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Electromagnetic Simulation Software

Wireless Charging Applications using XFdtd® Electromagnetic Simulation Software

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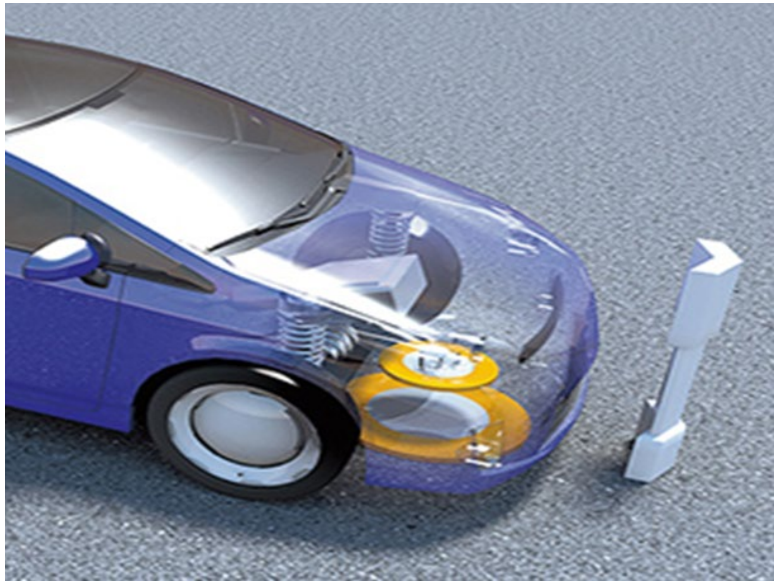
Wireless Charging Applications

Consumer Electronics

(1)

Electric Vehicles



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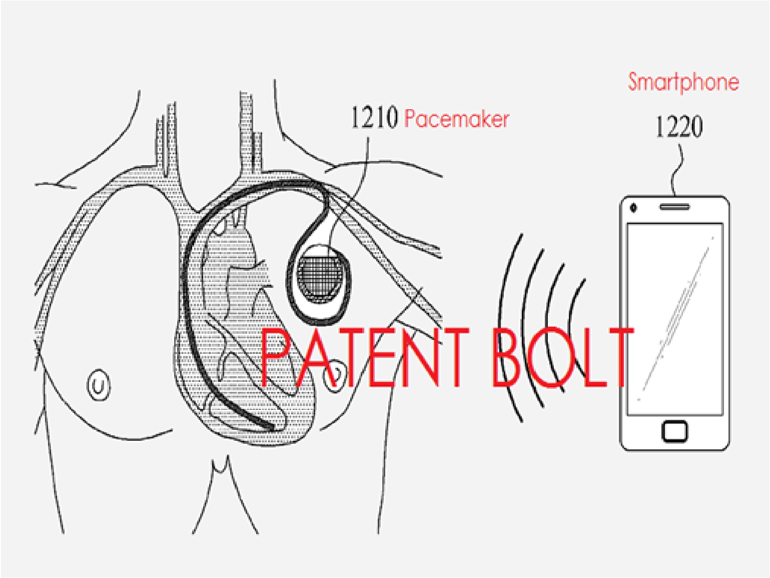
Biomedical Implants



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(1) https://bgr.com/2018/07/27/fast-wireless-charger-amazon-sale-charging-pad/
(2) https://en.tdk.eu/tdk-en/373562/tech-library/articles/applications---cases/applications---cases/thin-and-efficient-power-transmission/980554
(3) http://www.patentlymobile.com/2014/04/samsung-invents-wireless-charging-for-pacemakers-beyond.html

