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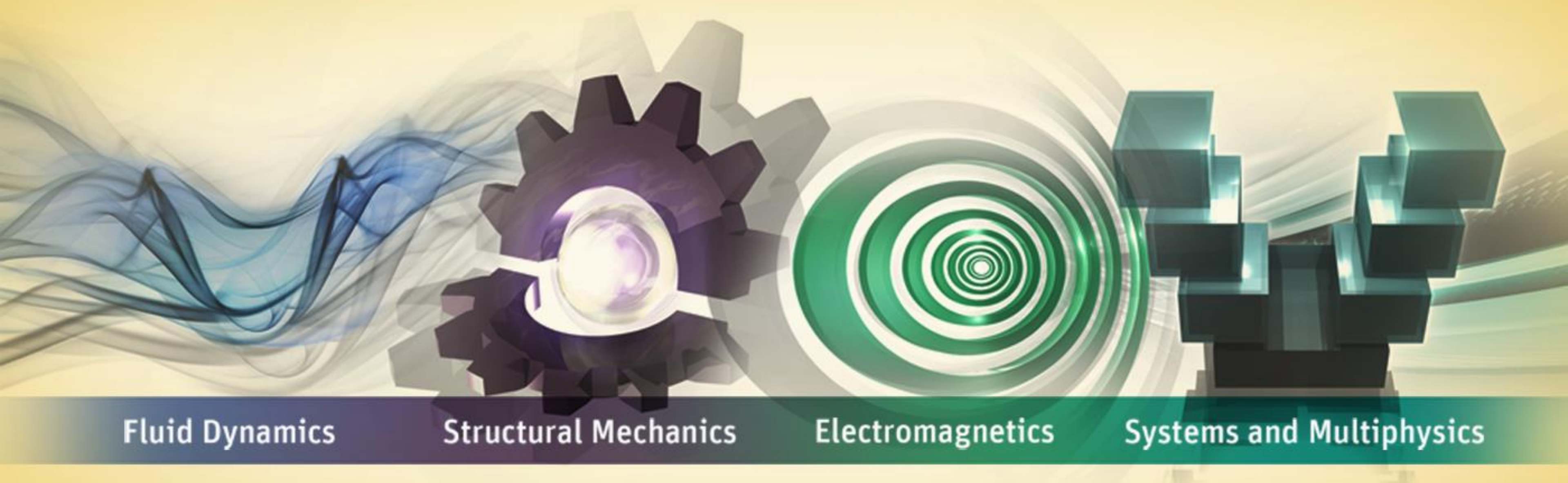
Wireless Power Transfer System Design



Julius Saitz

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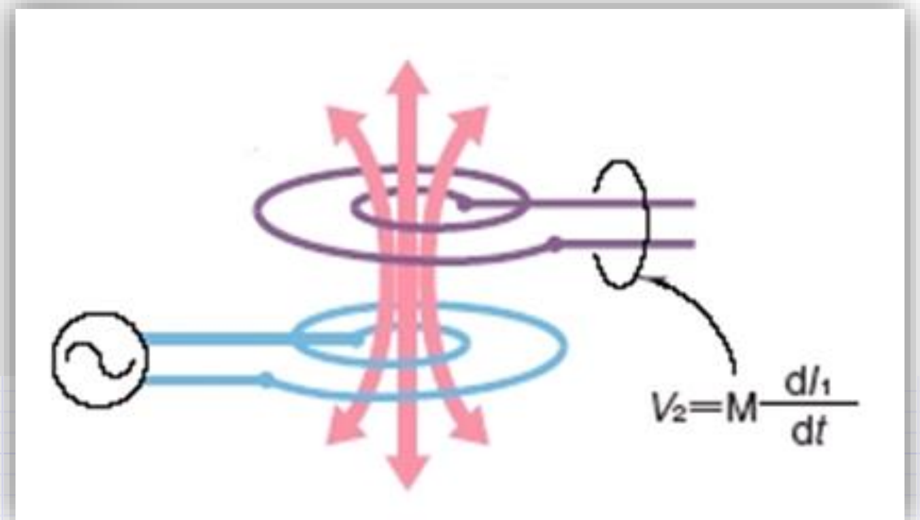
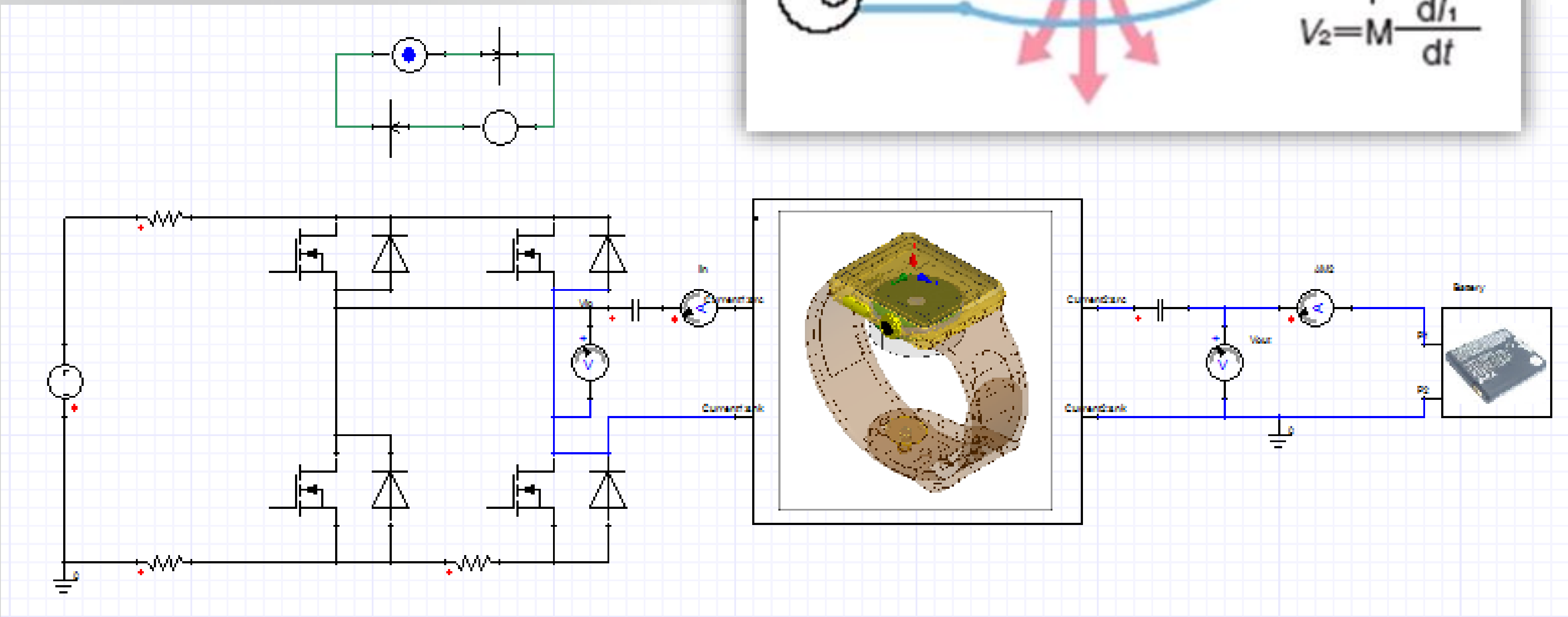
WPT System



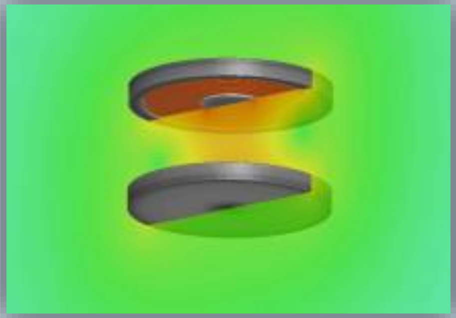


  April 27, 2015

Wireless Power Transfer (WPT)

Near-Field (Inductive coupling, resonant)

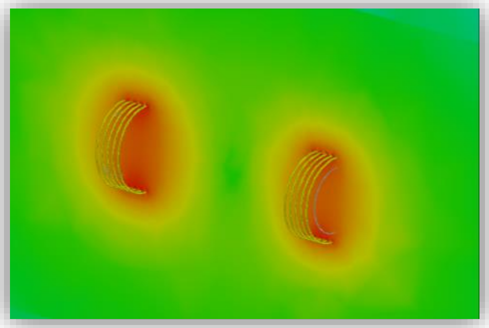
- Do not rely on propagating EM waves
- Operate at distances less than a wavelength of transmission signal
- Resonance obtained by use of external circuit capacitor
- Electric and magnetic fields can be solved separately



Focus of this presentation

Far-Field (resonant)

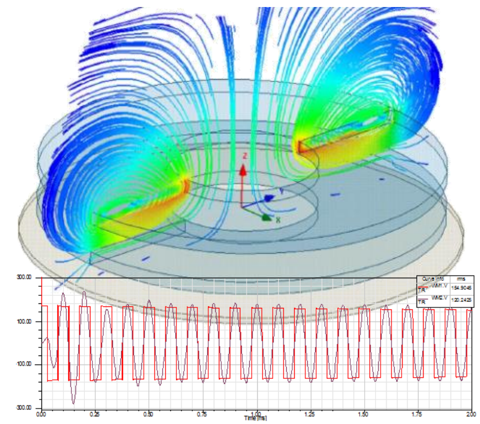
- Operating range to ~10 meters
- Self capacitance of coil turns are of importance
- Requires full wave solver with coupled electric and magnetic fields



Design Challenges

Magnetic Analysis

- Inductance/Resistance calculations versus frequency
- Ensure linear mode operation
- Relative Position sensitivity study
- Loss evaluation
- Effect of temperature on magnetic performance



Wireless Power Transfer

Circuit Analysis

- Operate in resonant mode, considering magnetic results
- Compute efficiency considering relative position
- Transient simulation considering frequency dependent effects

Thermal Management

- Consider local losses distribution in thermal evaluation
- Consider changing of electrical properties with temperature

Outline

- Large Gap Transformer Design Using Computational Electromagnetics
- Combination of Circuit and Magnetic Analysis for Resonance
- Thermal Management

