Magnetics Modeling in COMSOL Multiphysics

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ECE682 Power Electronics Technologies

2-13-20

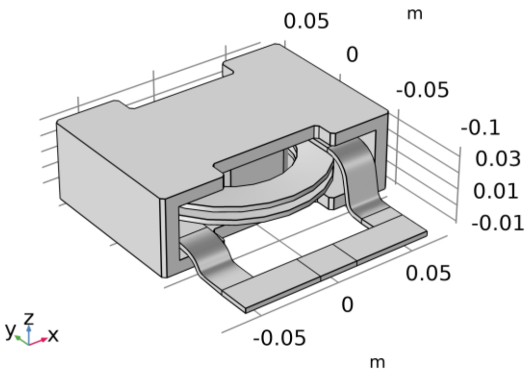
THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Outline

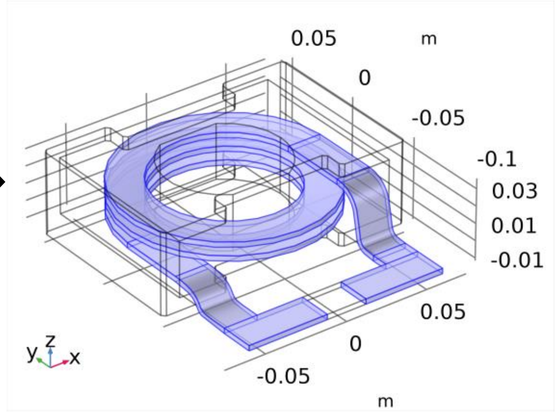
- Introduction
- COMSOL Overview
- Current Licenses and Capabilities
- Available Tutorials and Documentation
  - Electromagnetic Heating Walkthrough
- Wireless Power Transfer (WPT) for EVs Overview
  - WPT Magnetics Simulation in COMSOL

Introduction

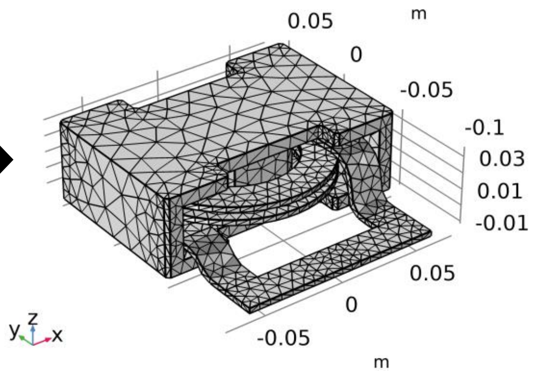
- Finite-Element Method/Analysis
  - Solving partial differential equations (PDEs) by breaking the problem down into smaller elements (finite elements)
    - Closed-form equations often rely on geometry-specific simplifications
  - Requires initial values and boundary conditions to determine solution
  - Popular in electromagnetism, structural analysis, heat transfer, fluid dynamics, …



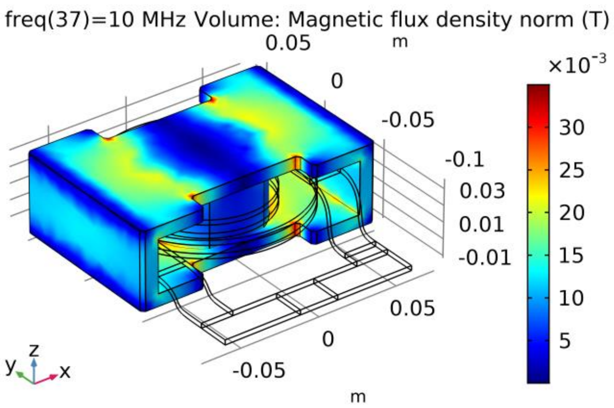
Define Geometry
(draw in software or import CAD, add surrounding air, ect.)



Set Boundary Conditions
(e.g. defining conductor)
Set Initial Conditions
(e.g. set currents)



Discretize Geometry
(based on physics and bounds or manually)



Compute Solution

Post-processing and finding lumped-element values, e.g. RLC

COMSOL Multiphysics

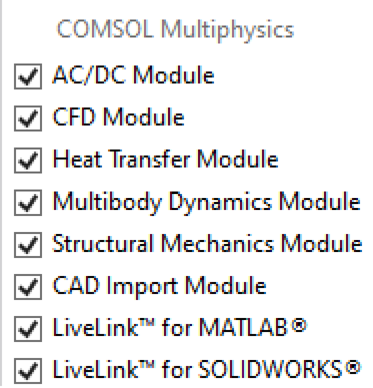
- Very general software for solving problems described by PDEs with FEA
- Main strength is the integration of all of these within a single GUI/program
  - Easy to do multiphysics simulations e.g. electromagnetic heating, plasma flow, actuators
- I personally learned it because ORNL uses it

Acoustics
Bioscience
Chemical reactions
Corrosion and corrosion protection
Diffusion
Electrochemistry
Electrodeposition
Electromagnetics
Fatigue analysis
Fluid dynamics
Fuel cells and batteries
Geophysics and geomechanics
Heat transfer
Layered shells and composite materials
Microelectromechanical systems (MEMS)
Microfluidics
Microwave engineering
Multibody dynamics
Optics
Optimization and sensitivity analysis
Particle tracing
Photonics
Piezoelectric devices
Pipe flow
Plasma physics
Porous media flow
Quantum mechanics
Radio-frequency components
Ray tracing and ray optics
Rotor dynamics
Semiconductor devices
Structural mechanics
Transport phenomena
Wave propagation

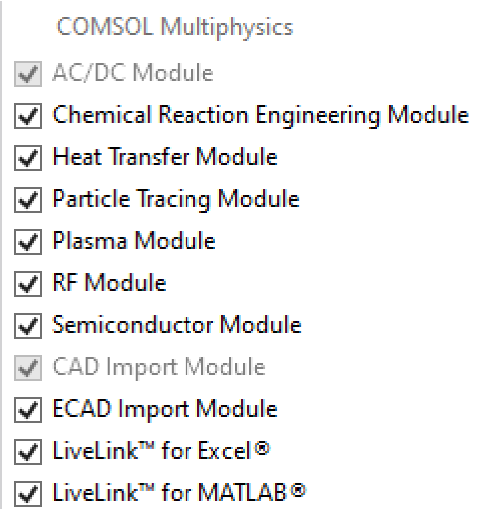
Current Licenses and Capabilities

- Should you use COMSOL?
  - Barriers to Entry:
    - Currently only two single-seat licenses within EECE
      - MABE has license, but does not have AC/DC module (magnetostatics)
    - Would need to learn new GUI
  - What about your problem is something that you cannot do in ANSYS or other software?
    - ✓ Check out 2019 ANSYS Electronics Desktop and other available software
    - ✓ Where multiple types of physics need to be coupled together that are not supported in other software
- Process to install/use COMSOL:
  - Ask professors/senior students about it
  - Get with Markus/EECS IT and install it on your desktop (RD servers do not have it)
  - Have an idea of who else is using the single-seat license in their research

