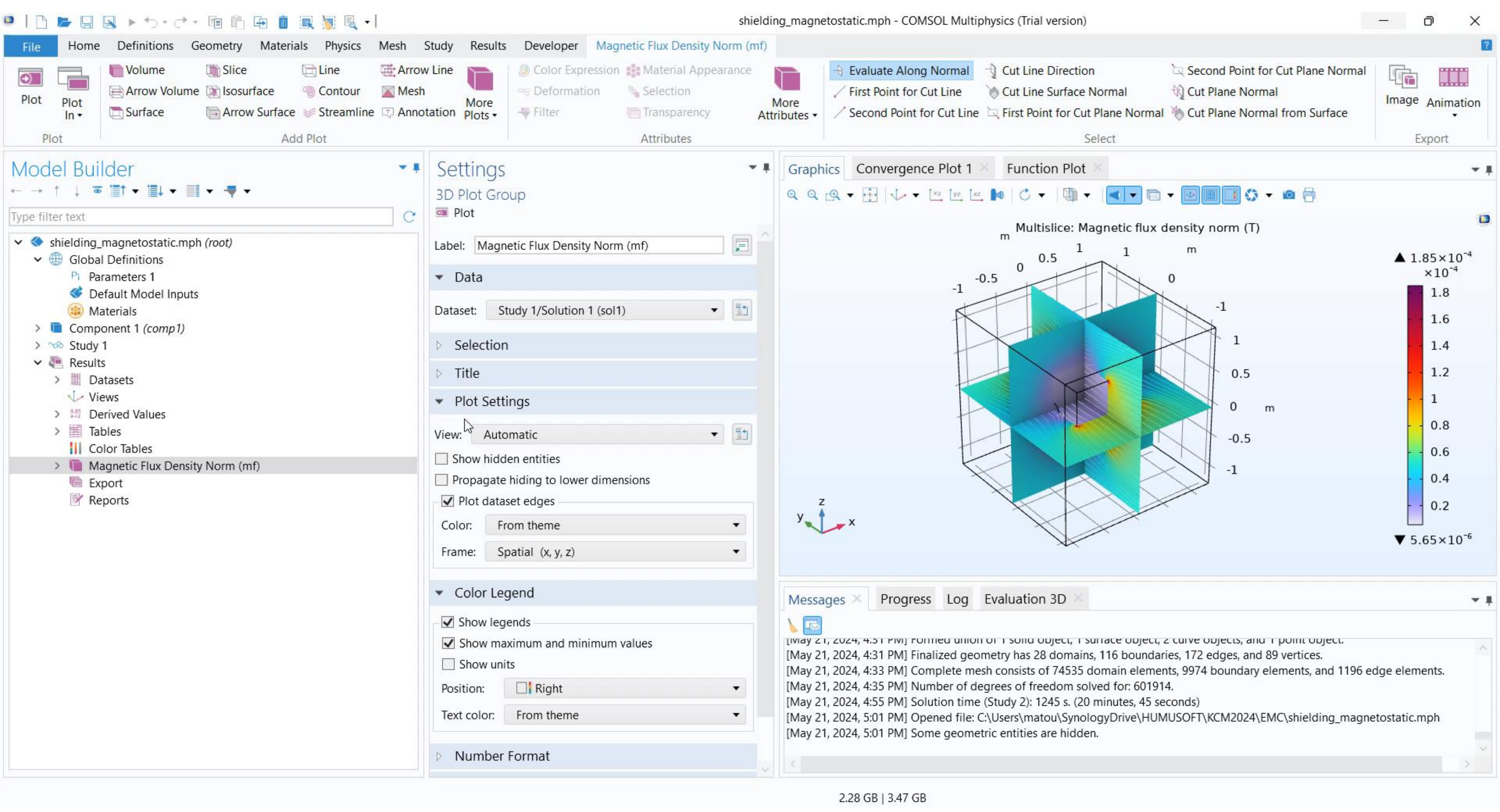
COMSOL

DEMO: Electromagnetic Shielding

- Shielding factor calculation
  - High permeability vs high conductivity shielding material comparison
  - 0.1 to 1000 Hz
- Transition Boundary Condition
- Induced surface current density visualization