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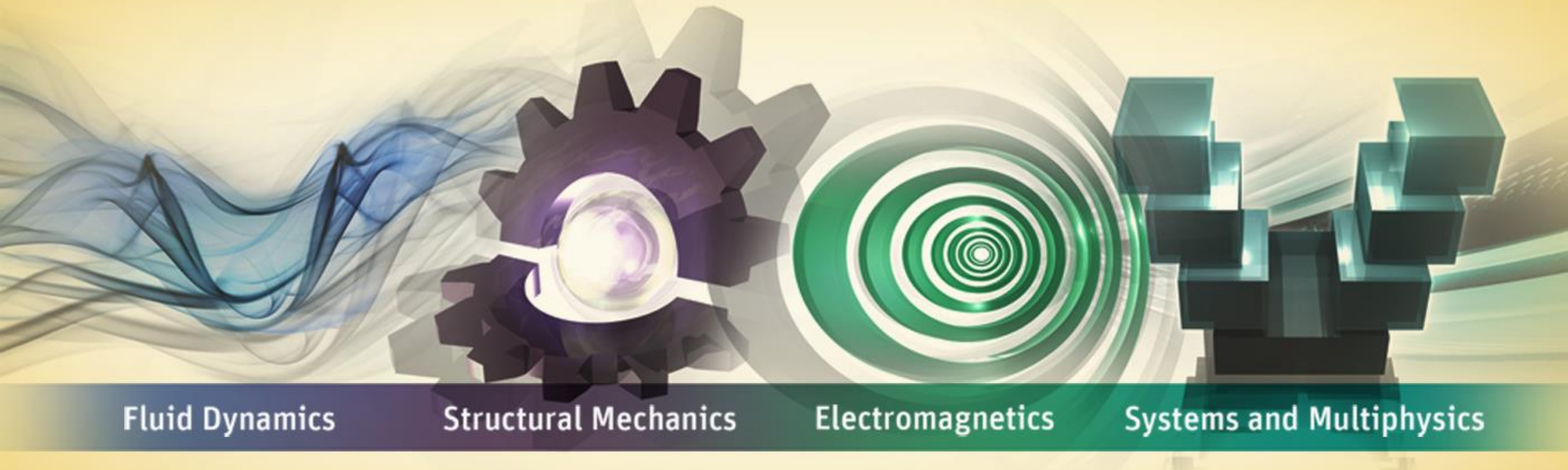
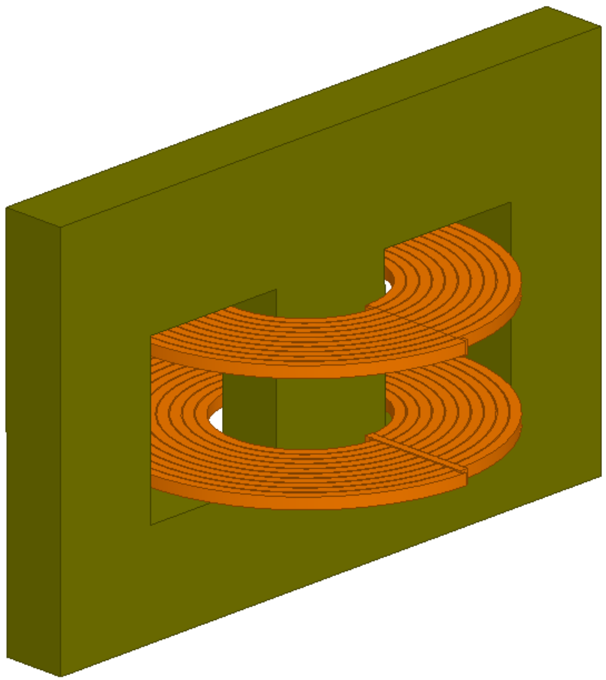
Large Gap Transformer Design Using Computational Electromagnetics



Regular Transformer

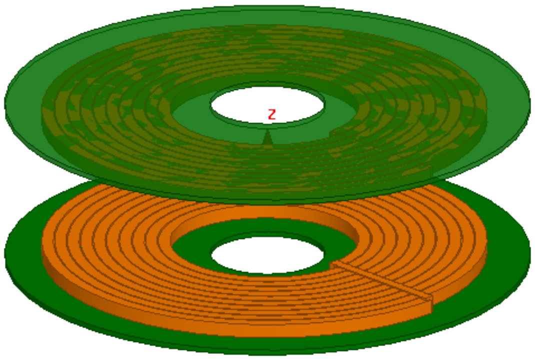
- Low reluctance flux path is available
- Mutual Coupling between the coils can be easily determined using Magnetic Circuit approach
- Leakage flux can be considered to be negligible
- Mutual inductance can be derived using flux balance
- Analytical solution possible within permissible level of accuracy



Large Gap Transformer

- No Specific path for the magnetic flux
- Leakage flux is significant enough and can not be neglected
- Analytical methods are proposed for calculation of Mutual inductance using Maxwell's formula for two coaxial circular coils

$$M = \frac{2\mu_0\sqrt{R_p R_s}}{k}\left[\left(1-\frac{k^2}{2}\right)K(k)-E(k)\right]$$



Application of these formulas to real life cases is almost impossible

Computation Electromagnetics can help to reduce problem complexity significantly

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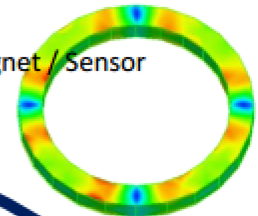
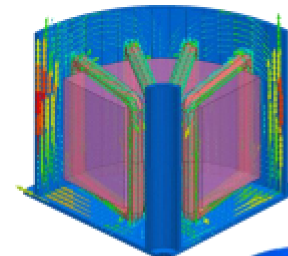
Maxwell

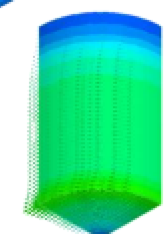
Maxwell is the electromagnetic field analysis software using the Finite Element Method

Magnet / Sensor

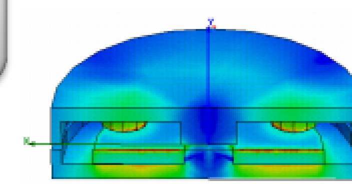


Transformer / Inductor

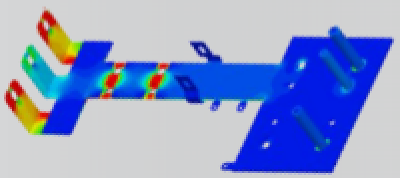




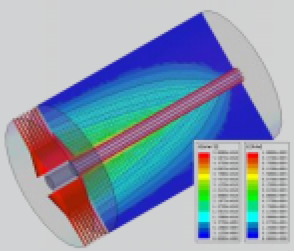
Induction Heating



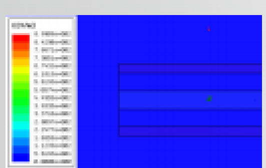
Motor / Actuator



Busbar



Cable



Capacitor

Magnetostatic

Eddy Current

Magnetic Transient

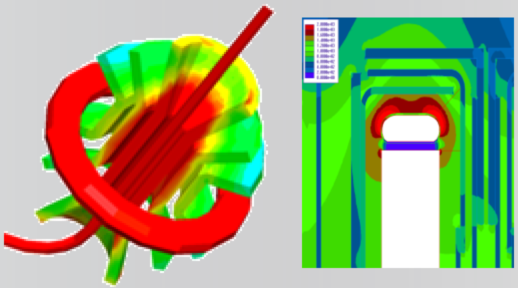
Electric Transient

Electrostatic

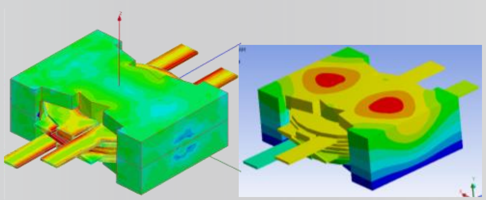
DC Conduction

Maxwell

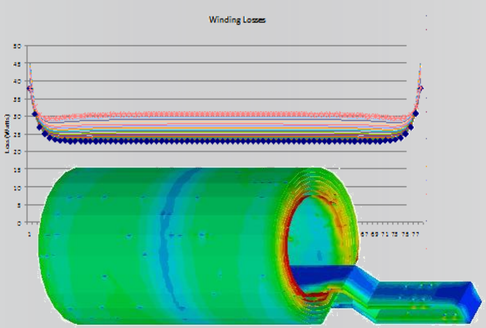
Transformers



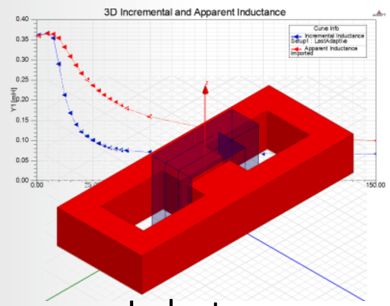
Insulation – Dielectric Withstand, Maximum E-field



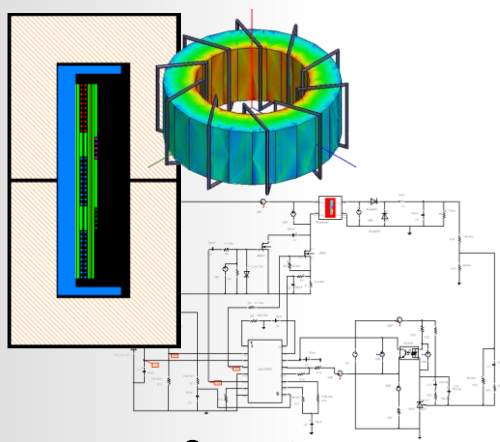
Losses and Temperature in Ferrite Core



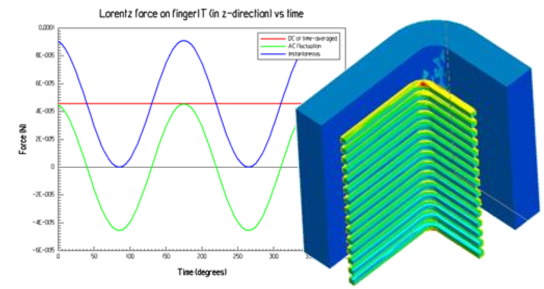
Load Analysis Foil Losses



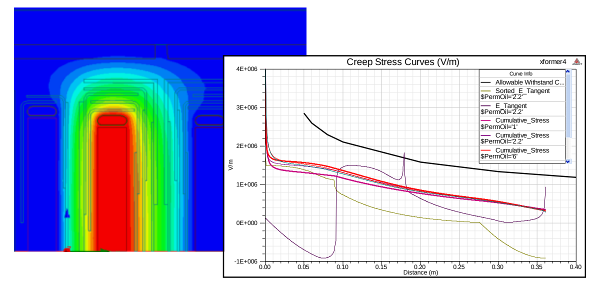
Inductance



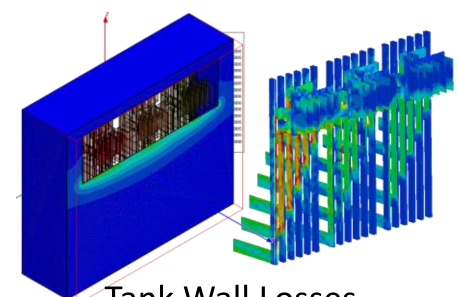
Converters



Lorentz Force



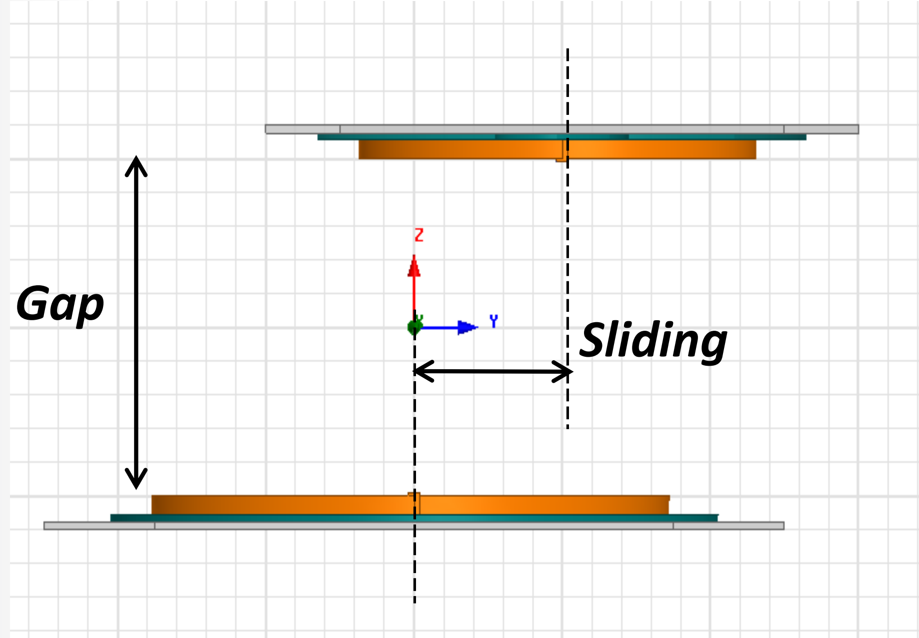
Creep Stress



Tank Wall Losses
Bus Bars

WPT Magnetic simulation Flow Chart

Magnetic Field Solver
+
Circuit / System Simulator



Magnetostatic

Core, Winding

Eddy Current
(time harmonic)

