Fourier Analysis and Optimization of Inductive Wireless Power Transfer for Electric Vehicle Charging

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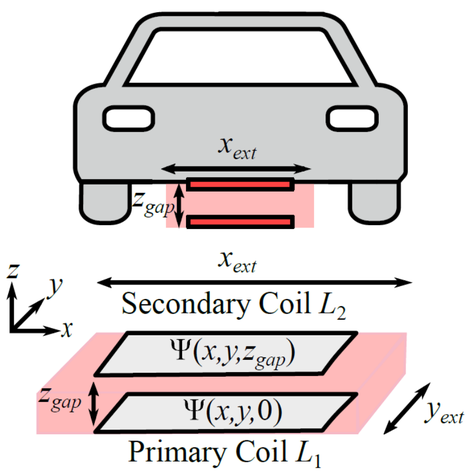
MOTIVATION

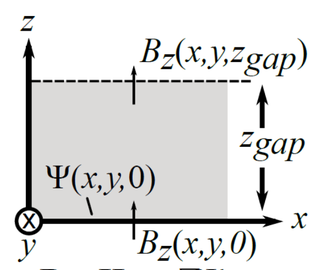
- Improve the power level and performance of wireless power transfer (WPT) for electric vehicles
- High power levels (120kW+) with high eff. and low stray field (<15μT for pacemakers) needed to compare with DC Fast charging

CHALLENGES

- Coil geometry has significant impact on system efficiency and stray field
- Difficult or time-consuming to parameterize coil geometries in FEA

APPROACH: FOURIER REPRESENTATION OF COIL SHAPES

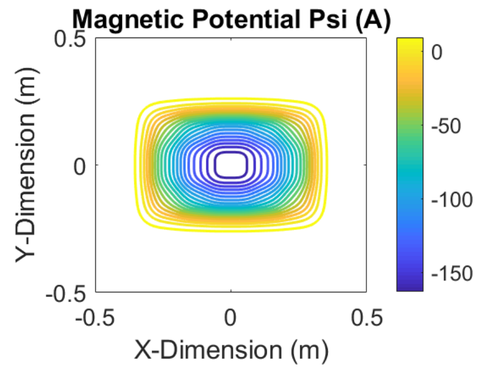




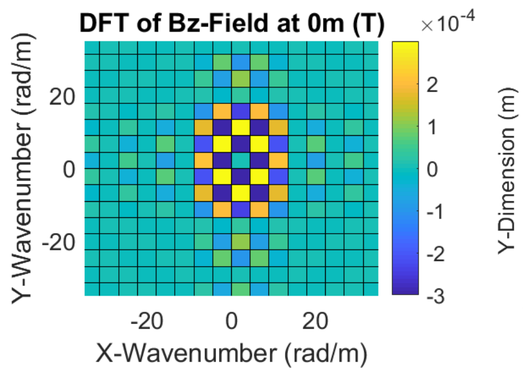
$\mathbf{B}=\mu\mathbf{H}=-\mu\nabla\Psi$

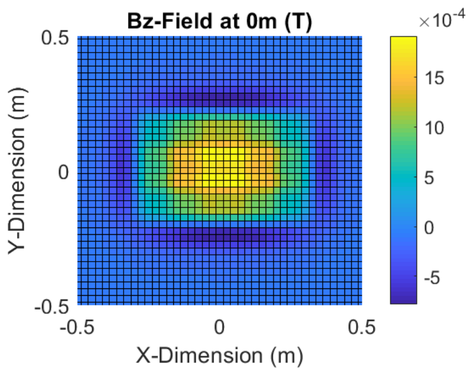
$B_z=-\mu\,\partial\Psi/\partial z=-\mu\gamma\Psi$