Wireless Power Transfer Methods

Far Field – Radiative

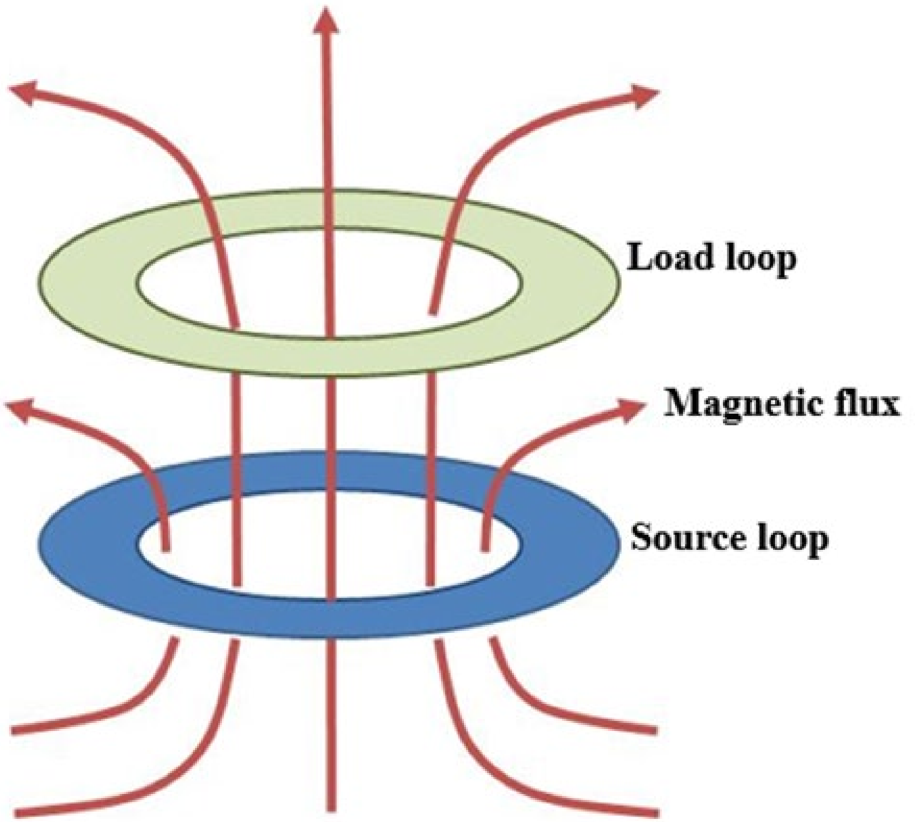
- Uses microwaves and lasers.
- Used for long distance wireless power transfer.
- Low power transfer efficiency.
- Safety concerns.

Near Field – Inductive Coupling

- No radiative mechanism.
- Used for short distance wireless power transfer.
- Higher power transfer efficiency.
- Safer and has already been used for many applications (e.g., wireless charging, biomedical implants, etc.).

Inductive Coupling

- Consists of two loops: a source loop and a load loop.
- The source loop is connected to an AC power source and generates oscillating magnetic fields in its surroundings.
- When the load loop is brought into the vicinity of the source loop, an electromotive force is induced in the load loop and produces a current flow.



Wireless Charging Design Metrics

Self-Inductance of Coil

Power Transfer Efficiency

Mutual-Inductance

Coupling Coefficient

Quality Factor

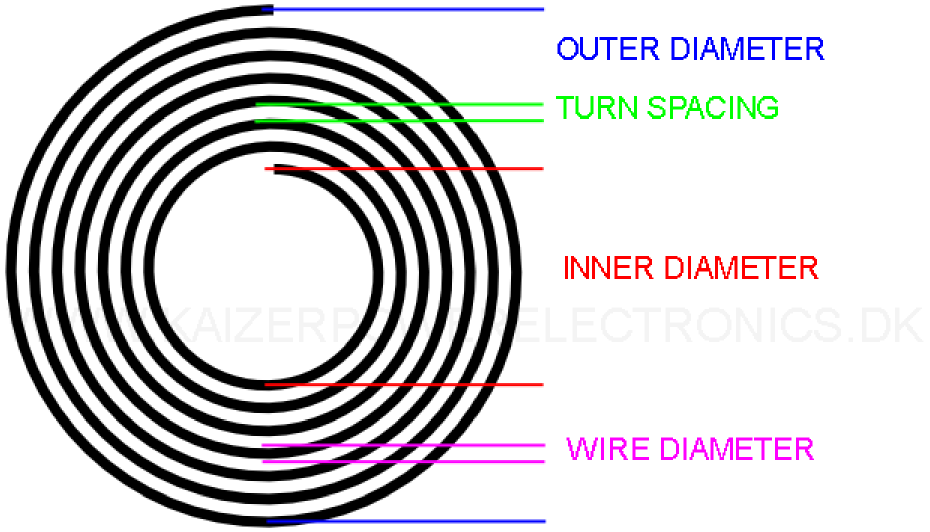
Magnetized Ferrite

Self-Resonating Frequency

Inductance of a Flat Spiral Coil

Inductance depends on the following parameters:

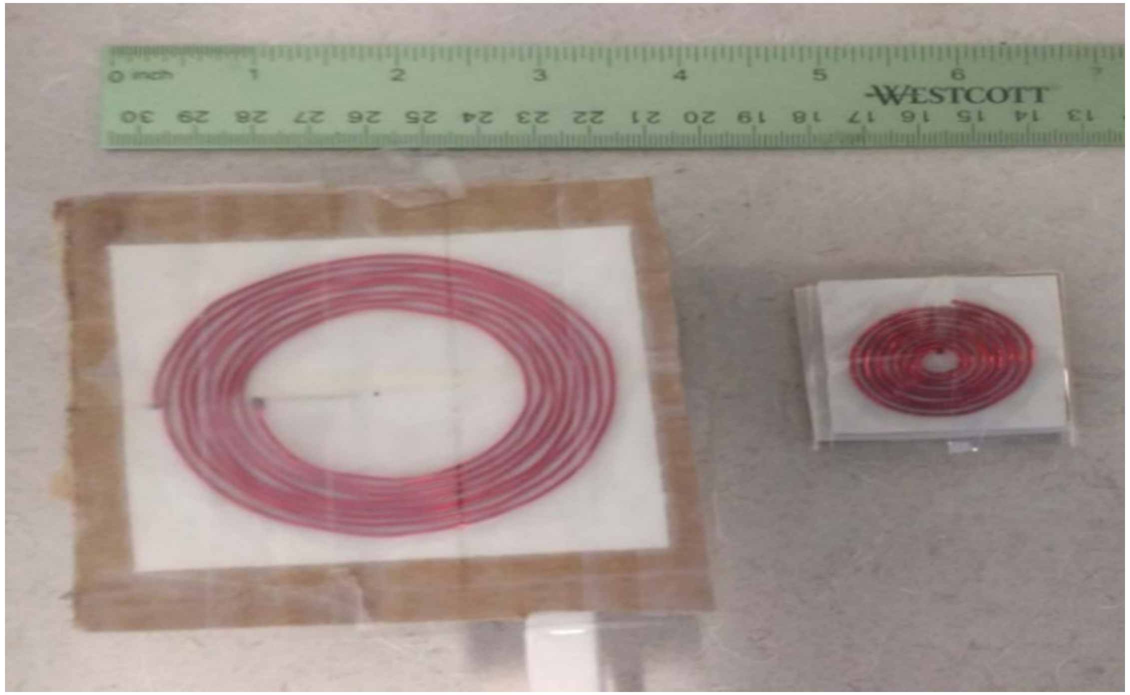
- Diameter of the copper (or low resistive Litz) wire.
- Number of turns.
- Spacing between turns.
- Inner diameter of coil.
- Outer diameter of coil.



Online calculator based on Wheeler approximations:

http://www.tesla-institute.com/!app/sim/fscic.php

Lab Measurement



Coil	Diameter (mm)	Number of turns	Wire radius (mm)	Gap (mm)
Transmitter	70	8	0.4059	1
Receiver	35	8	0.4059	1

Transmitter (right) and receiver (left) coil specs from lab measurement.