Dr. Wang/
Dr. Tolbert's License



Dr. Fathy's License



Module Overview

- AC/DC Module
  - Electric and magnetic fields in static and low-frequency applications
    - Maxwell's equations with quasi-static approximation
    - Size of device is less than 1/10 the wavelength
- RF Module
  - Electric and magnetic fields in high-frequency applications
    - Maxwell's equations, propagating waves
- CFD (Computational Fluid Dynamics) Module
  - Fluid flow in closed and open systems
- Heat Transfer Module
  - Conduction, convection, and radiation

Ampere-Maxwell Equation

$$\nabla \times \mathbf{H} = \mathbf{J} + \boxed{\frac{\partial \mathbf{D}}{\partial t}}$$

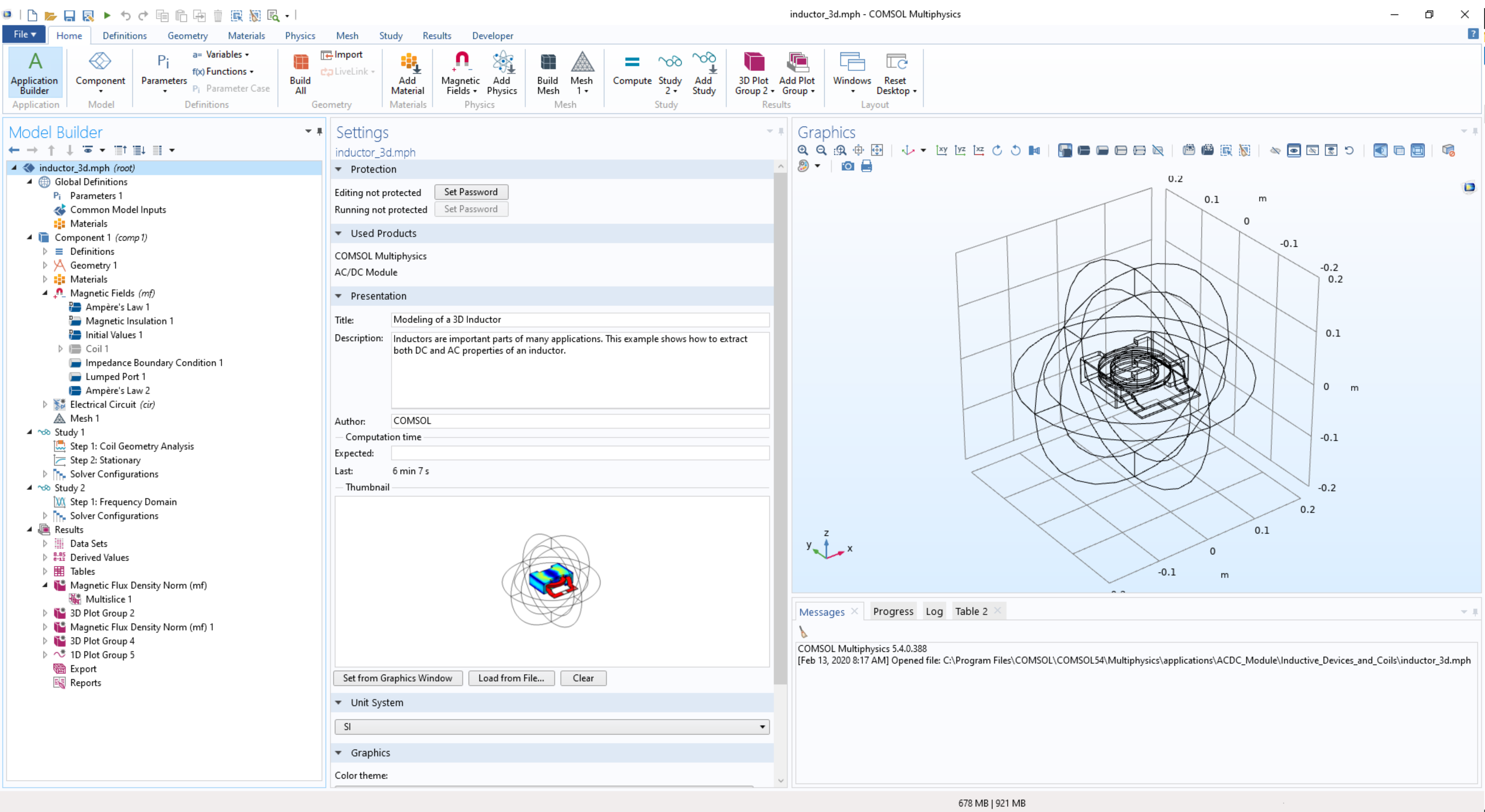
Faraday's Equation

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Current Continuity

$$\nabla \cdot \mathbf{J} = \boxed{\frac{\partial \rho}{\partial t}}$$