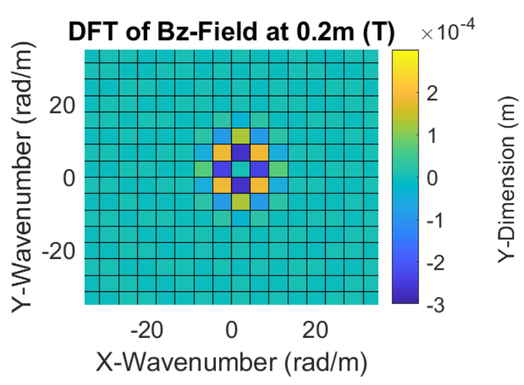
$\cos(k_x x)\cos(k_y y)=(e^{jk_x x}+e^{-jk_x x})(e^{jk_y y}+e^{-jk_y y})/4$

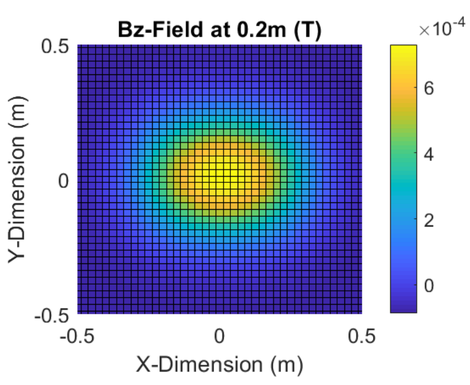


Set 1: $\cos k_x x \cos k_y y$









$$\nabla^2\mathbf{B}=\frac{\partial^2\mathbf{B}}{\partial x^2}+\frac{\partial^2\mathbf{B}}{\partial y^2}+\frac{\partial^2\mathbf{B}}{\partial y^2}=0$$

$$k_x^2+k_y^2+k_z^2=0$$

$$k_z=\pm\sqrt{-k_x^2-k_y^2}=\pm j\gamma$$

$$B_z(x,y,z)=B_0e^{j(k_xx+k_yy)}e^{j\left(j\sqrt{k_x^2+k_y^2}\right)z}=B_0e^{j(k_xx+k_yy)}e^{-\gamma z}$$

Inputs

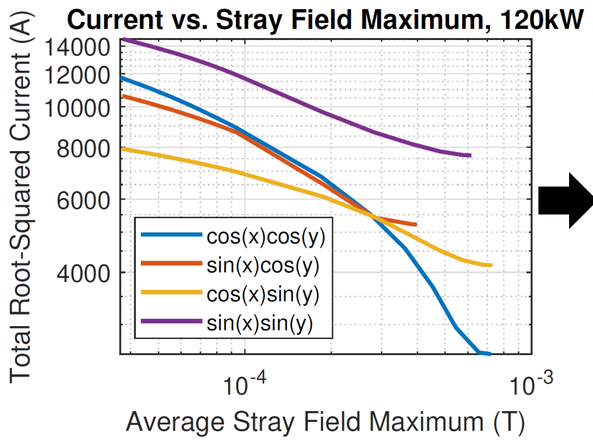
Coil Dimensions: 40cm x 50cm
Airgap: 210cm; Power Level: 120kW
Stray Field Limit: 5μT to 1mT @ 60cm x 60cm