Impedance Model

Circuit / System
Simulator
(AC / TR)

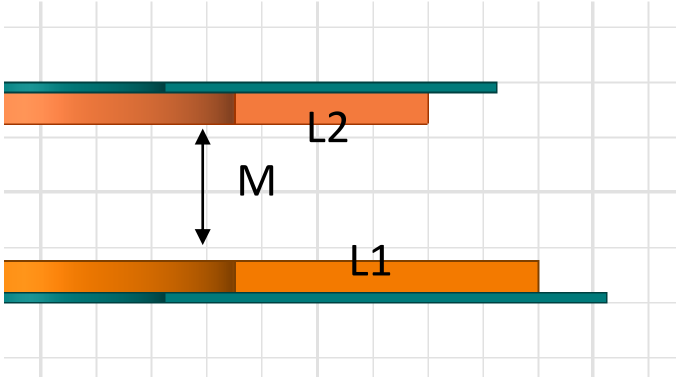
Eddy Current

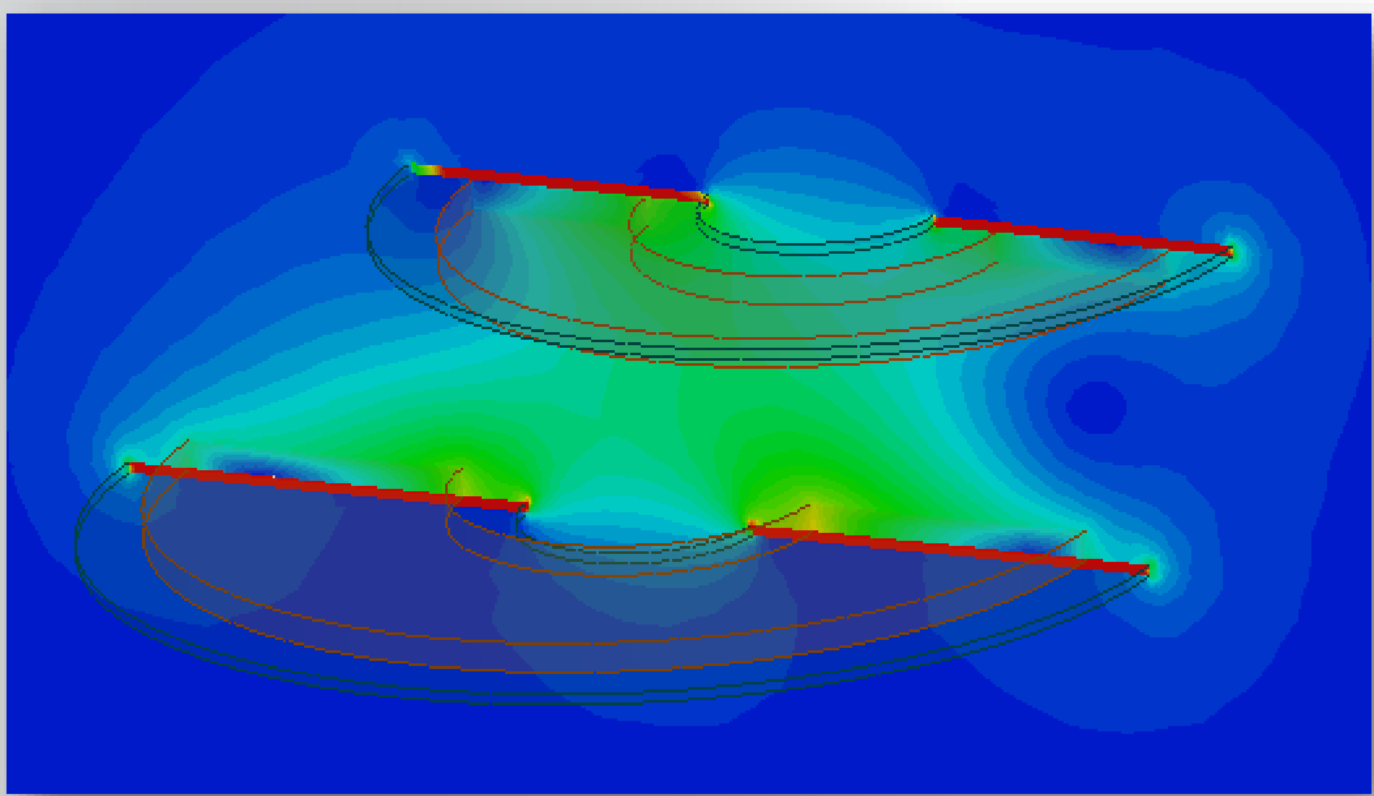
Fields, Losses

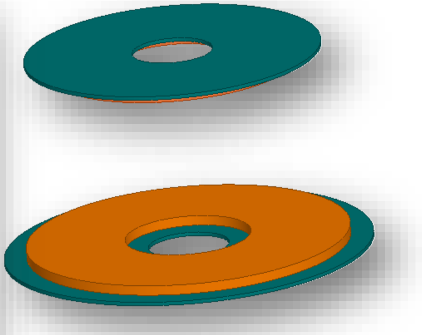
Circuit / Drive / Controller design
Waveform, Efficiency, Power factor, Response

Magnetostatic Analysis

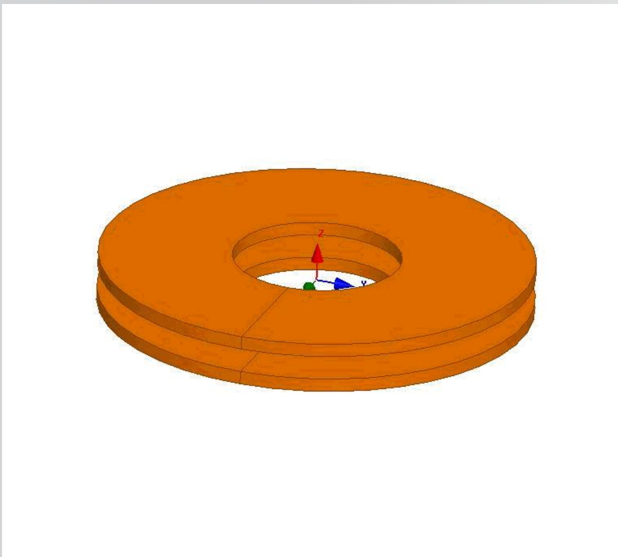
- Saturation
- Magnetic shielding
- Self and Mutual Inductance
- Coupling Coefficient

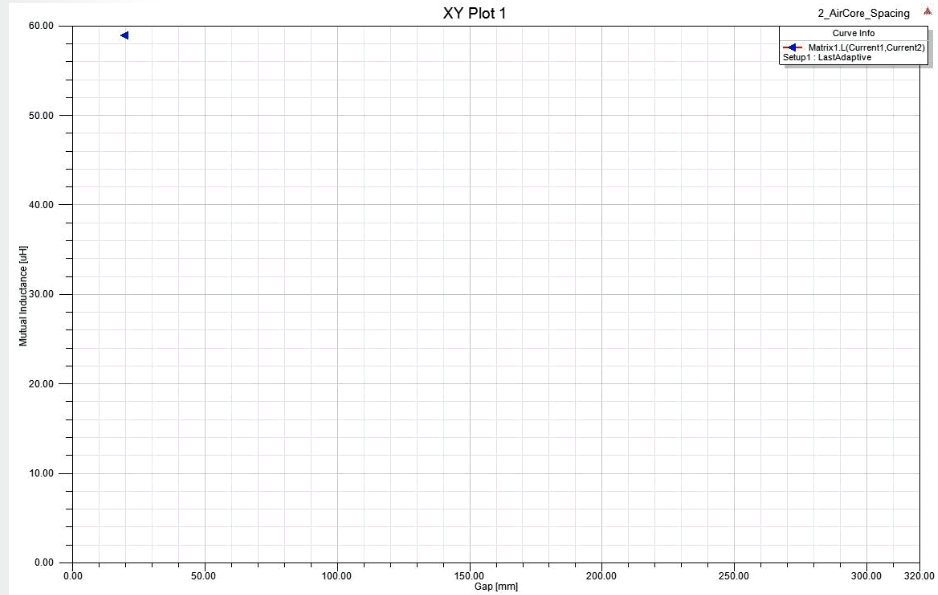


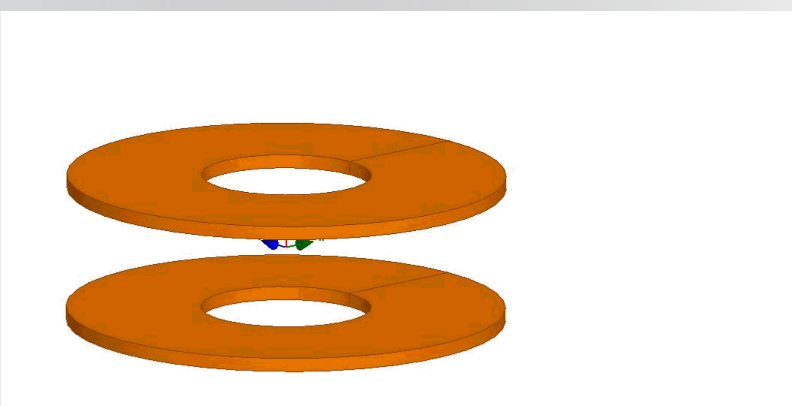


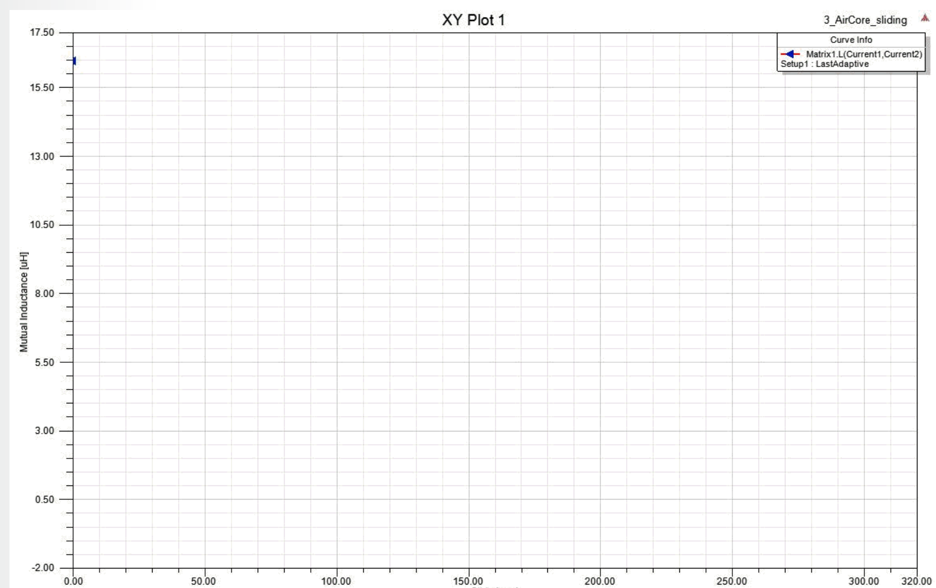


Parametric Analysis using Maxwell





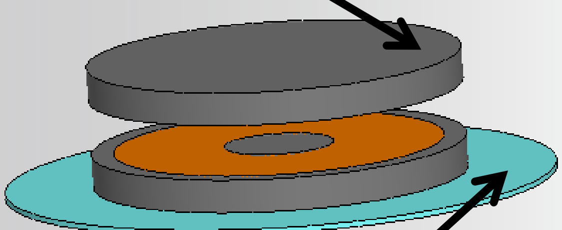




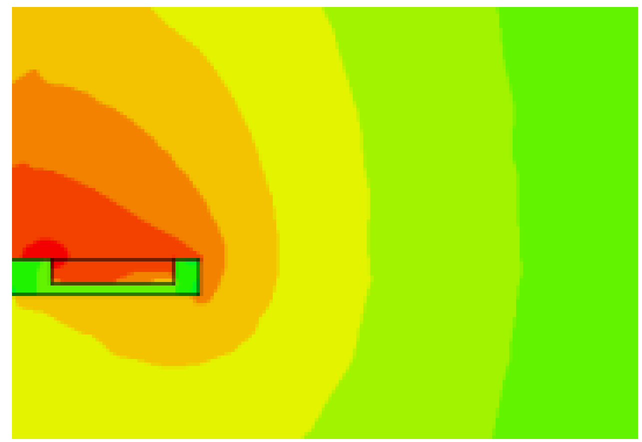
Eddy Current (Frequency domain)