$\boxed{}$ = Neglected in AC/DC Module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Used Products
COMSOL Multiphysics
AC/DC Module
Presentation
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Author: COMSOL
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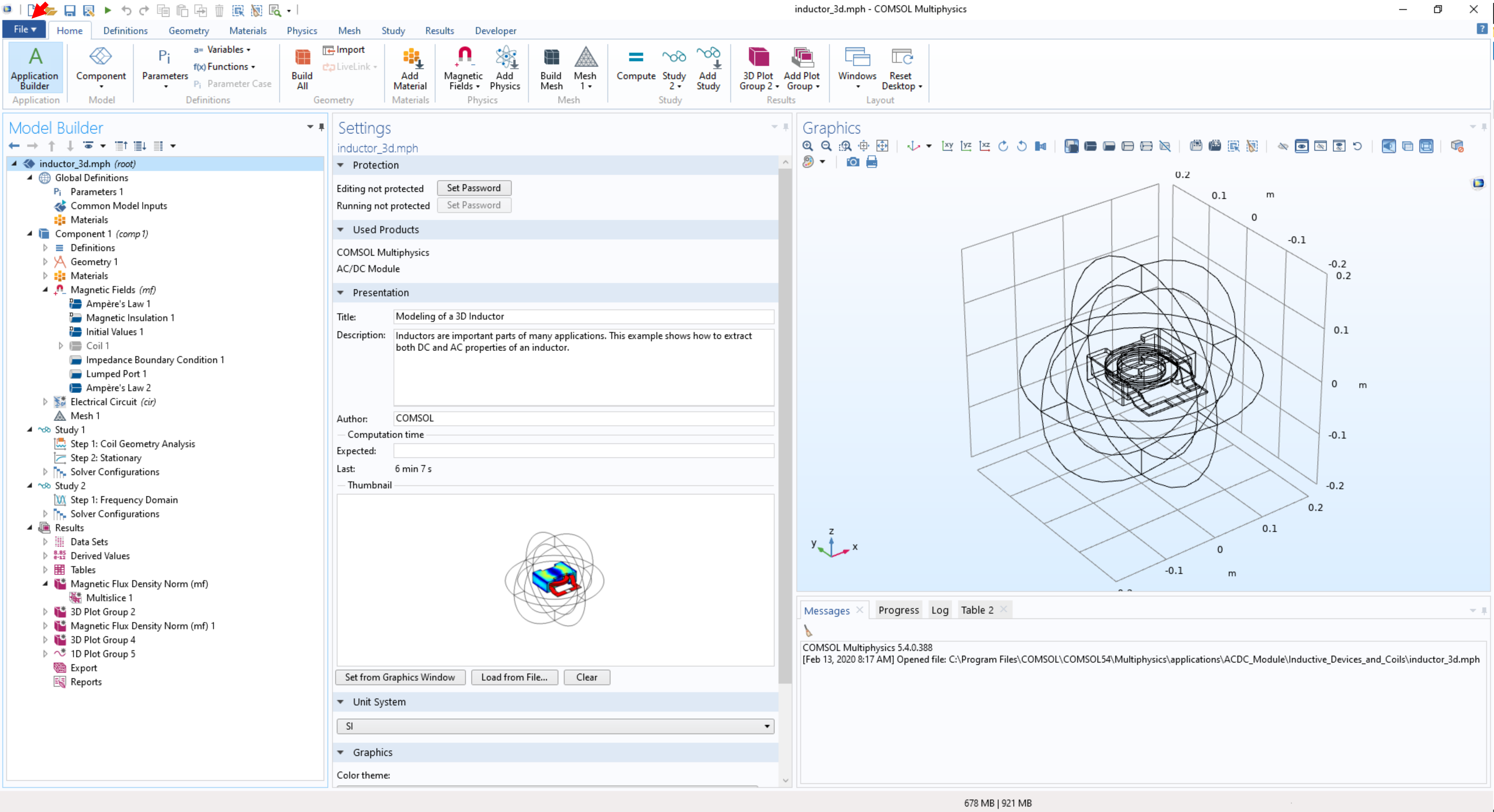
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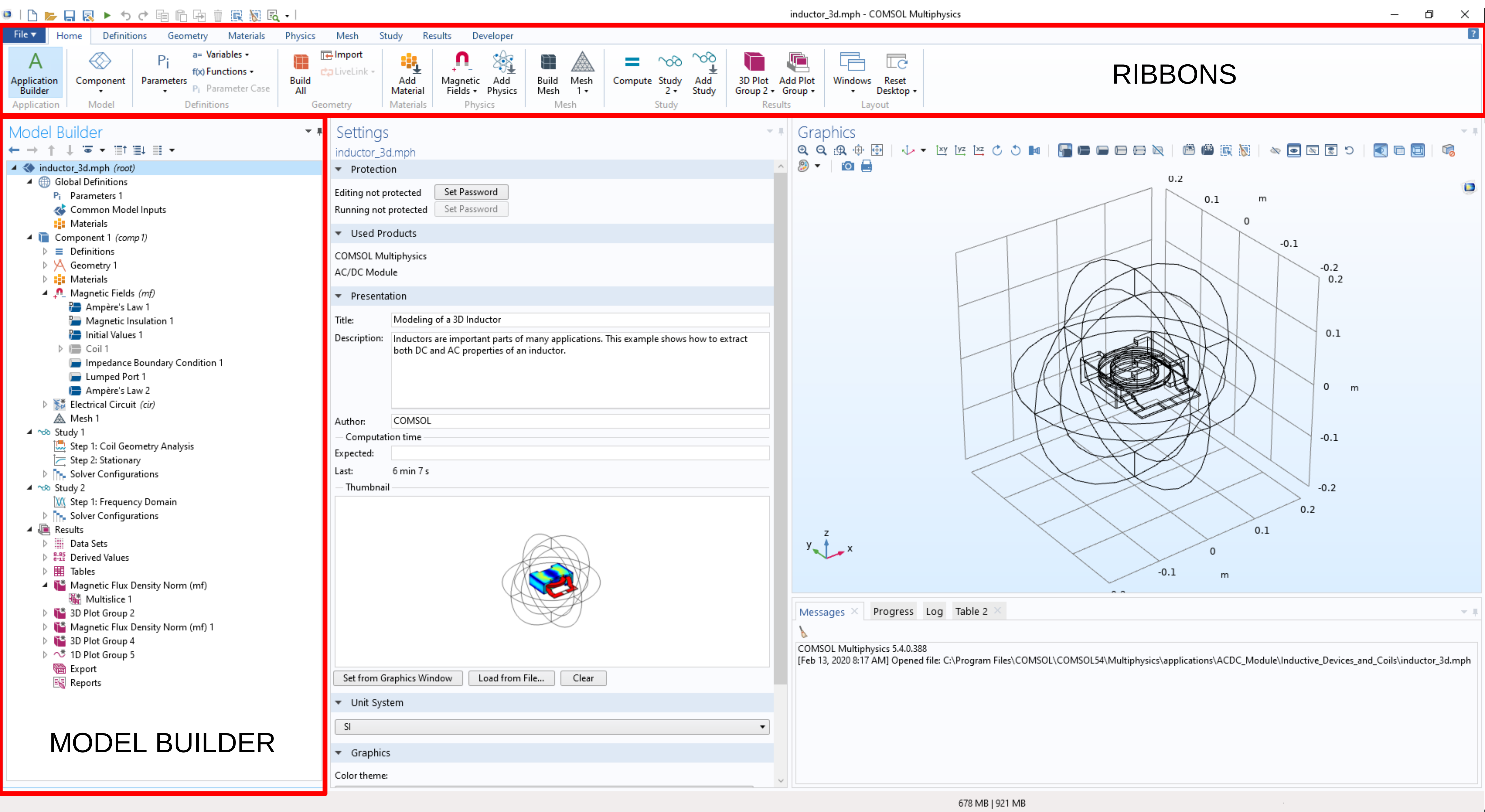
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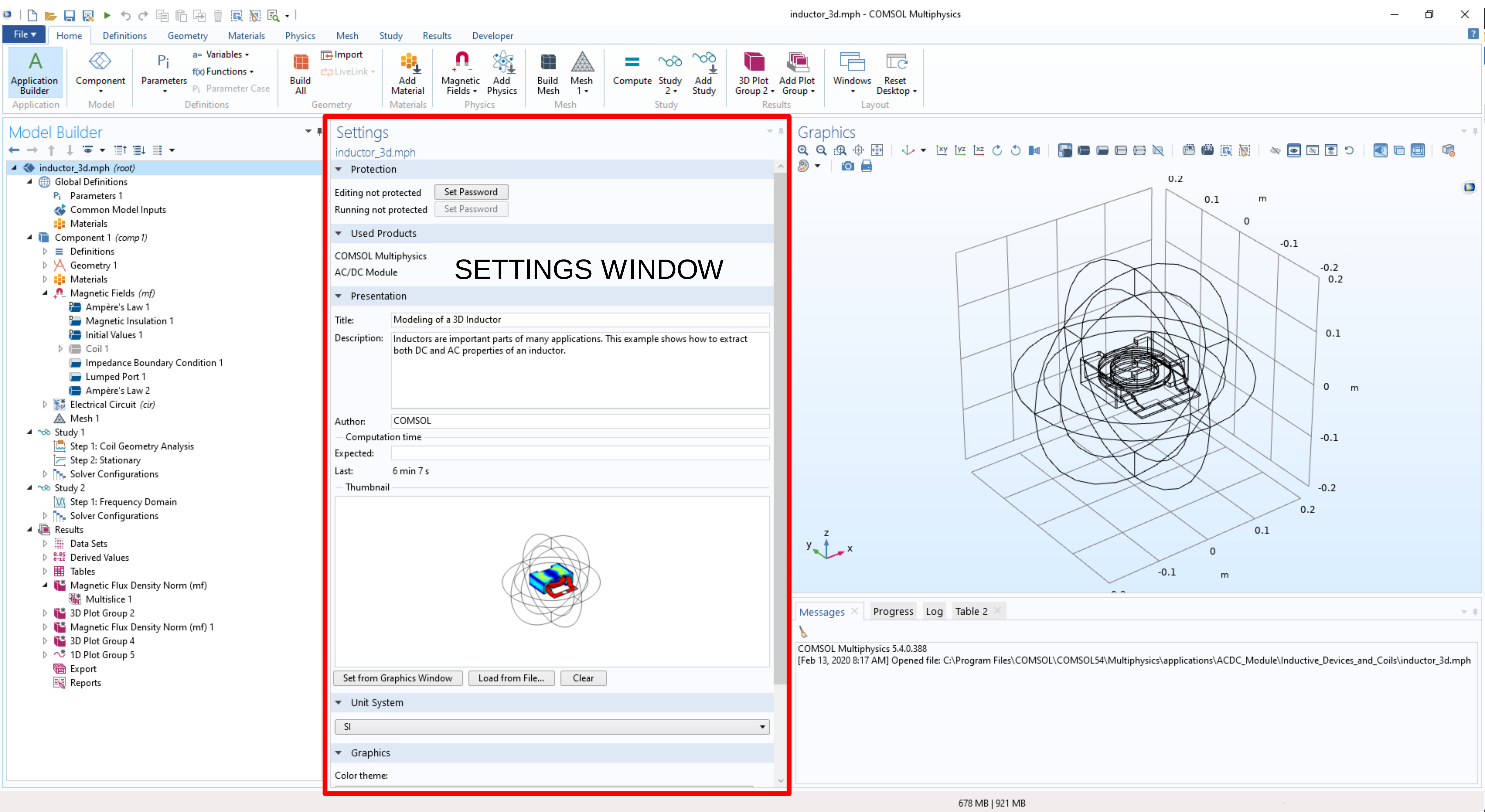