Optimization Algorithm

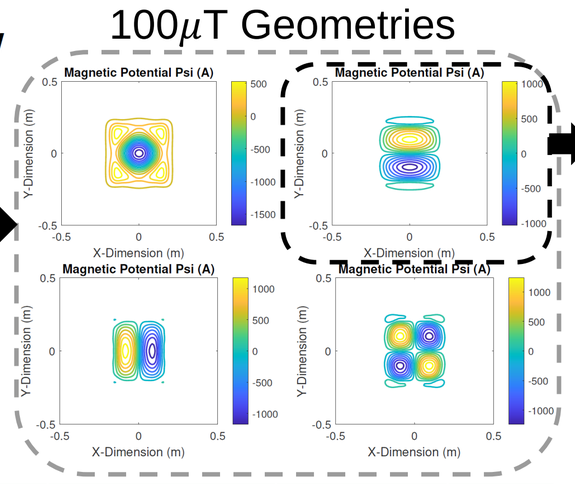
Post-Processing

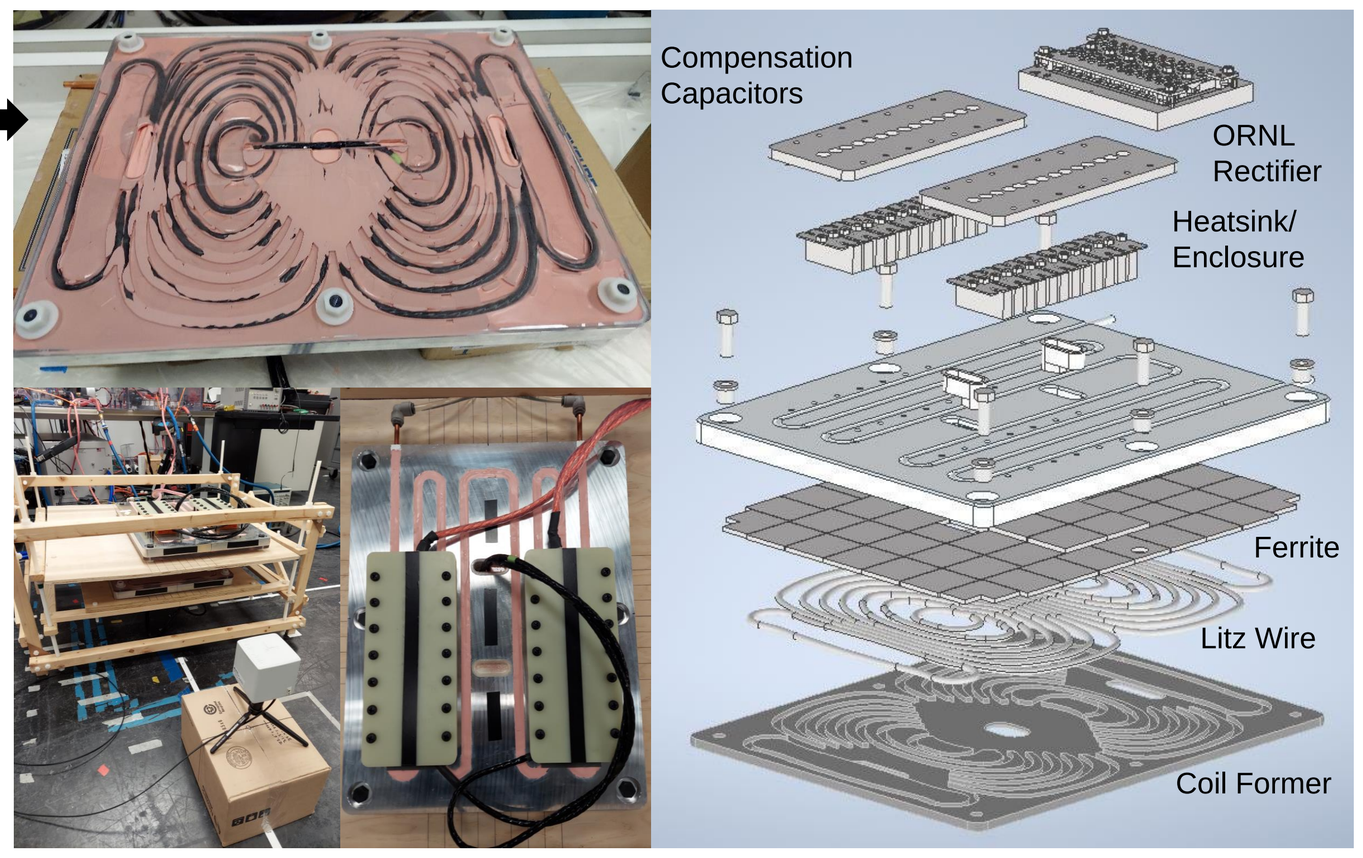
Iterate turns, ferrite and Litz selection
Loss Models, Misalignment