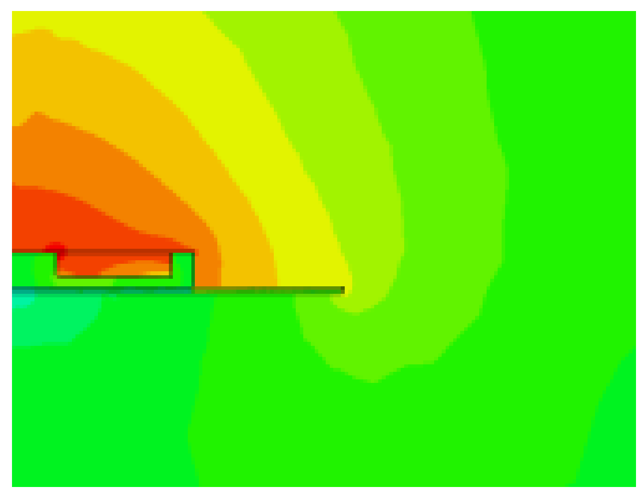
- Impedance vs frequency
- State Space Model for Circuit Analysis
- Losses
- Eddy current shielding

Core(Power Ferrite)



Shield Plate (Aluminum)





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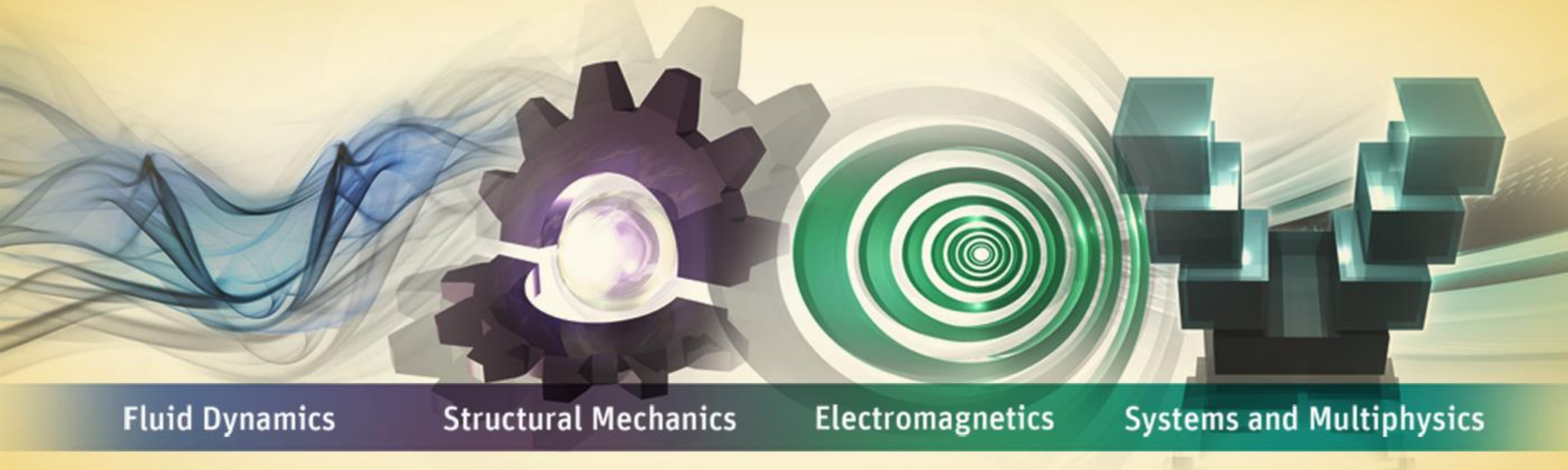
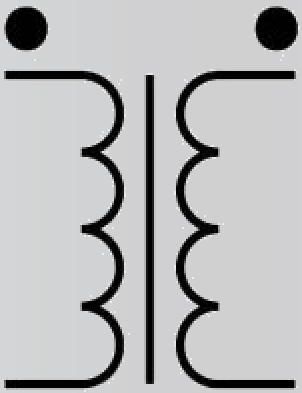
Combination of Circuit and Magnetic Analysis for Resonance

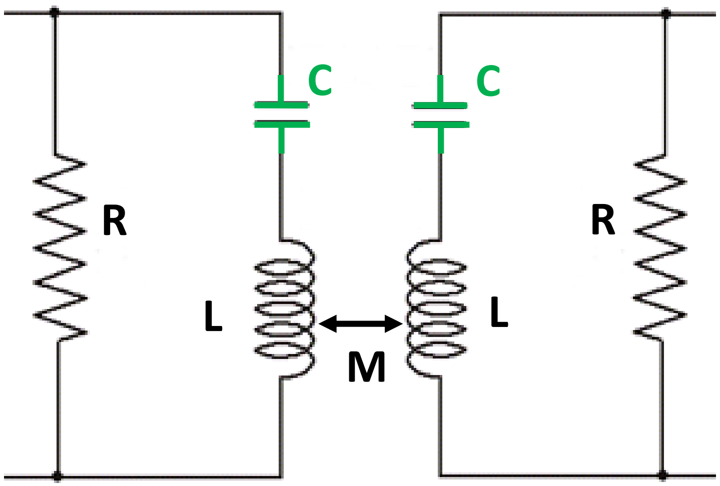


Inductive Type Coupling – Near Field

1) Electromagnetic analysis to determine R, L, M

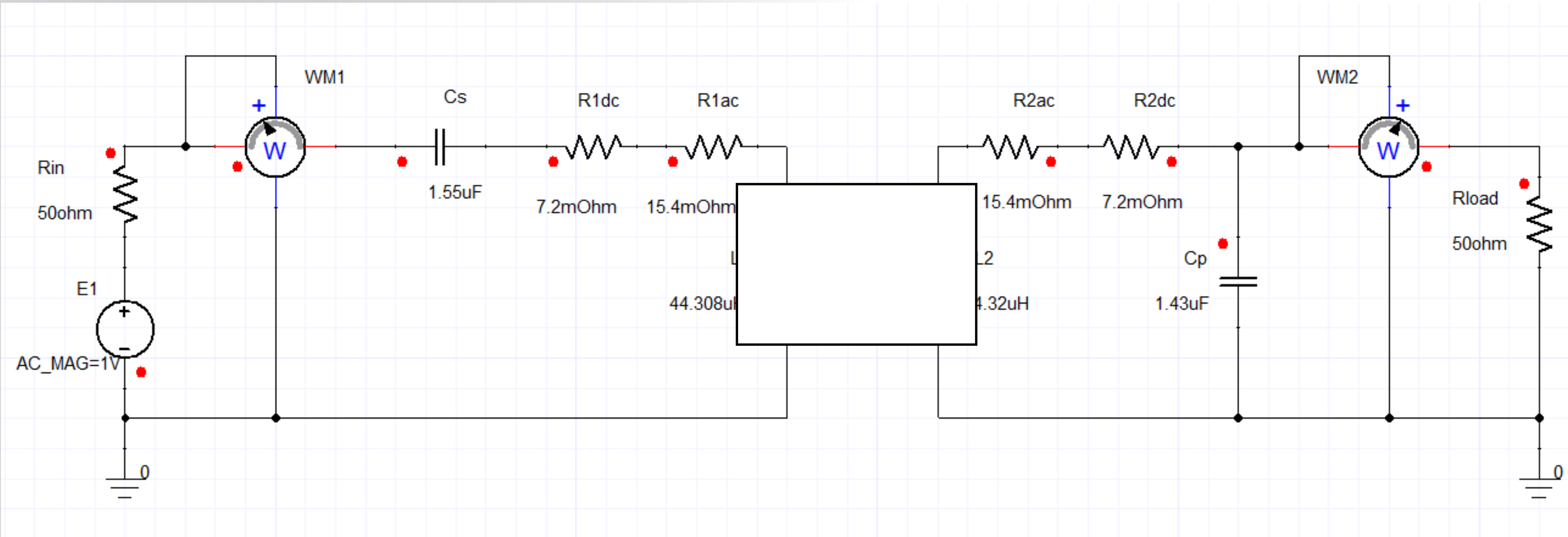


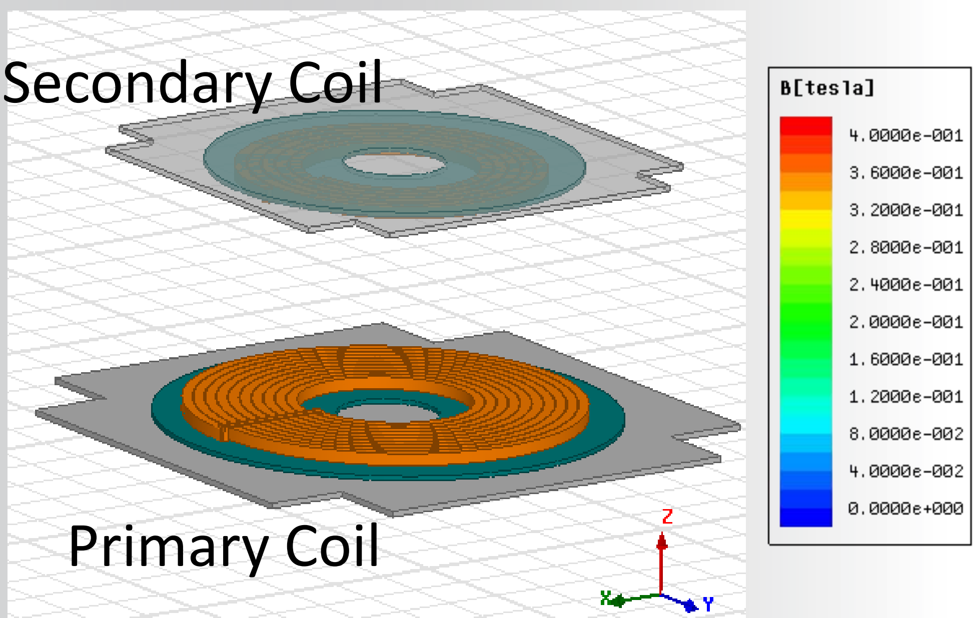
Magnetic → R, L, M



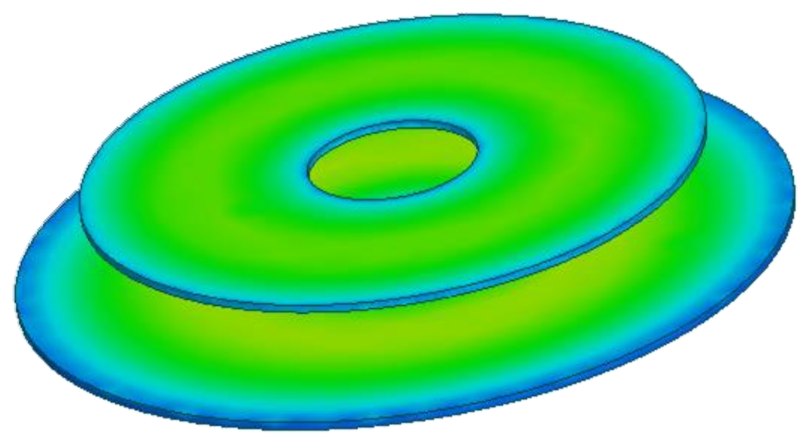
2) Resonant circuit realized by a lumped capacitance parameter in the circuit simulator