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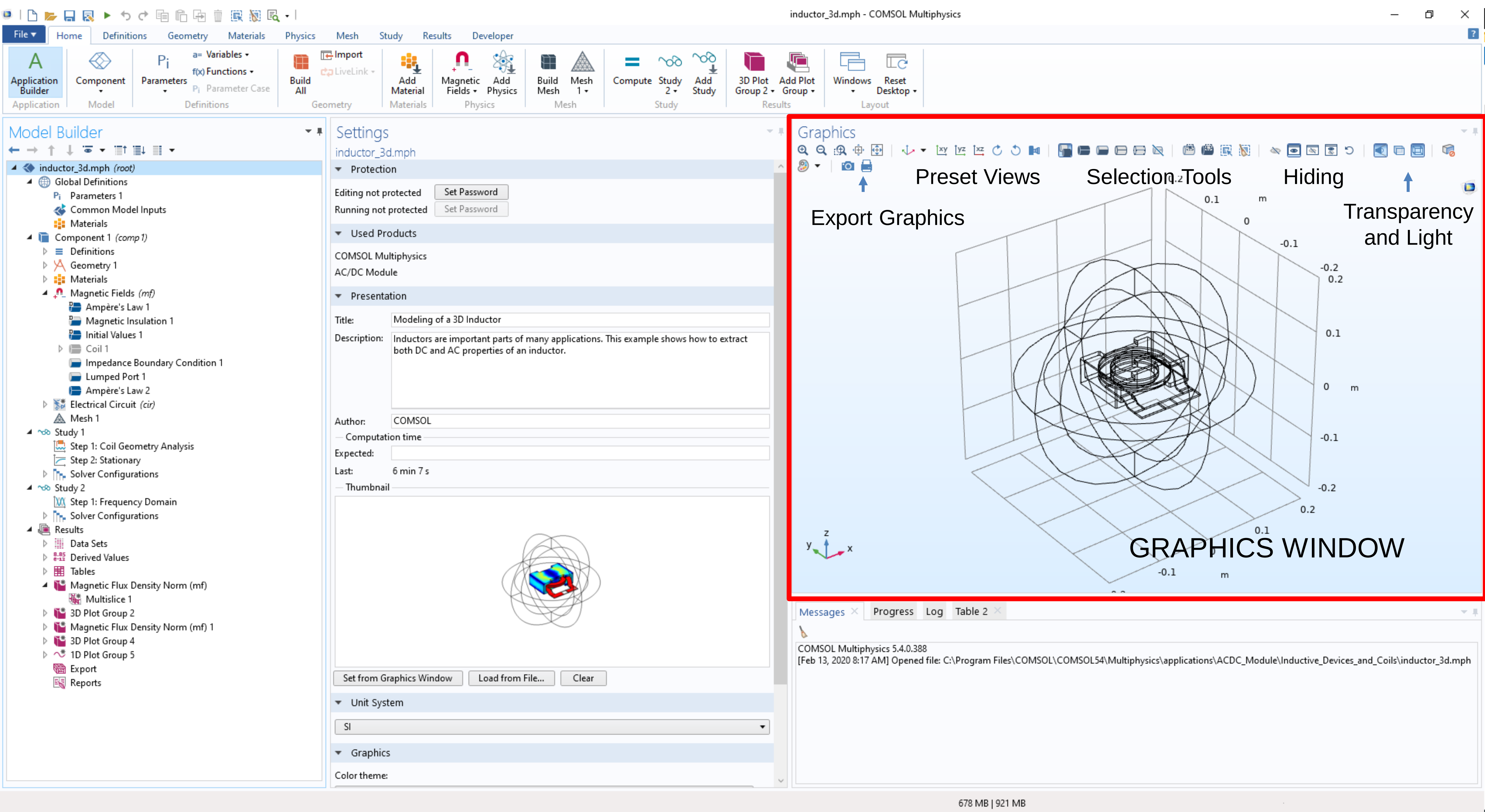
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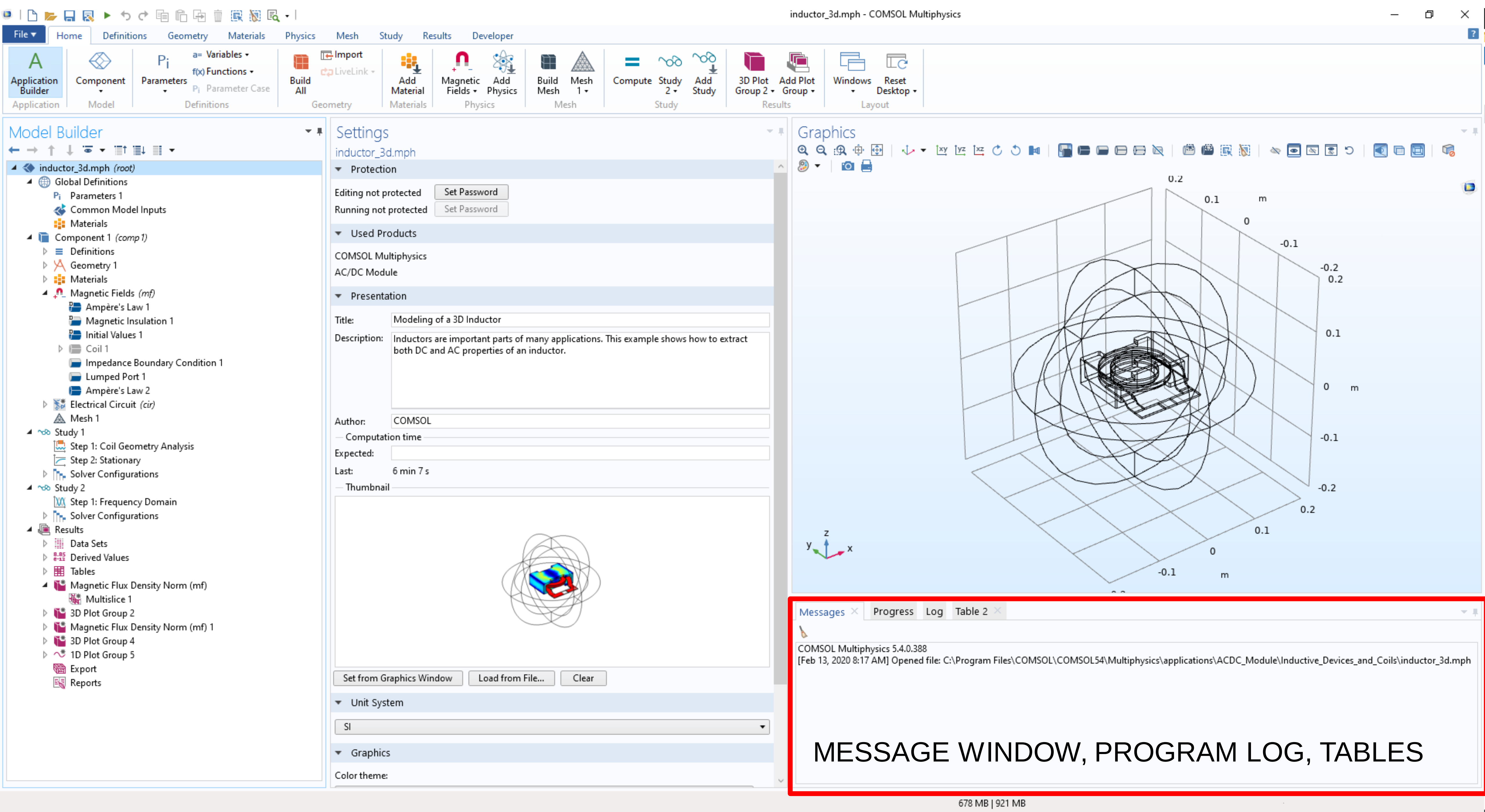