RESULTS



100μT Geometries





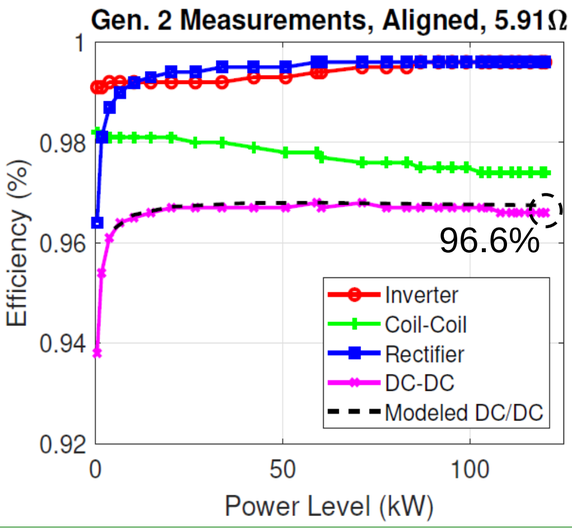
System/ Power Level	Airgap	Power Density	Stray Field at 80cm – X,Y	Efficiency	Freq.
This work Gen. 2 DD/ 120kW	125mm	0.42m x 0.54m 530kW/m^2 4.1kW/kg	At 101kW 2.8μT, 4.1μT	96.6% DC/DC	89kHz
ORNL DD/ 120kW	125mm	0.88m x 0.67m 195kW/m^2 2.3kW/kg	At 11kW 19.1μT, 12.3μT	97.1% DC/DC	25kHz
ETH Zurich Rect./ 50kW	160mm	0.76m x 0.41m 160kW/m^2 3.2kW/kg	At 50kW N/A , 22.5μT	95.8% DC/DC	85kHz

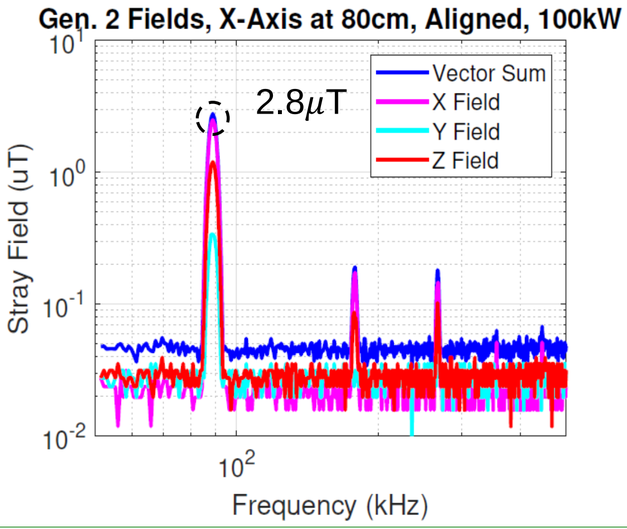
CONCLUSION

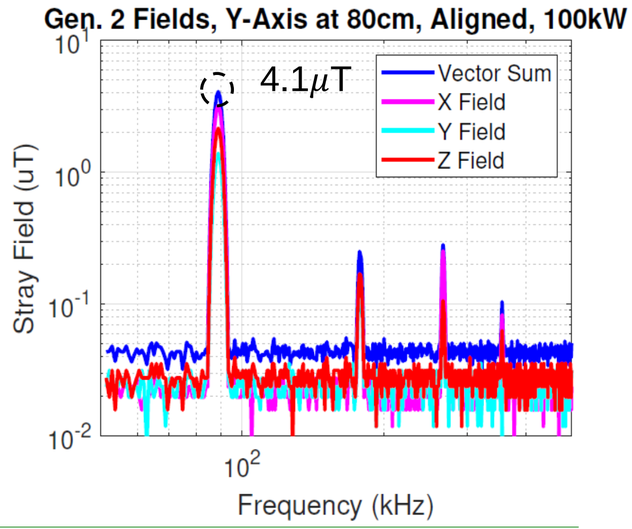
- Fourier optimization and analysis is used to design efficient, generalized coil geometries with low stray field

FUTURE WORK

- High-temperature and mission profile operation; polyphase interoperability







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