System Approach with Simplorer

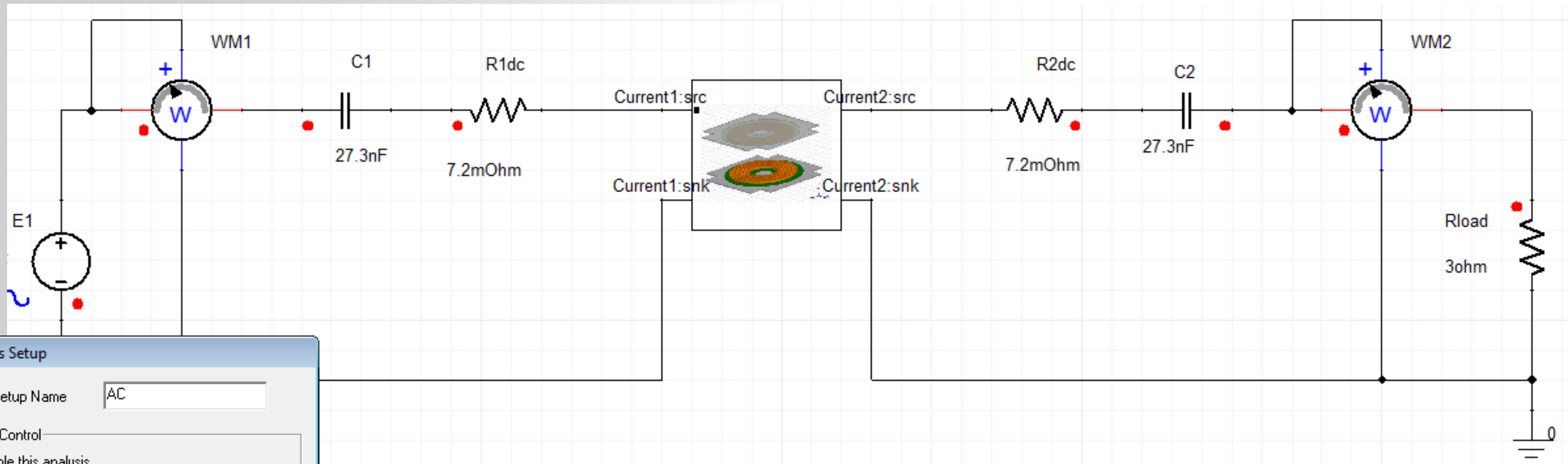


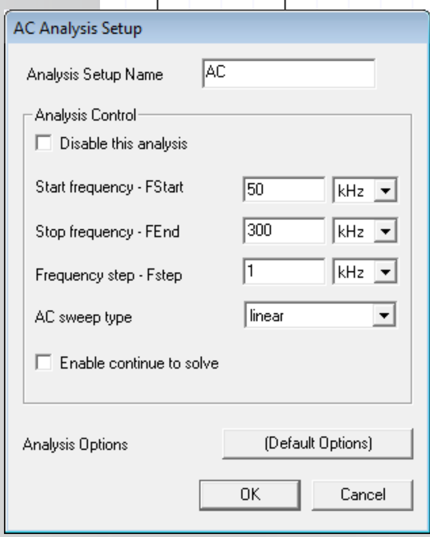


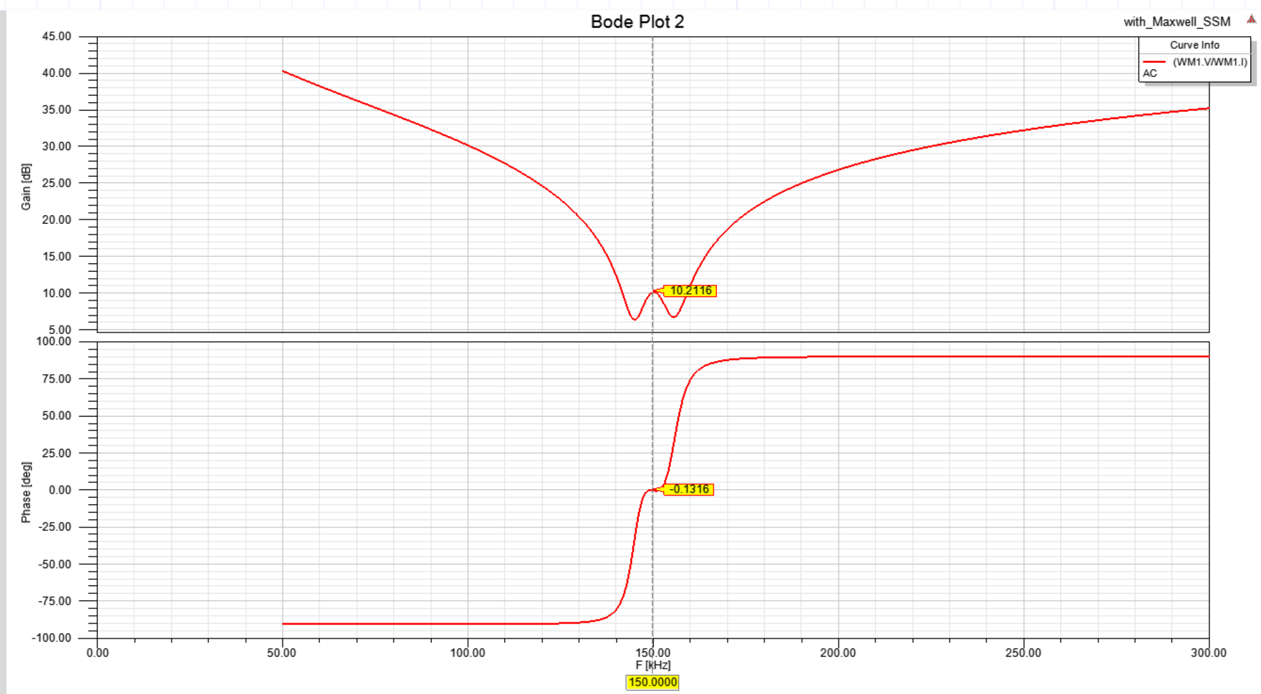
Reduced Order Model (ROM)