shielding_magnetostatic.mph - COMSOL Multiphysics (Trial version)
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Magnetic Flux Density Norm (mf)
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Component 1 (comp1)
Study 1
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Derived Values
Tables
Color Tables
Magnetic Flux Density Norm (mf)
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Reports
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3D Plot Group
Plot
Label: Magnetic Flux Density Norm (mf)
Data
Dataset: Study 1/Solution 1 (sol1)
Selection
Title
Plot Settings
View: Automatic
Show hidden entities
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Color: From theme
Frame: Spatial (x, y, z)
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Evaluation 3D
[May 21, 2024, 4:31 PM] Finalized geometry has 28 domains, 116 boundaries, 172 edges, and 89 vertices.
[May 21, 2024, 4:33 PM] Complete mesh consists of 74535 domain elements, 9974 boundary elements, and 1196 edge elements.
[May 21, 2024, 4:35 PM] Number of degrees of freedom solved for: 601914.
[May 21, 2024, 4:55 PM] Solution time (Study 2): 1245 s. (20 minutes, 45 seconds)
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[May 21, 2024, 5:01 PM] Some geometric entities are hidden.
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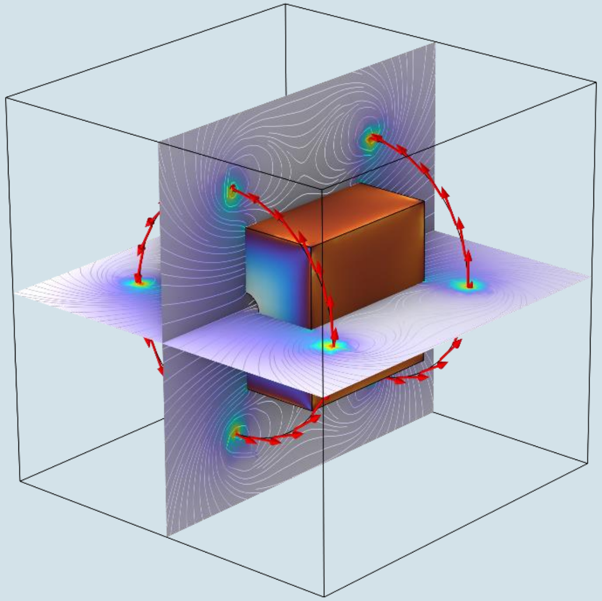
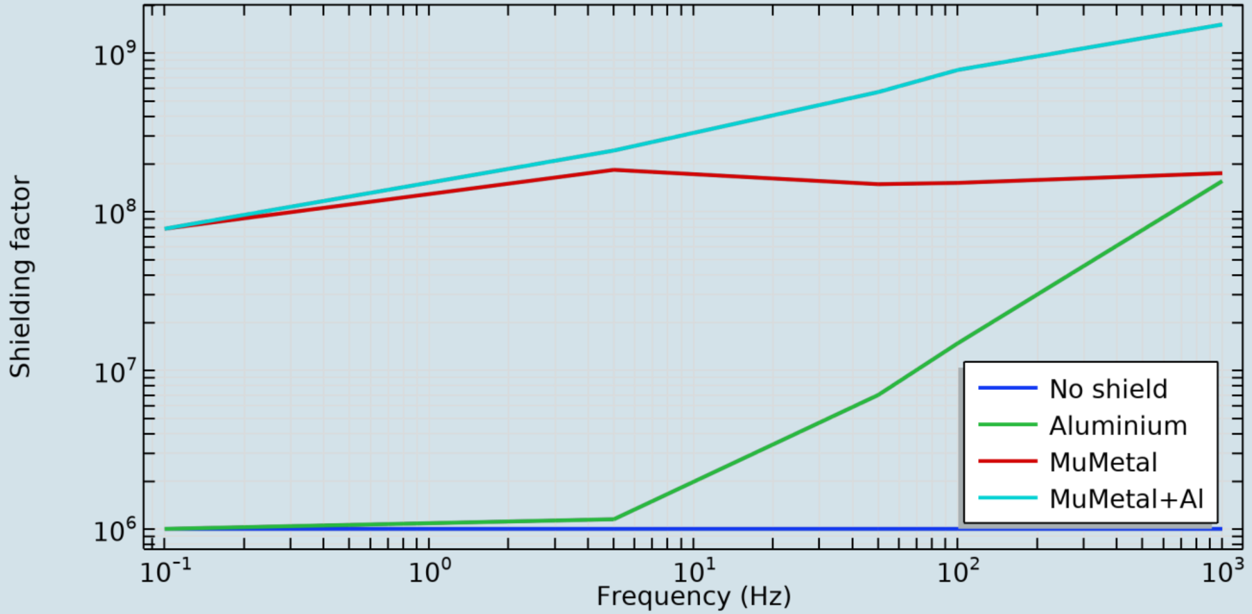
Layered Transition Boundary Condition