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MESSAGE WINDOW, PROGRAM LOG, TABLES
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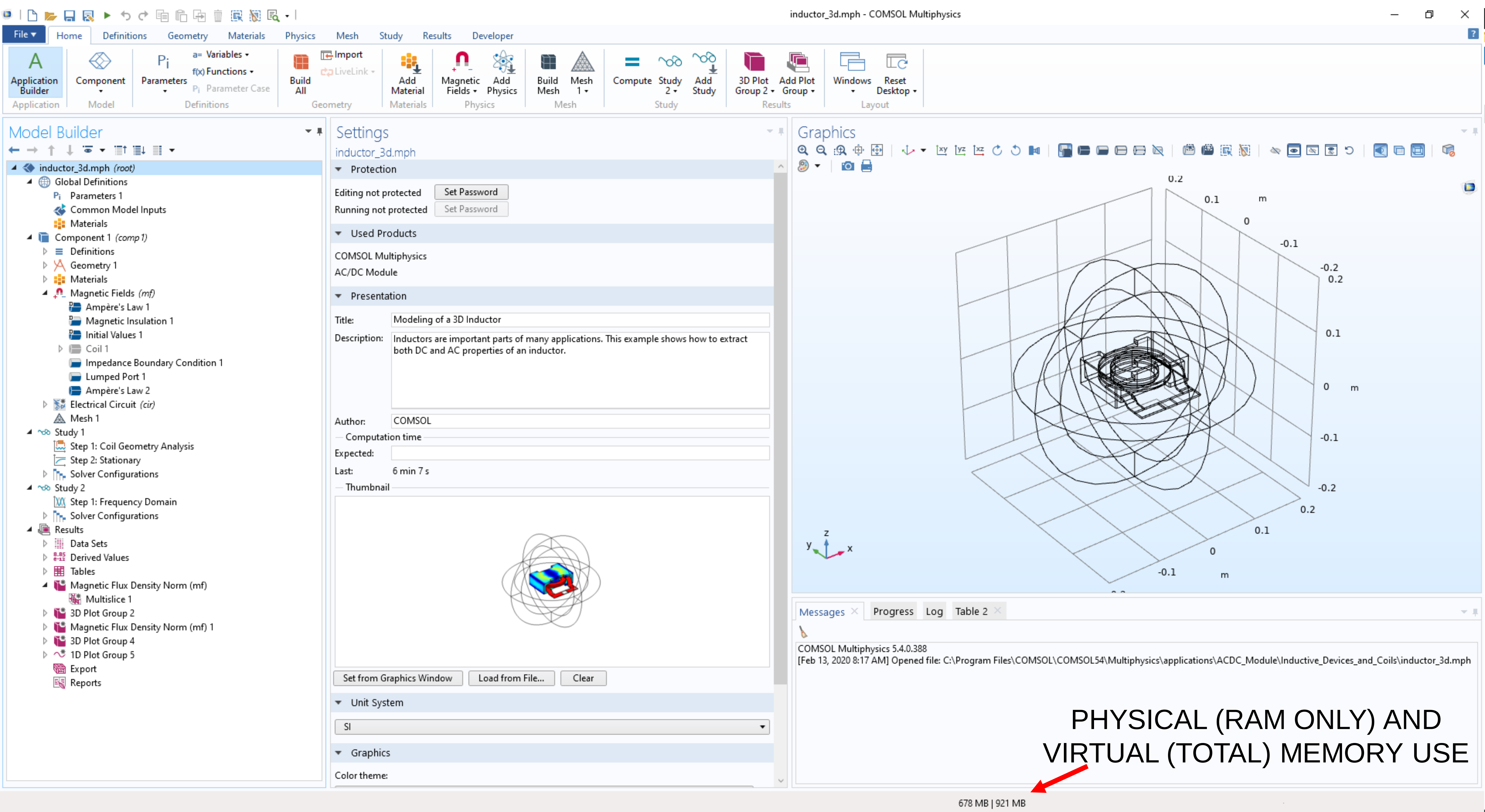