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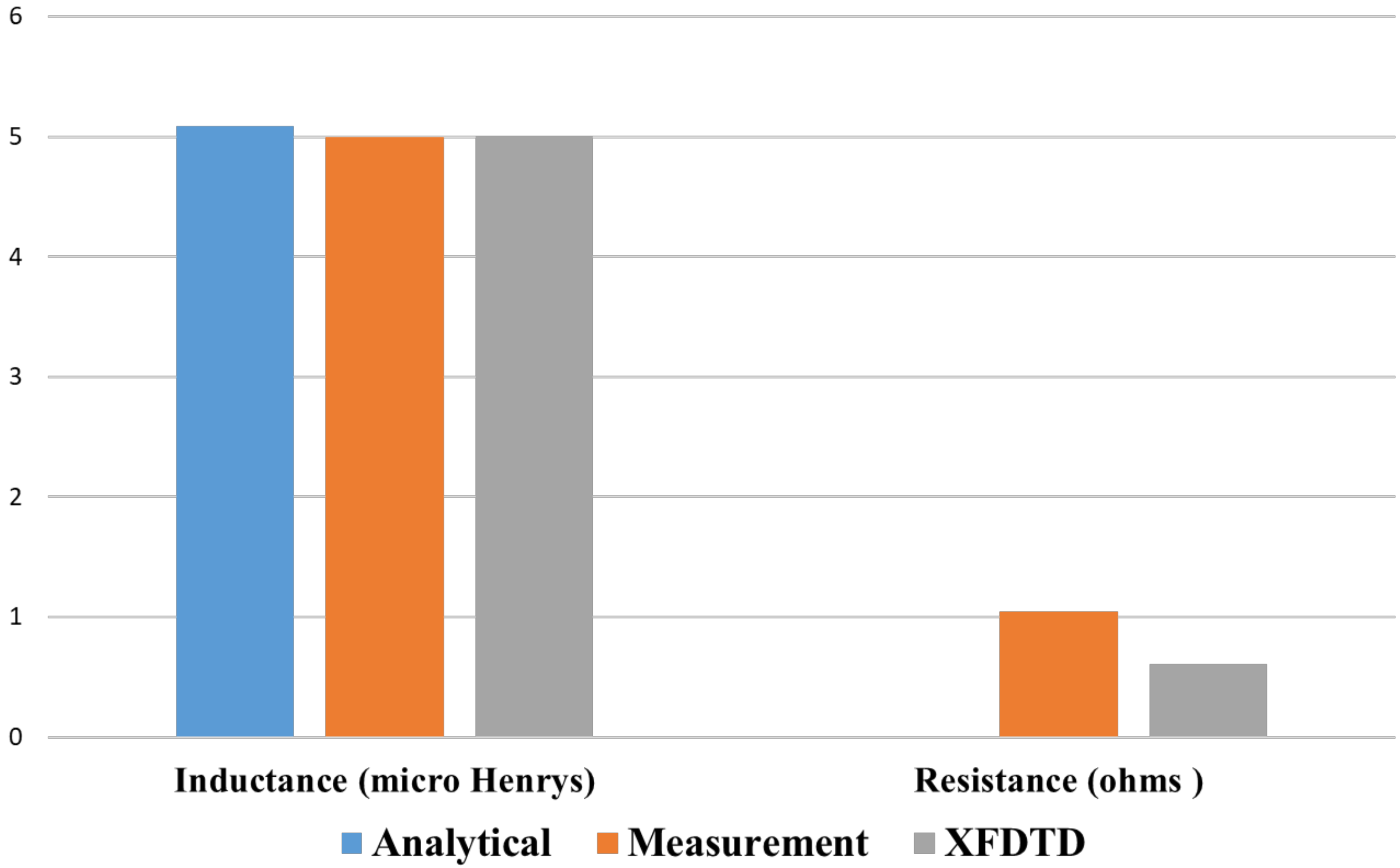
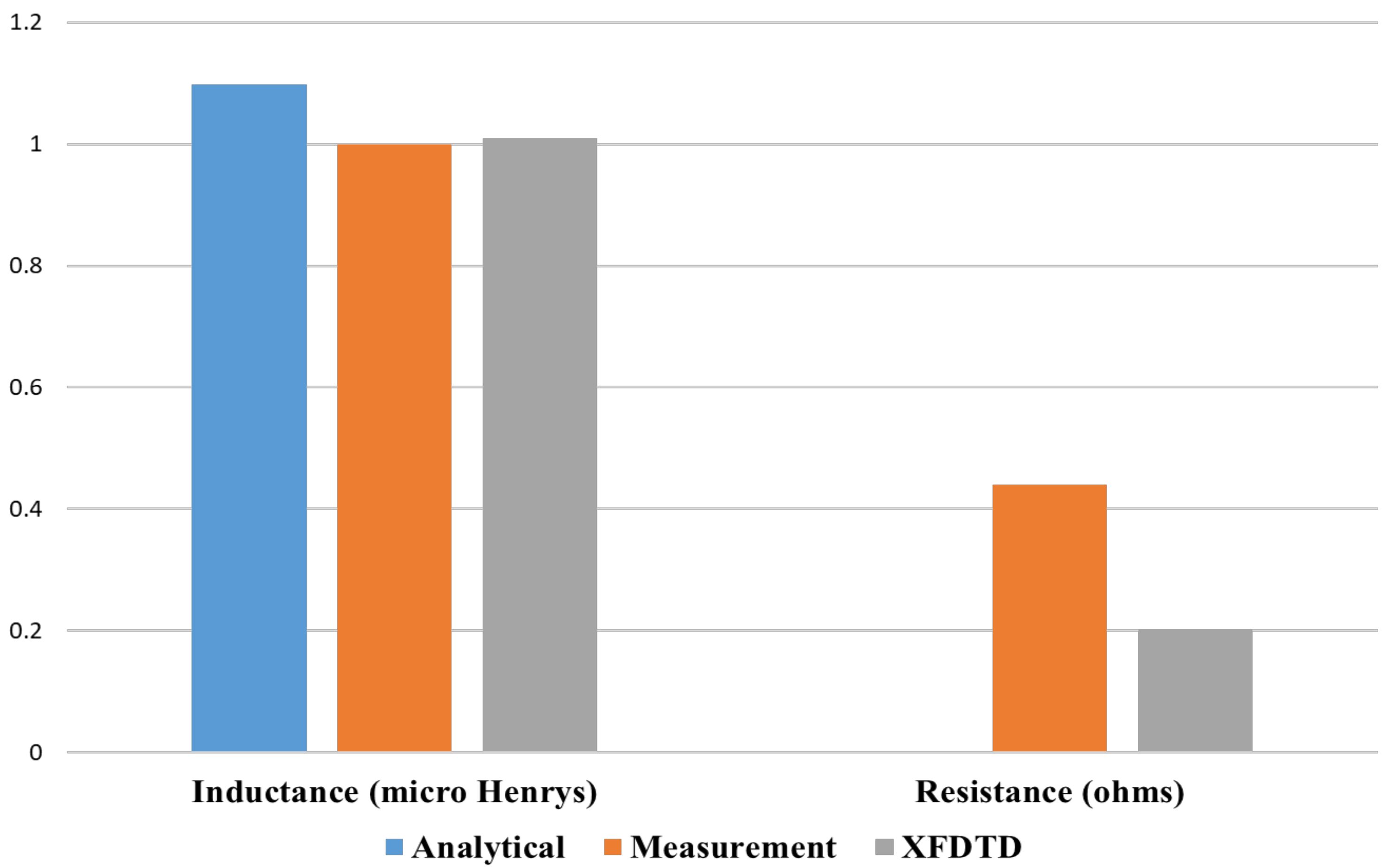
XFdtd Validation of Transmitter Coil