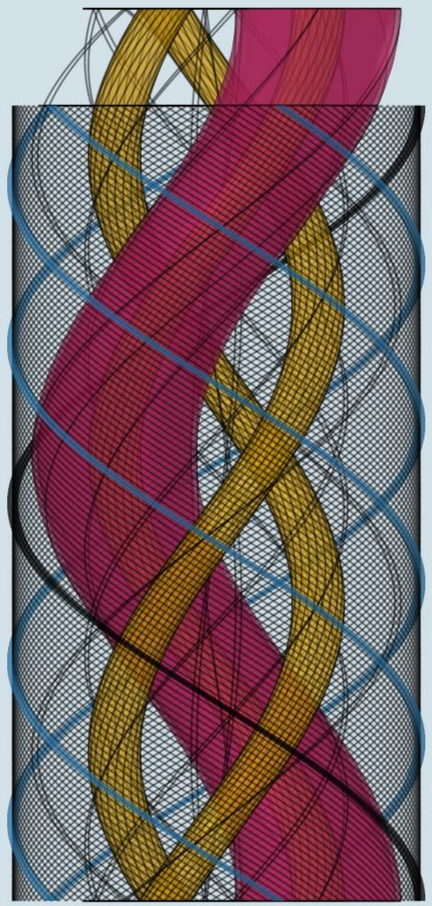
- Combining highly conductive layers with high permeability materials in shielding
- Gold plated copper of circuit board trace
- Defined by Layered Material and Layered Material link features
  - Material composition
  - Layers' thickness
  - Number of virtual mesh elements per layer
  - Layer rotation (anisotropic material properties)