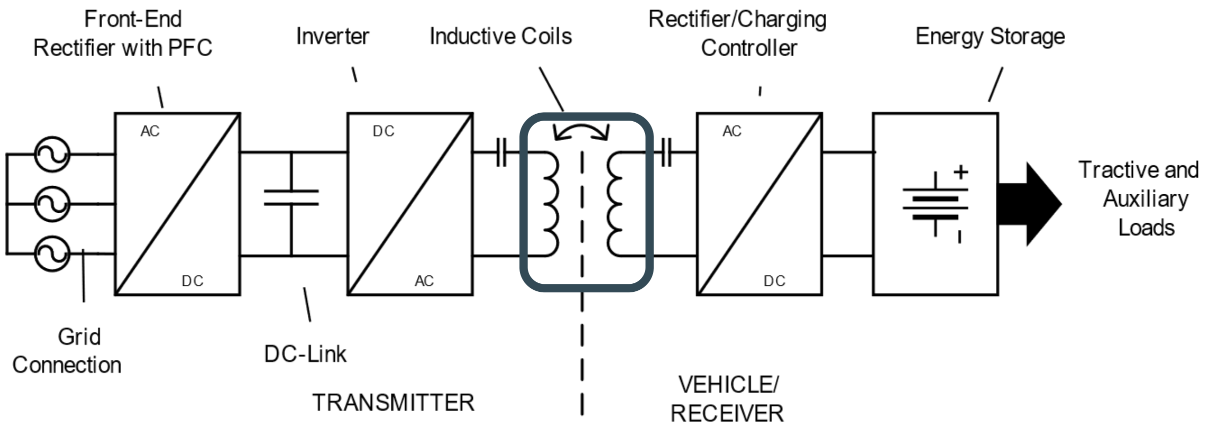
PHYSICAL (RAM ONLY) AND VIRTUAL (TOTAL) MEMORY USE

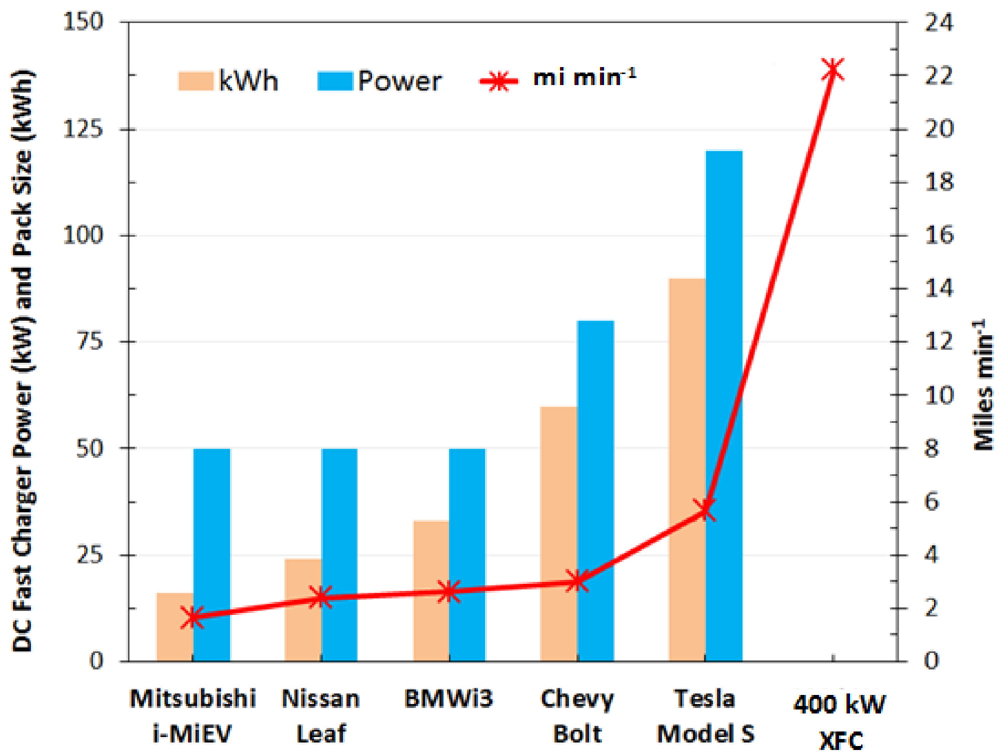
AVAILABLE TUTORIALS AND DOCUMENTATION

ELECTROMAGNETIC HEATING WALKTHROUGH

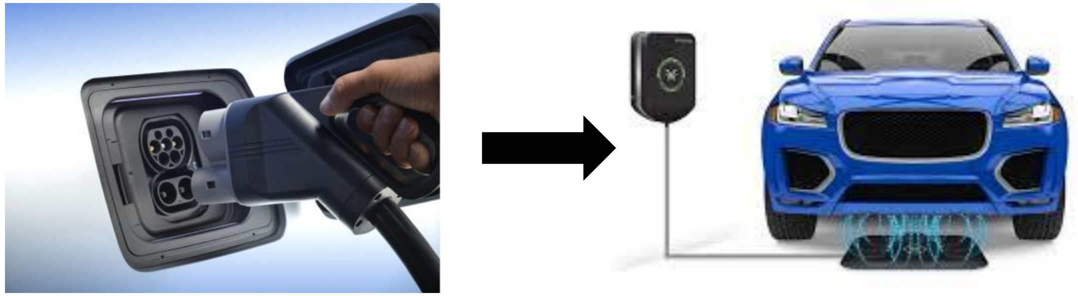
Wireless Power Transfer (WPT) for EVs

- Possible improvements in
  operating lifespan (no moving or exposed parts)
  safety and convenience (no user interaction)
  - Several commercial products for static wireless charging (e.g. Plugless <10kW)
  - Increasing demand in electric buses (e.g. Momentum Dynamics, CARTA 200kW)
- Higher power levels are desired at lower cost and weights to enable fast charging
  - Research ongoing on higher-power systems (e.g. ORNL demonstrated 120kW in 2018)





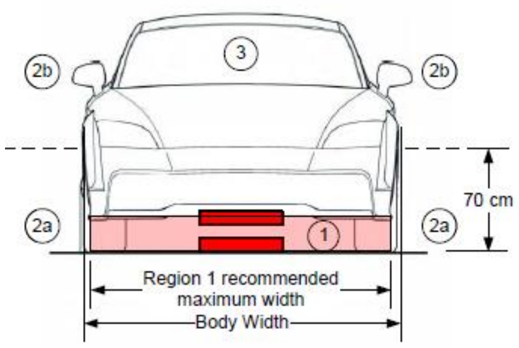
D. Howell *et al.*, "Enabling fast charging: A technology gap assessment," US Department of Energy, October 2017.



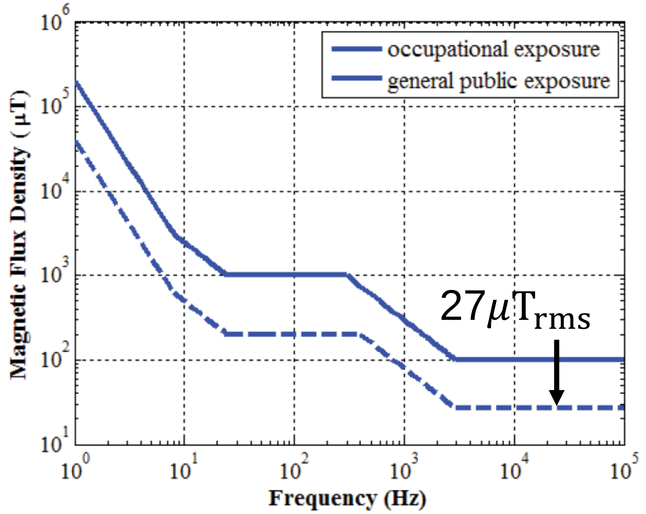
Constraints/Tradeoffs

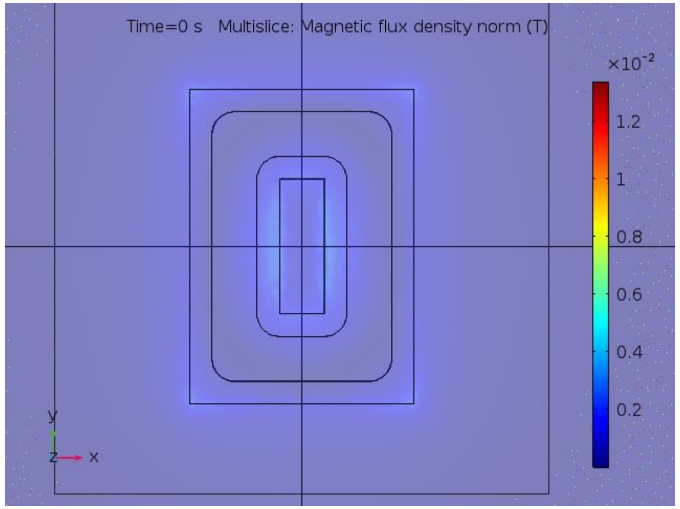
- Design is often done analytically on a case-by case basis or by iterative FEA approaches
  - Stray field outside of the vehicle extents must be limited
  - Surface field of coil also may be limited
  - Size of coil, coupling and inductances dictate power transfer
- Design of WPT system and coil geometry must be done as a tradeoff
  - Basic power transfer equation $P = 2\pi f M I_1 I_2$