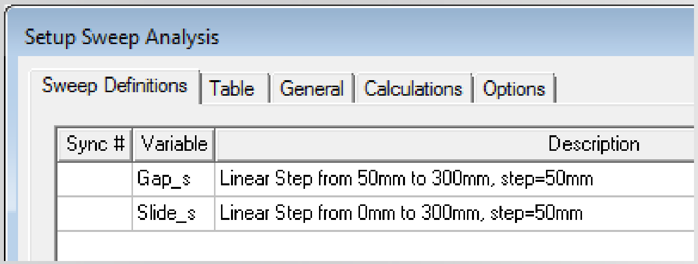
Frequency Domain Analysis: System Level

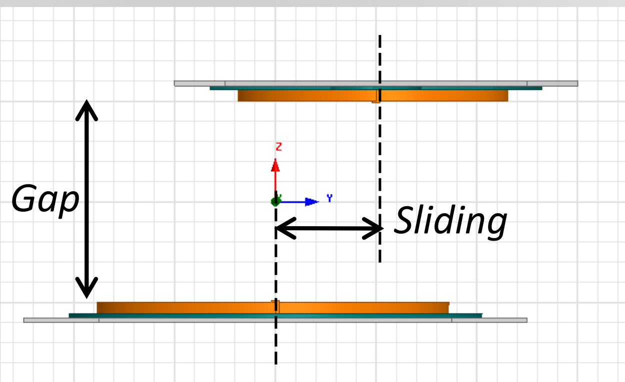


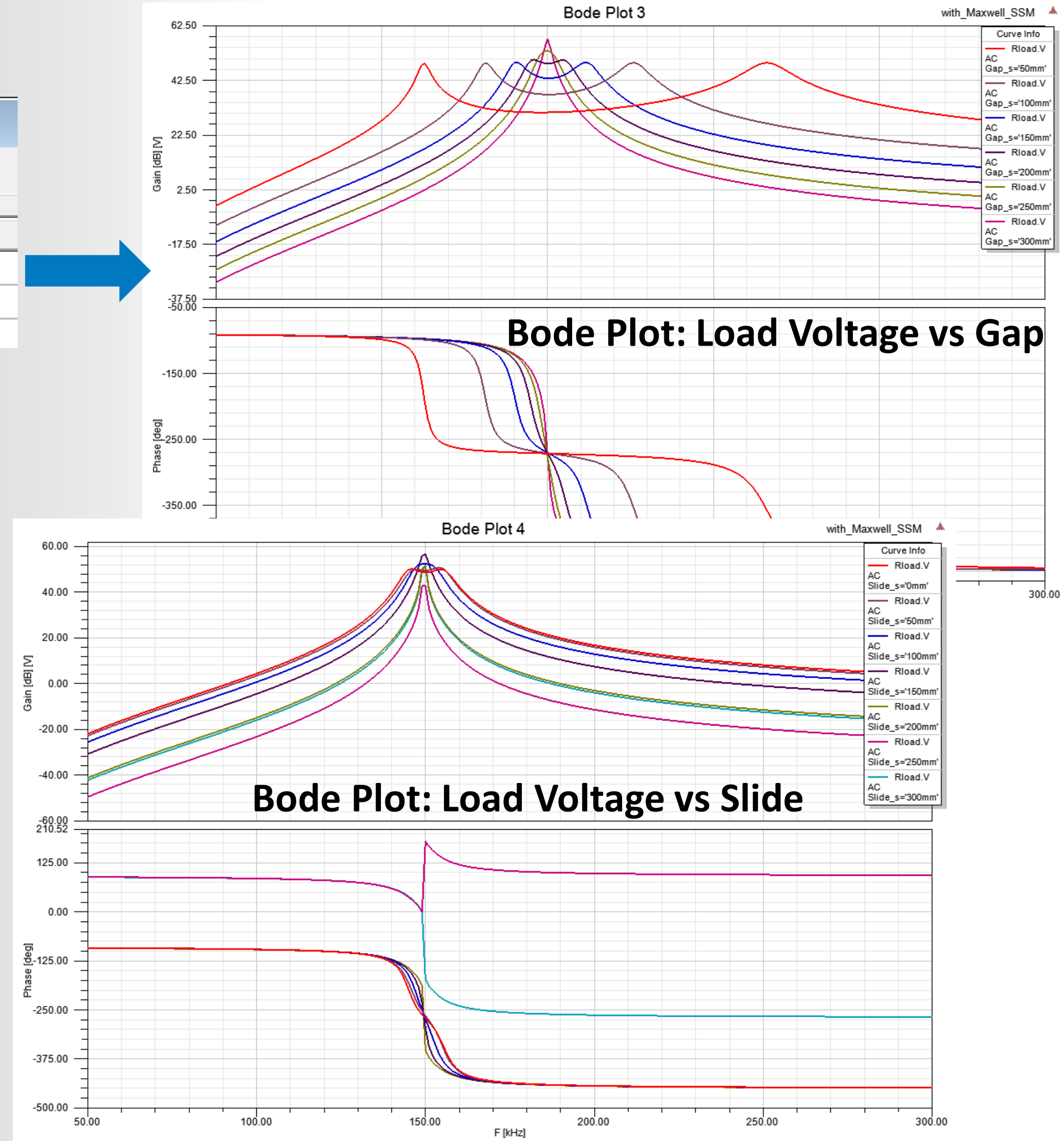




Parametric Analysis: Frequency Domain

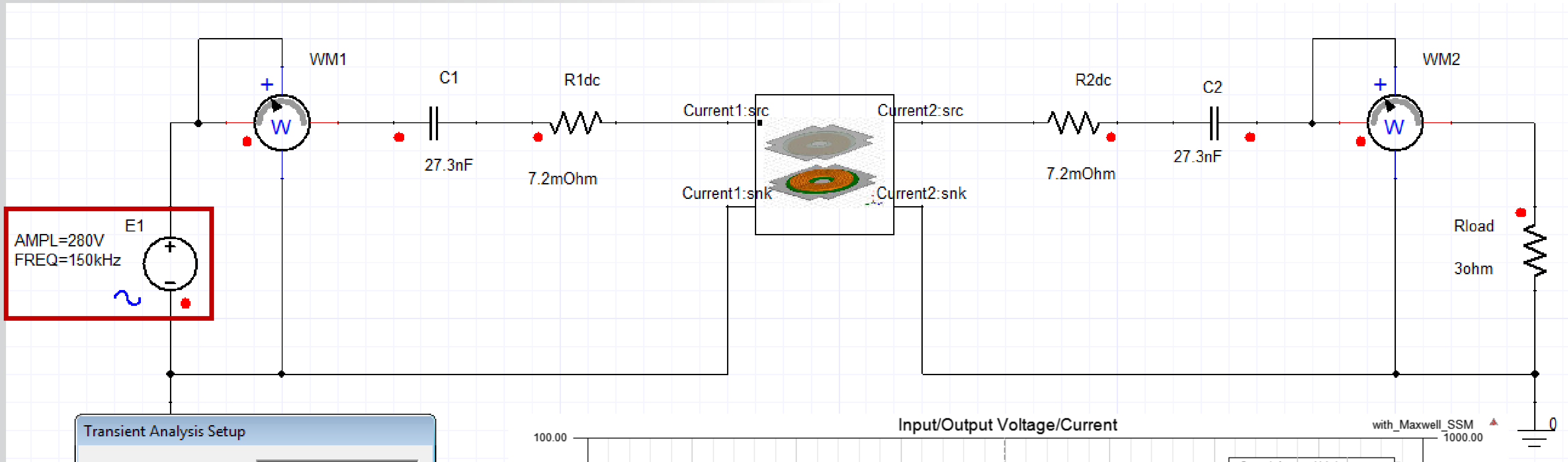


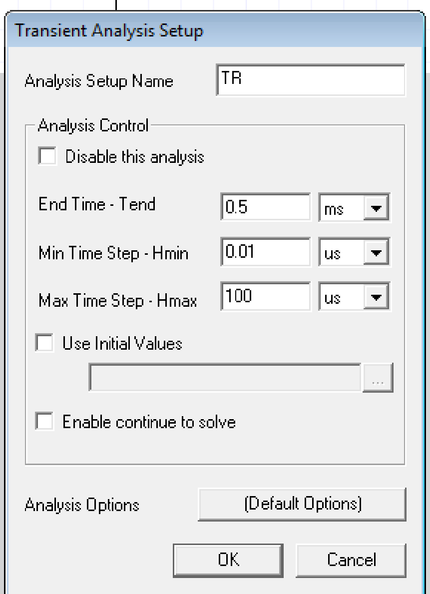




Geometric parameters are Available in the circuit environment

Transient Analysis




Transient Analysis Setup

Analysis Setup Name: TR

Analysis Control

- [ ] Disable this analysis

End Time - Tend: 0.5 ms

Min Time Step - Hmin: 0.01 us

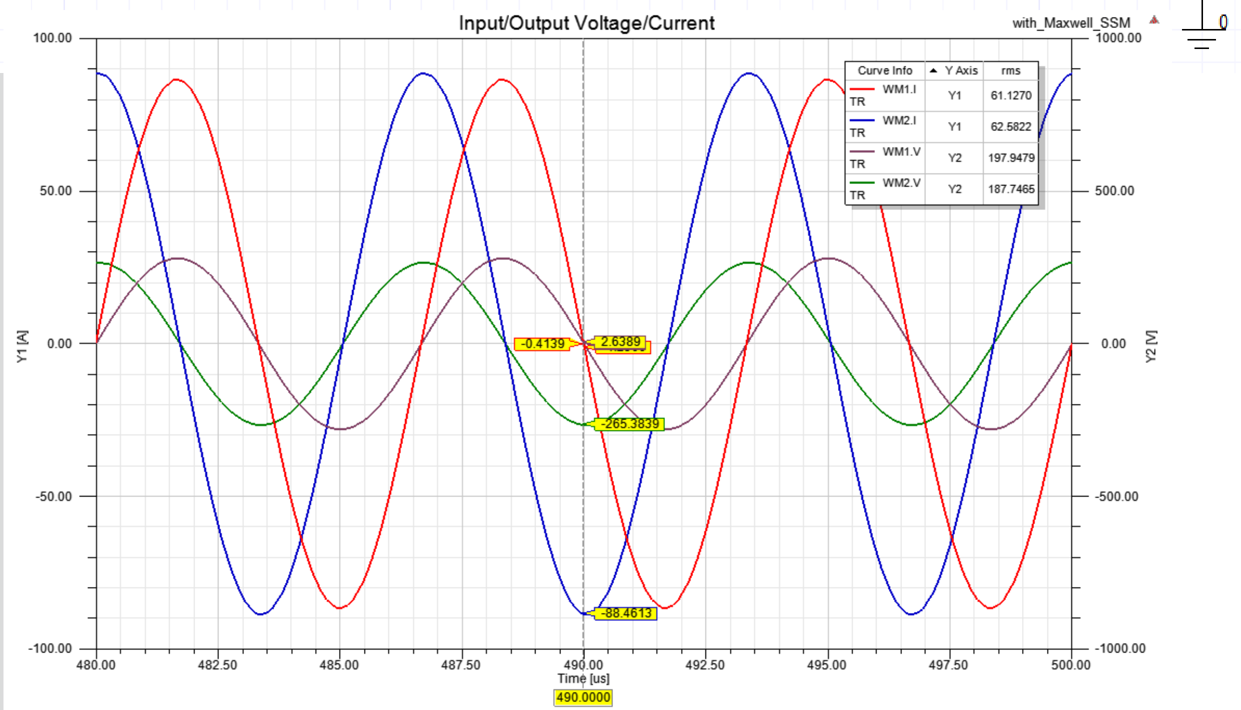
Max Time Step - Hmax: 100 us

- [ ] Use Initial Values

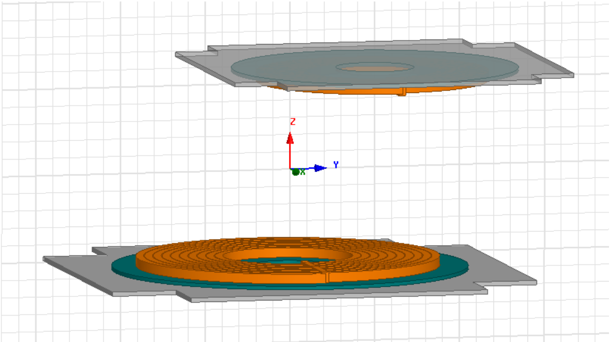
- [ ] Enable continue to solve

Analysis Options: (Default Options)

OK | Cancel



Efficiency Map

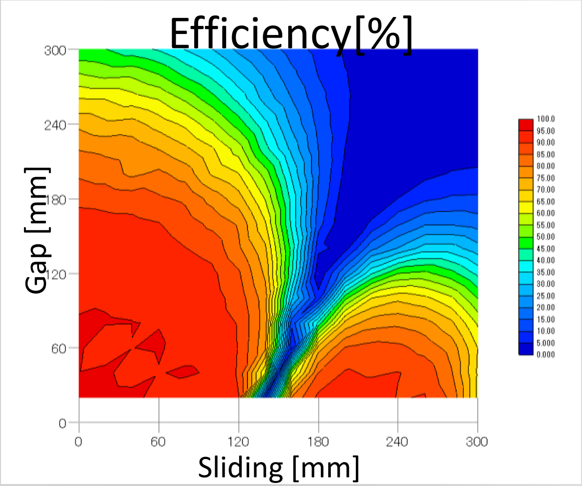


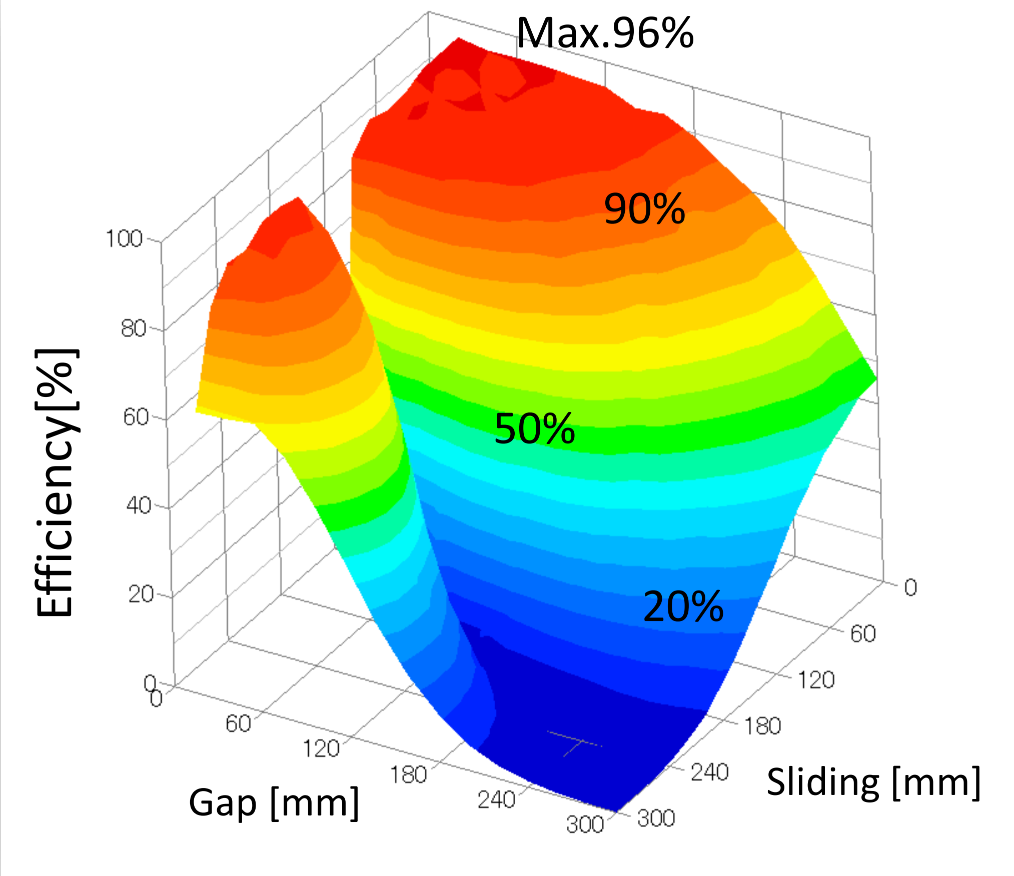
Output/Input Power

Tuned capacitance for each conditions

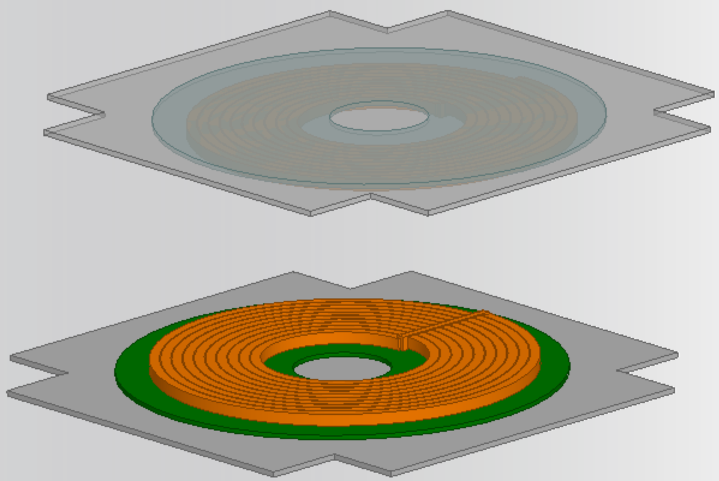
$$P = VI\cos\theta$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100[\%]$$