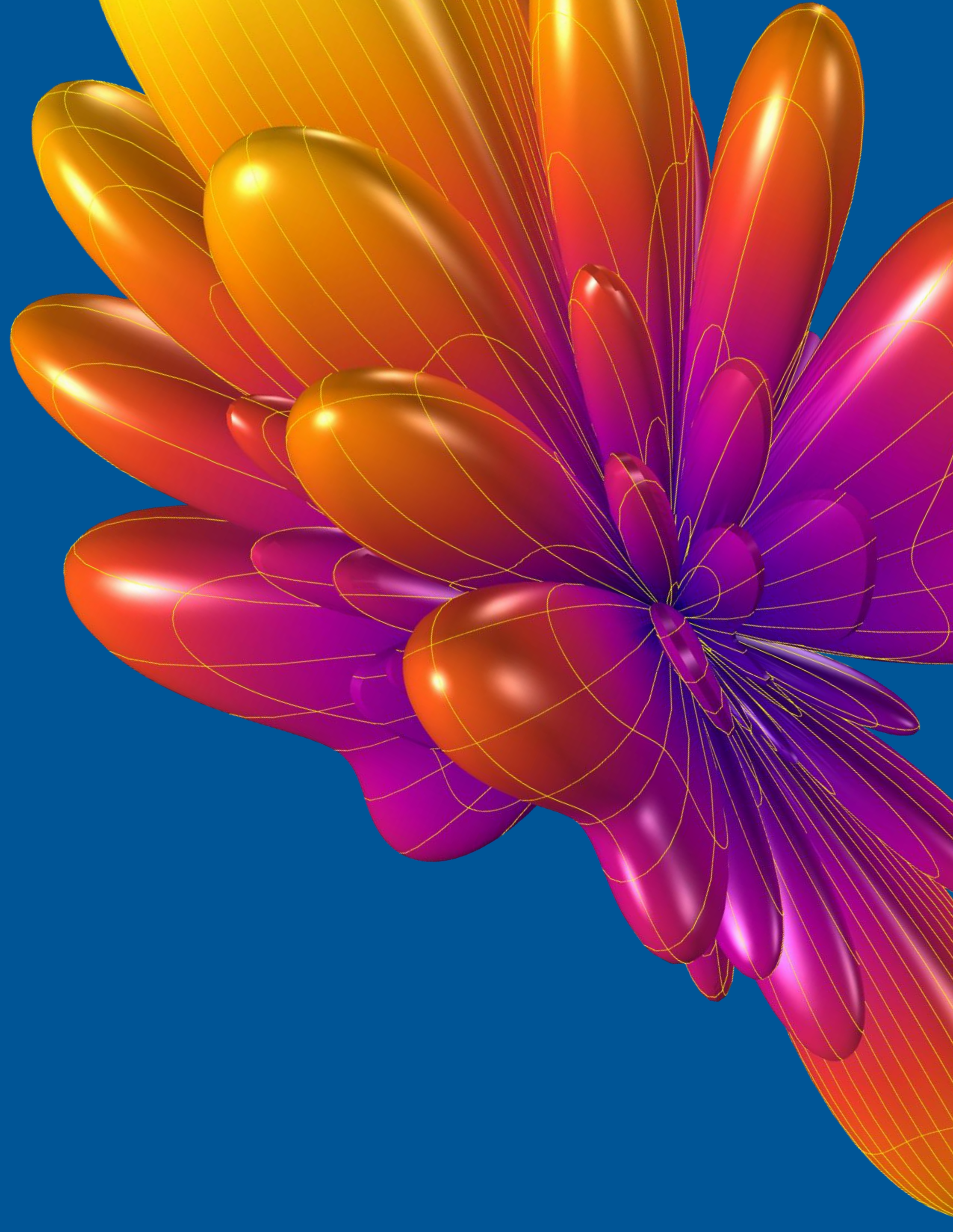


Cable Tutorial Series

- 3D twisted cable modelling
  - No longer a task for dedicated codes run on large clusters
  - Increasing efficiency with a sufficiently large safety margin
  - Numerical models made with COMSOL Multiphysics® complement and replace traditional methods (IEC)
- Includes capacitive, inductive and thermal effects
- Online cable resources:
  - Cable Tutorial Series
  - Submarine Cable Analyzer