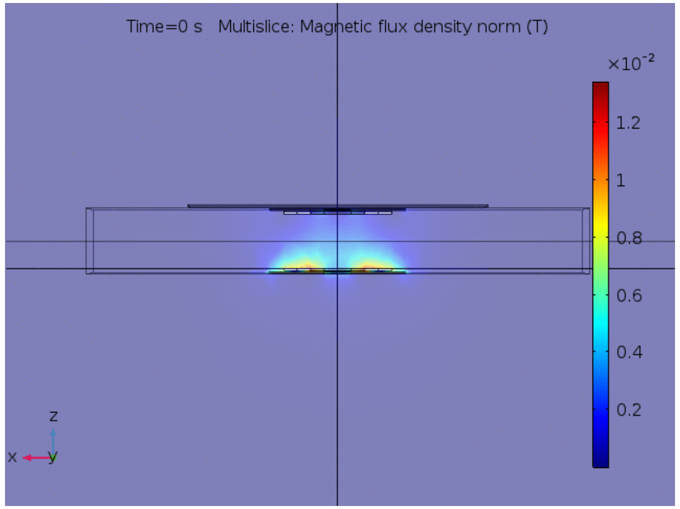
SAE J2954 Guidelines

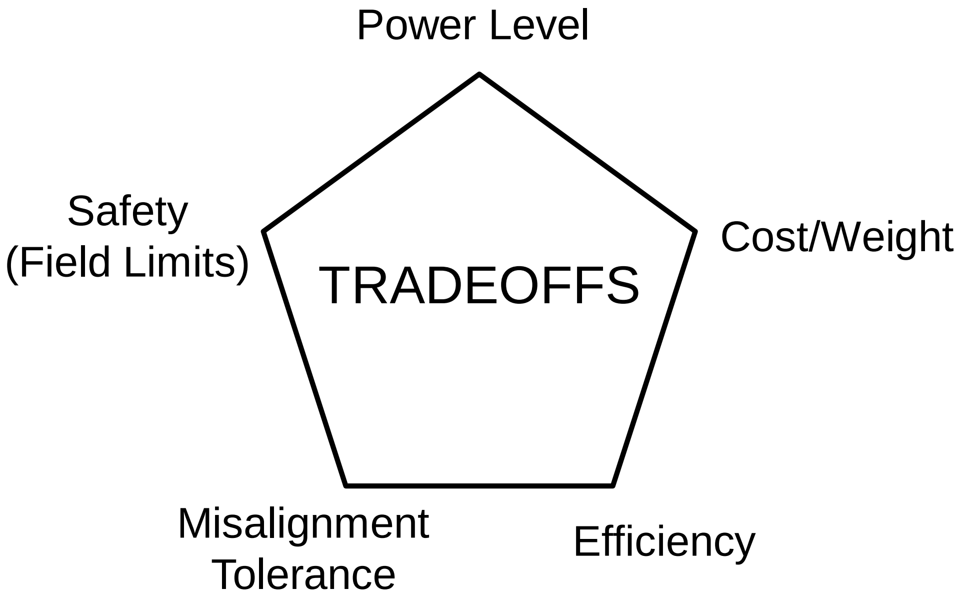


ICNIRP 2010 Limits





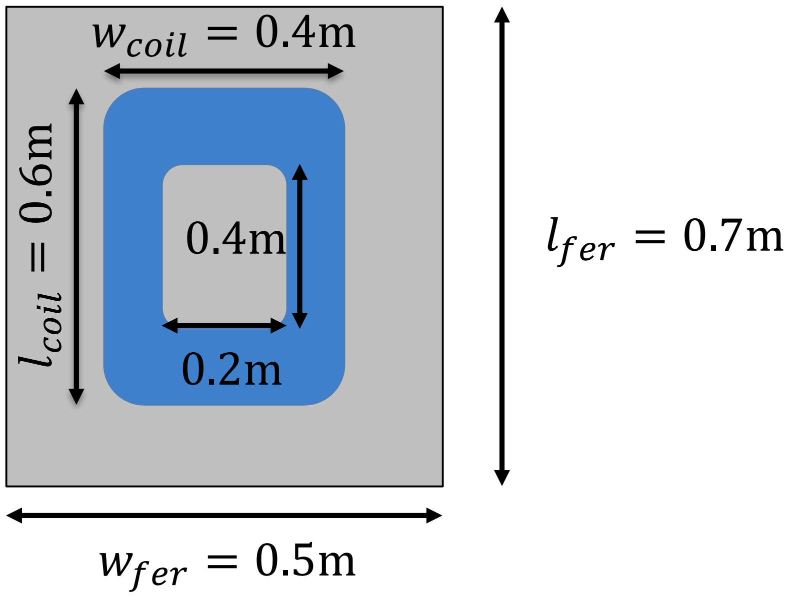


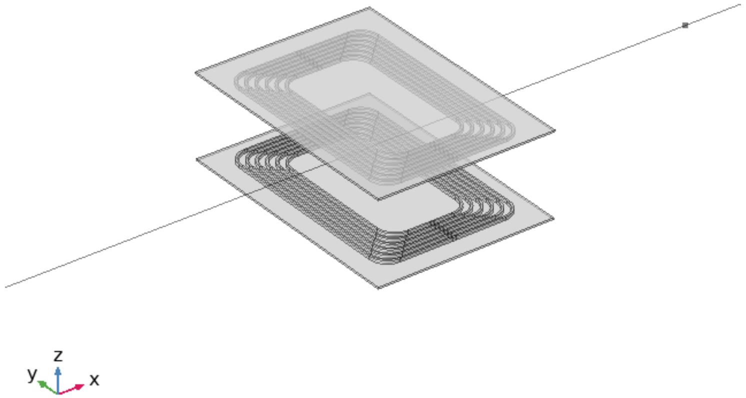


Example Fields - 0.4mx0.6m rectangular coil, 200mm gap – 60kW

WPT System Geometry

- Let the software do as much of the math/geometry as possible
  - Always Helpful to Draw Out Your Problem Before Trying to Draw It
  - Can use parameters to set known values/dimensions
    - Also helps when transitioning to parametric studies
- Start as lumped coil if possible, transition to discretized turns later





Separation of $z_{gap} = 200\text{mm}$

WPT SIMULATION IN COMSOL