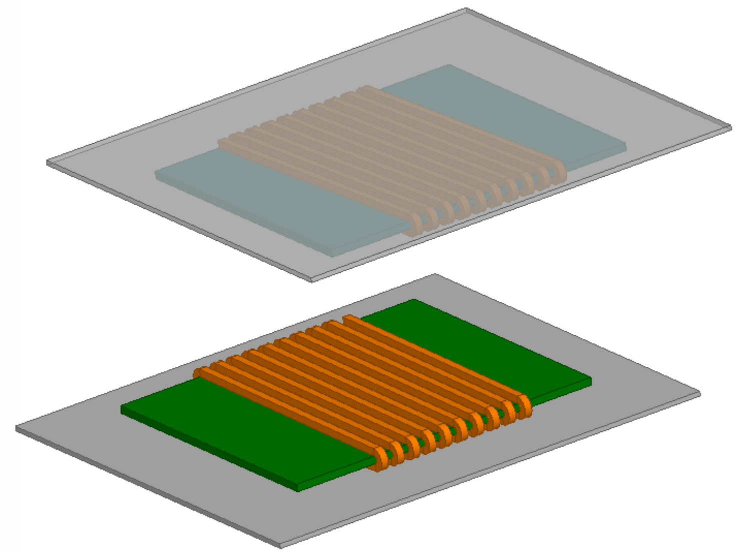




Optimize the Design: Various Shape Types



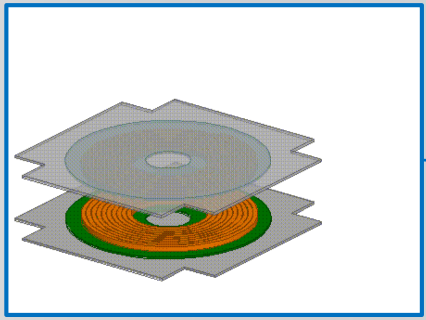
Disk Coil type

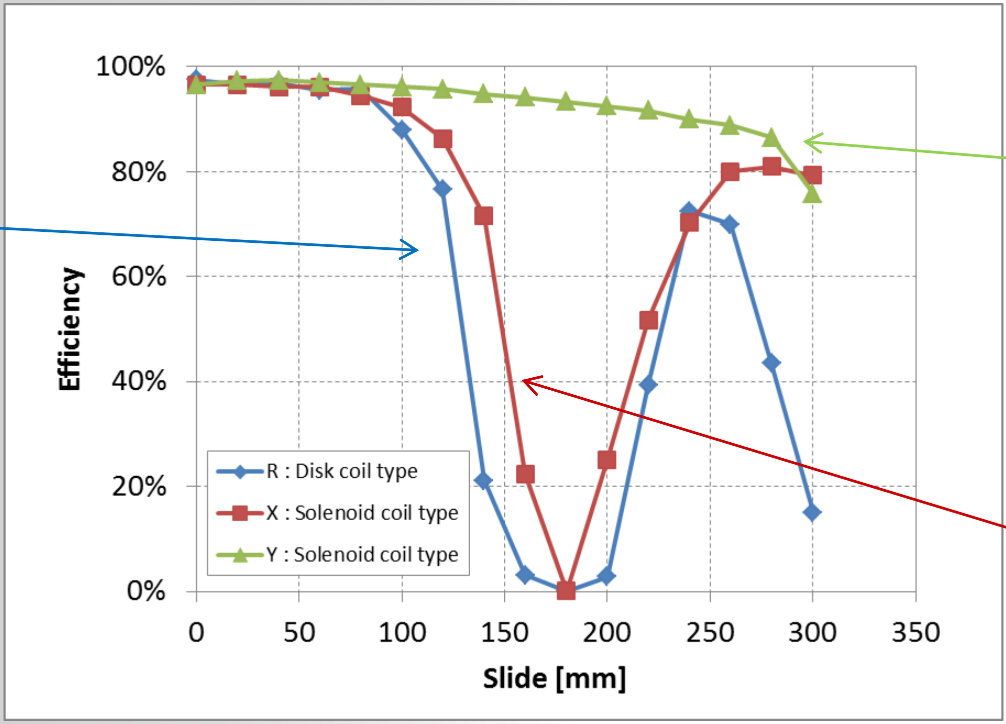


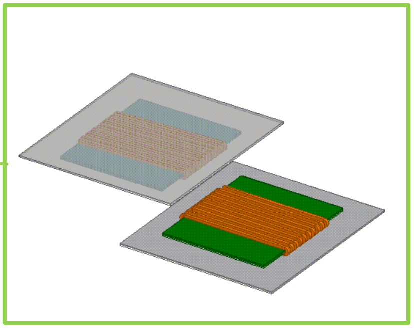
Solenoid Coil type

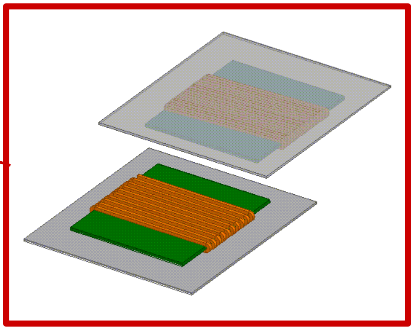
Efficiency as a function of sliding direction and distance