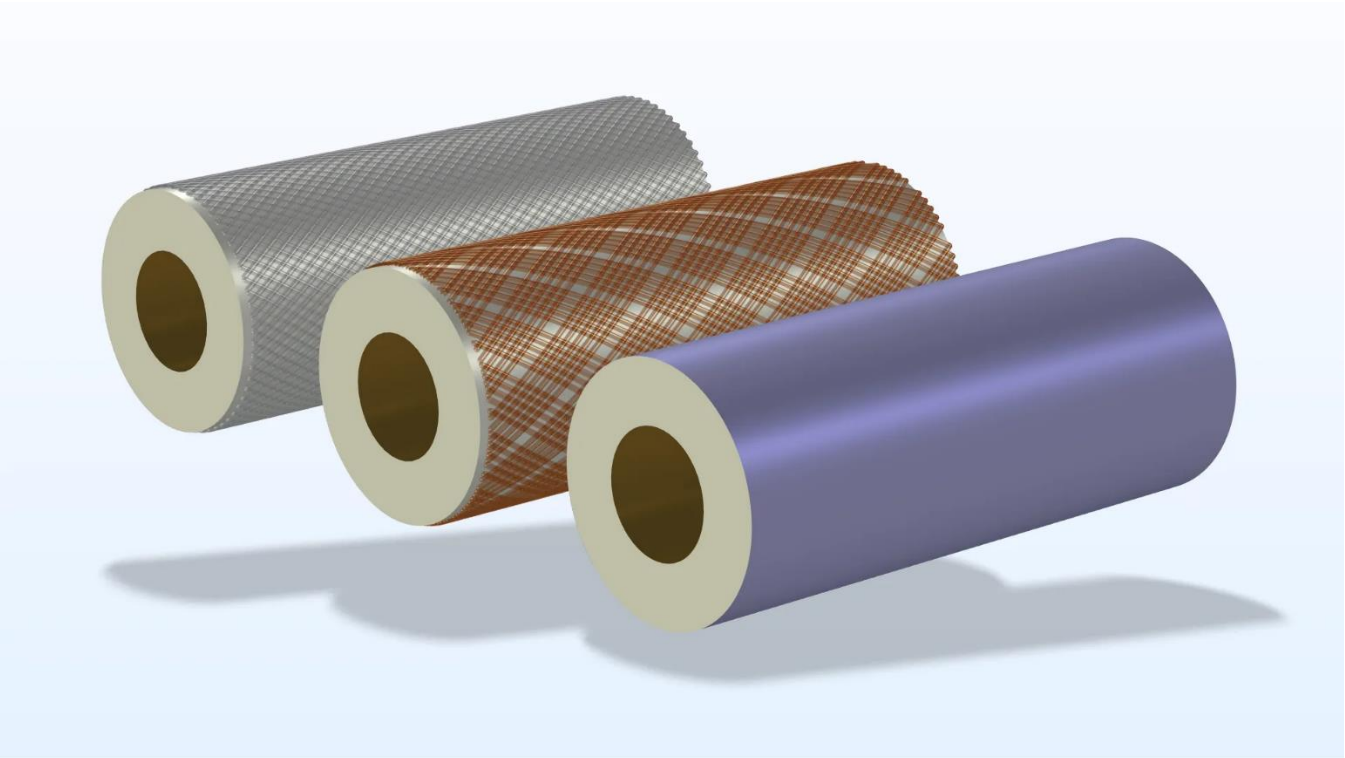


High Frequency Fields:
Wave Radiation Problem



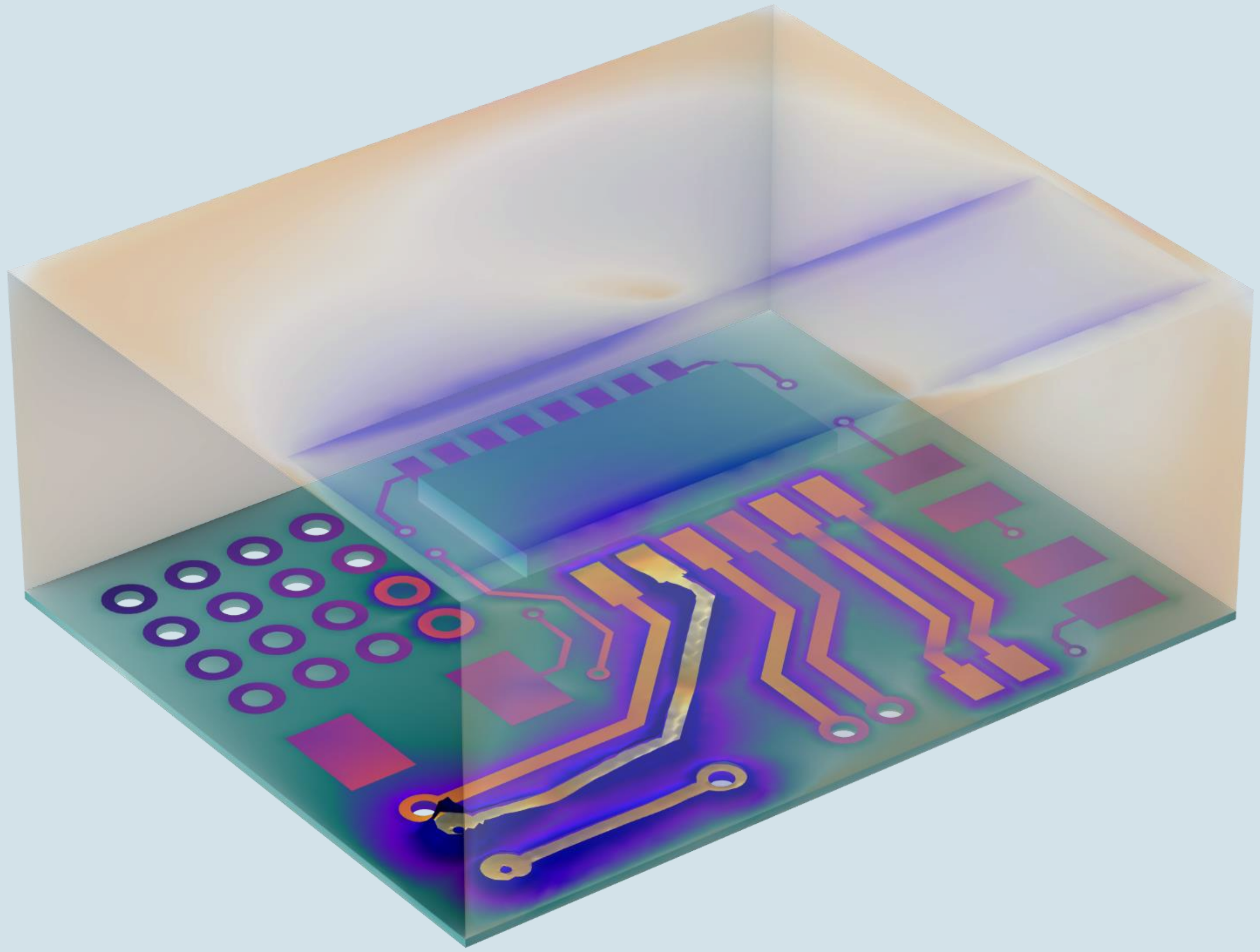
Shielding in RF: Cable Shield

- “Thin layer” type boundary condition
- Reduced computational demands
- Enables efficient simulation of intricate shielding geometry types using a streamlined boundary condition
  - Braided shields
  - Perforated shields