- Gap between coils kept constant



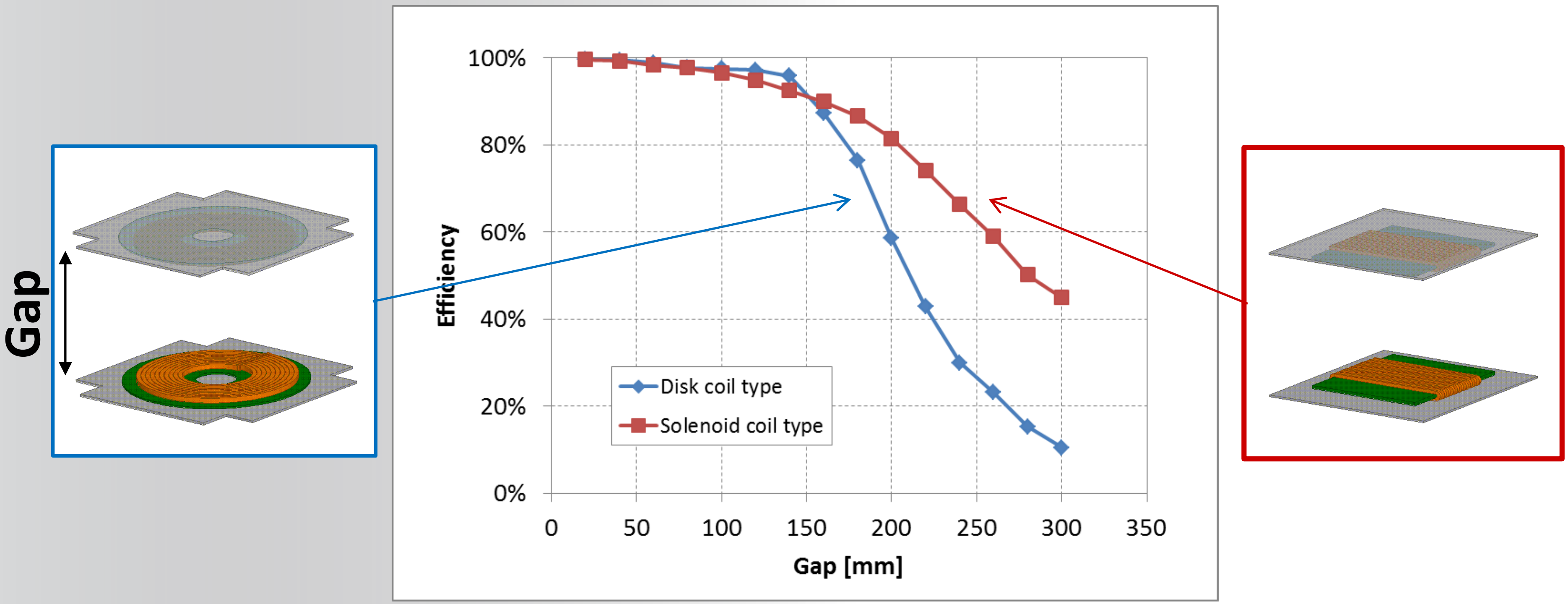




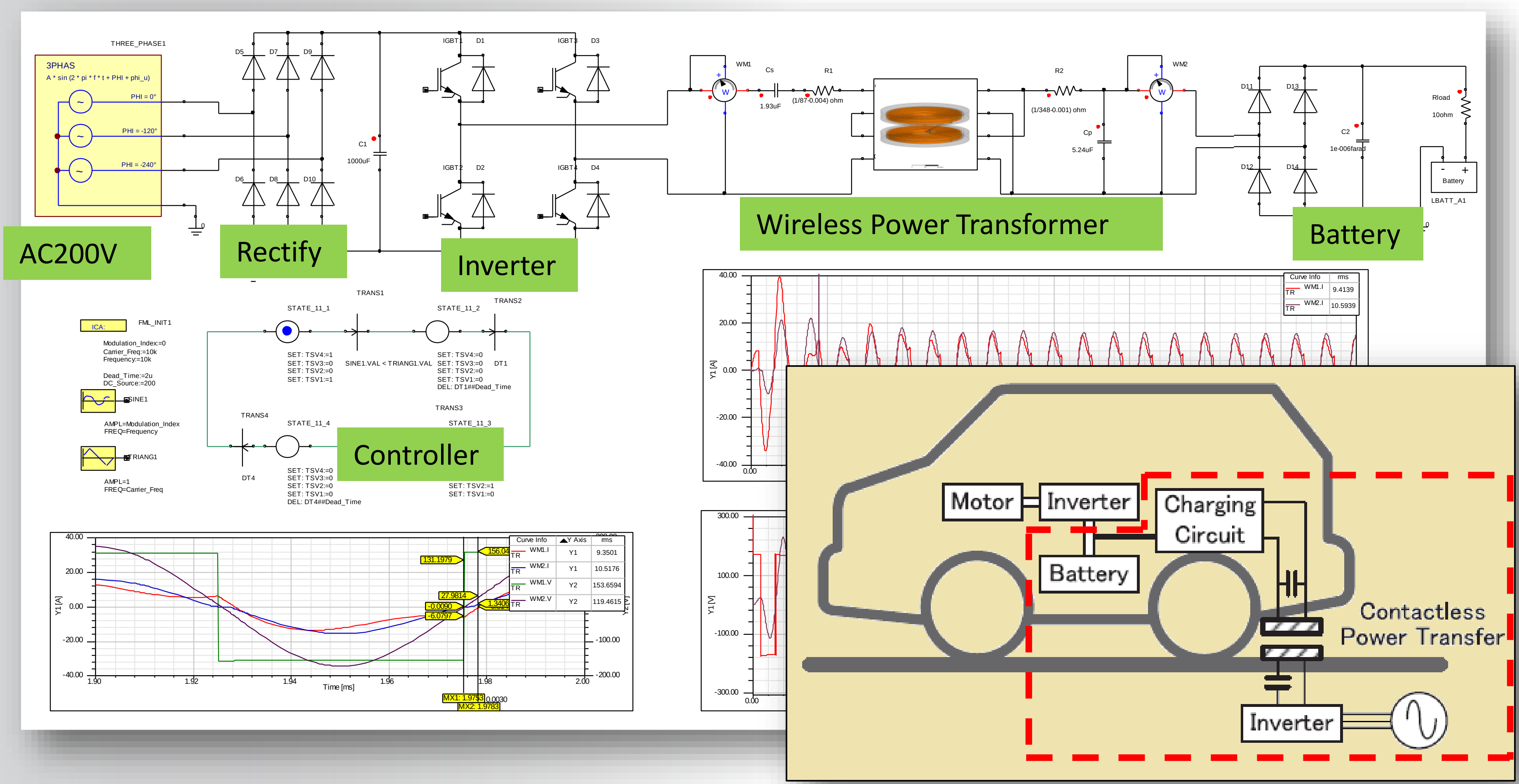


Efficiency as a function of gap between coils

- Zero sliding



System Simulation – WPT



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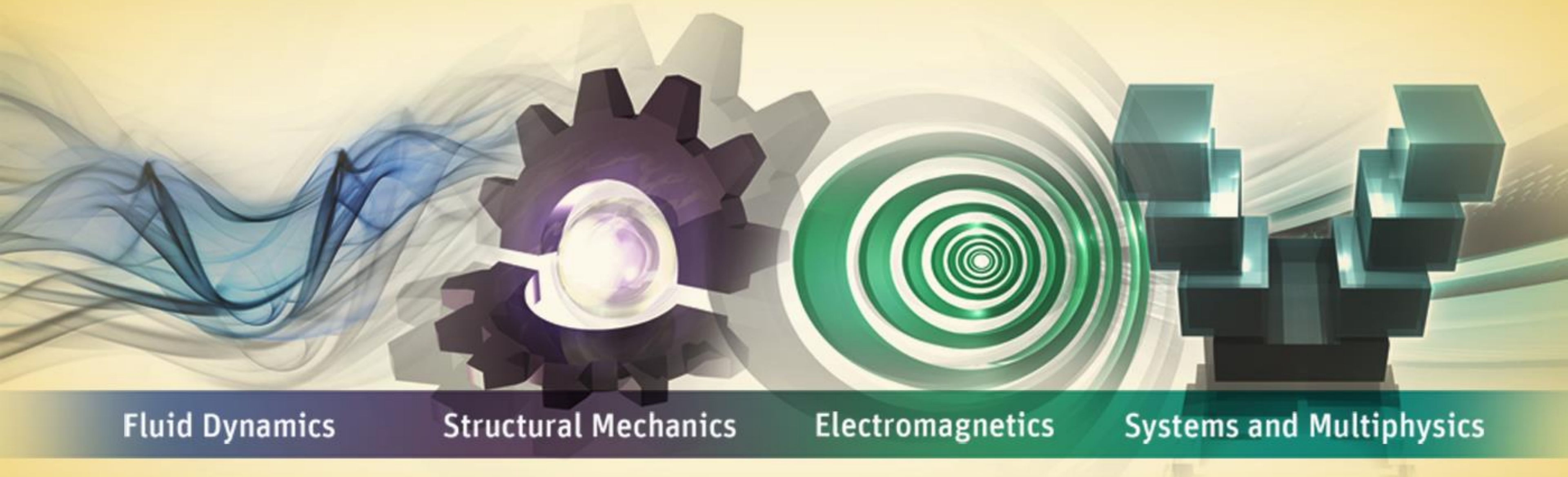
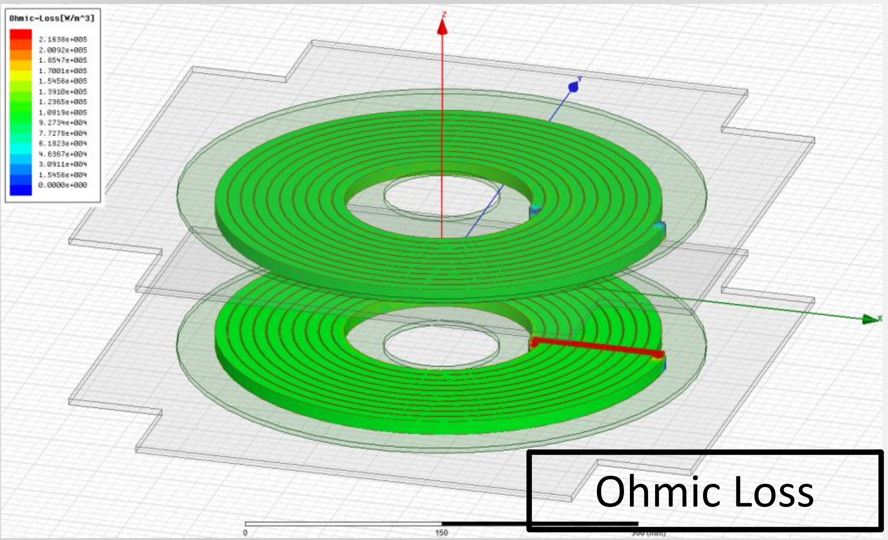
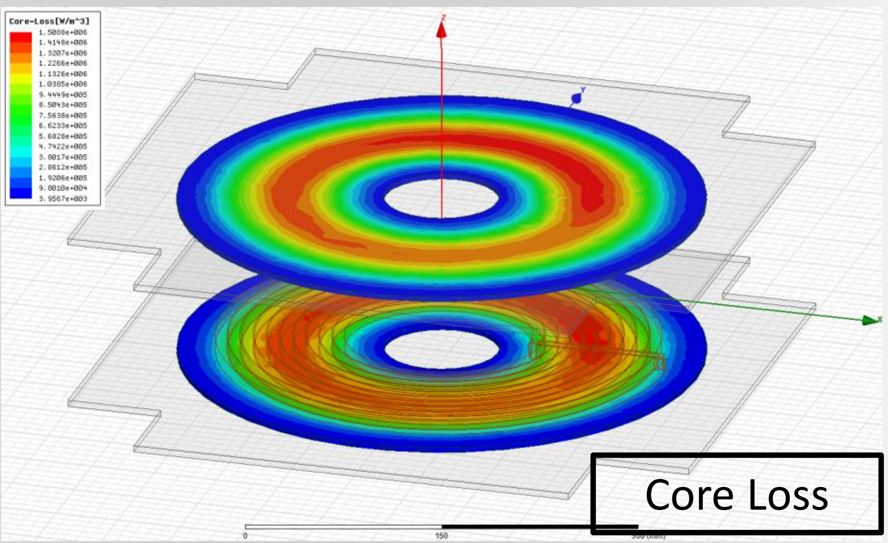
Thermal Management



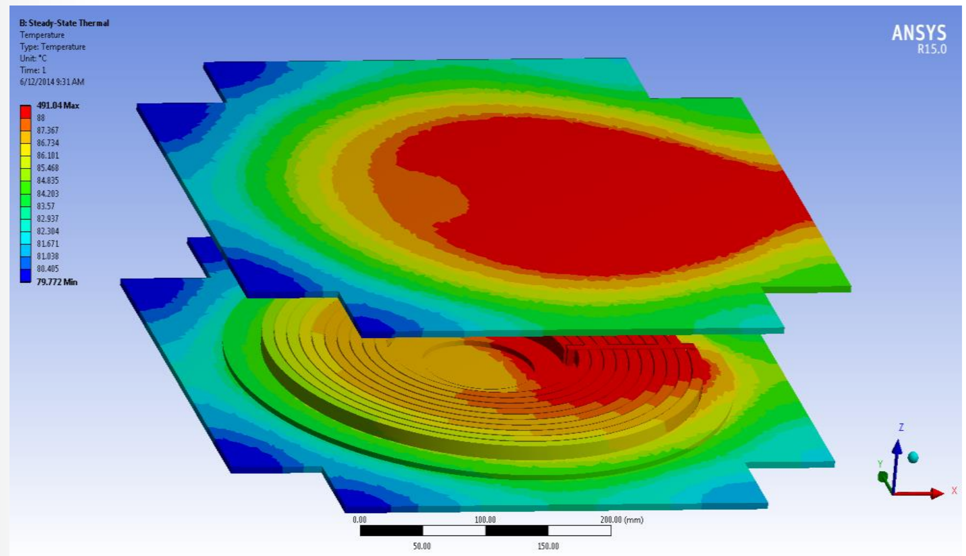
Temperature in ANSYS Mechanical or CFD



Ohmic Loss



Core Loss

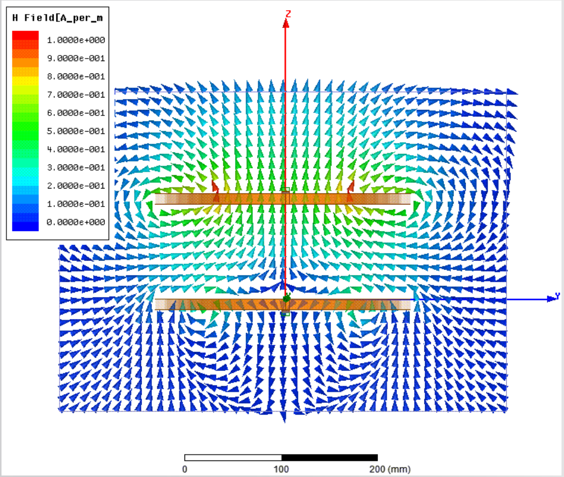


Temperature

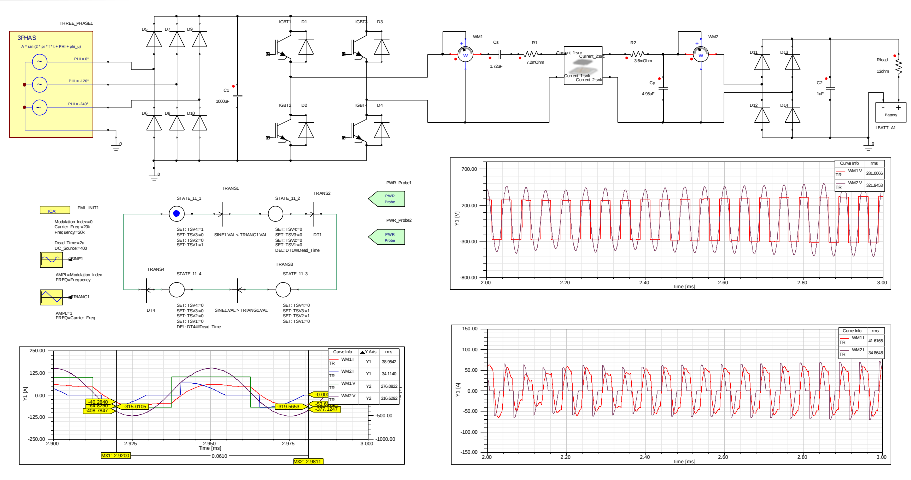
Summary

ANSYS offers a comprehensive modeling solution for Wireless Power Transfer systems:

- Magnetostatic
- Frequency domain
- Circuit and system level
- Thermal



Wireless Power Transfer Electromagnetics



System Level Modeling Electromagnetic-Circuit