DEMO: EMC/EMI of a Circuit Board

- Emission and immunity analysis of a circuit board
    1. **Emission**: One of the lines is excited and the crosstalk to adjacent line is calculated together with leaked power
    2. **Immunity**: External antenna impact on circuit board
- A brief dive into postprocessing magic ✨



circuit_emiemc.mph - COMSOL Multiphysics (Trial version)

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

New

Model Wizard

Blank Model

Help Cancel Show on startup

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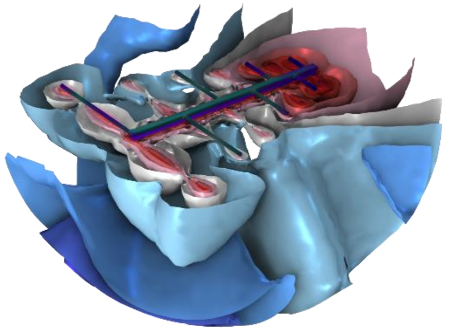
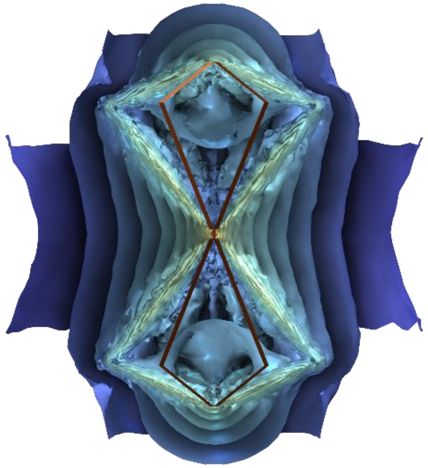
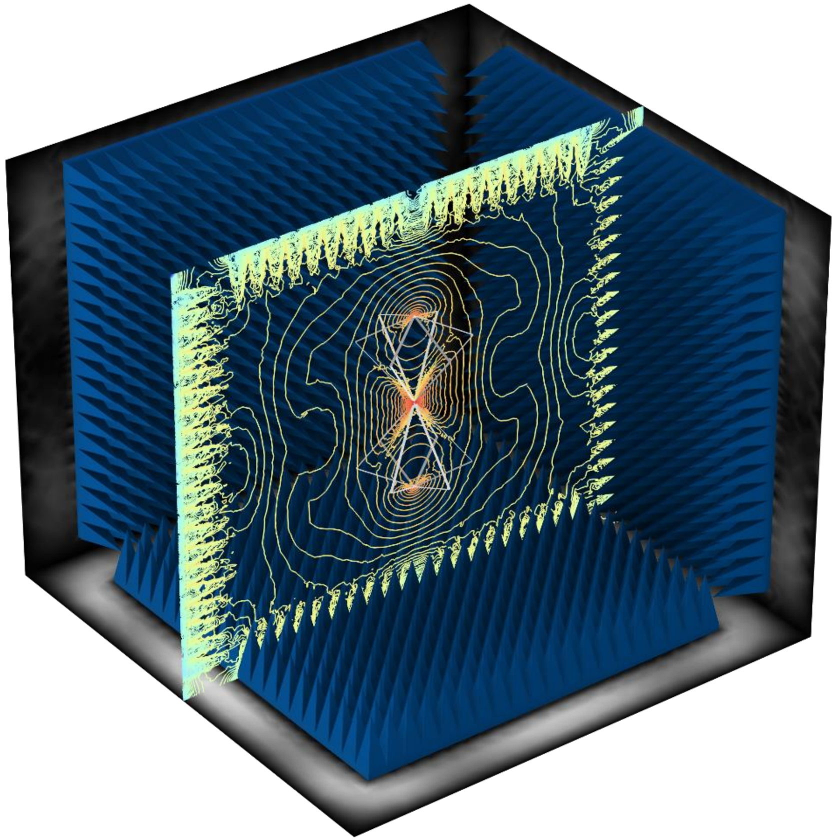
Designing EMC/EMI Testing Laboratory with COMSOL

Antennas for EMC/EMI Testing





Anechoic Chamber FEM Model



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