Note: There is no standard or accurate way to analytically determine parasitic resistance (unlike Wheeler's method for calculating self-inductance), therefore analytical resistance results are not shown.

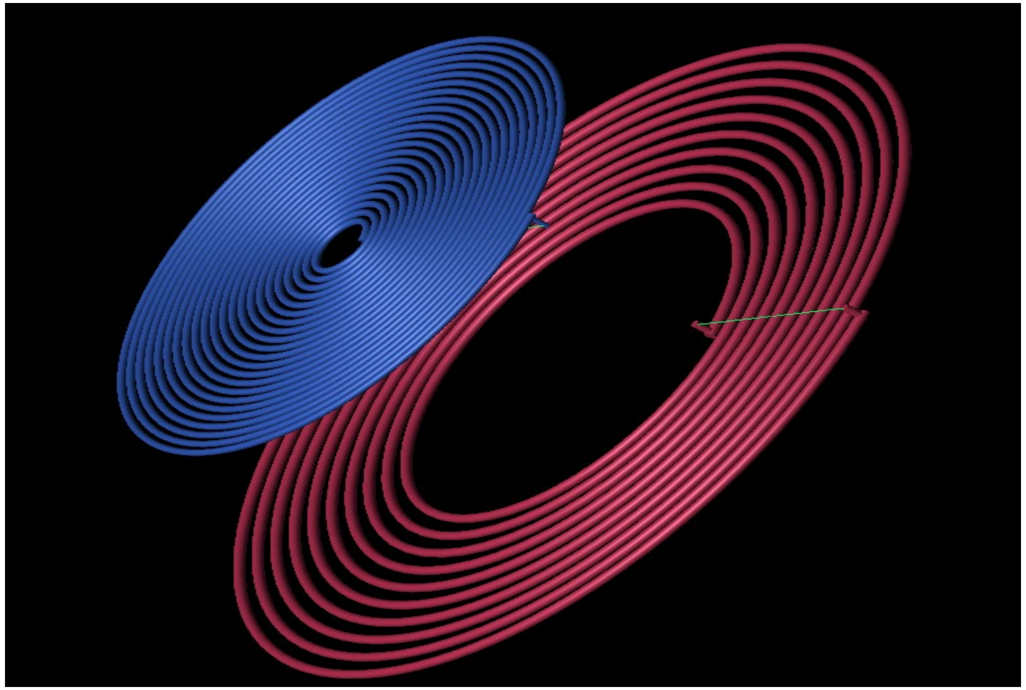
XFdtd Validation of Receiver Coil

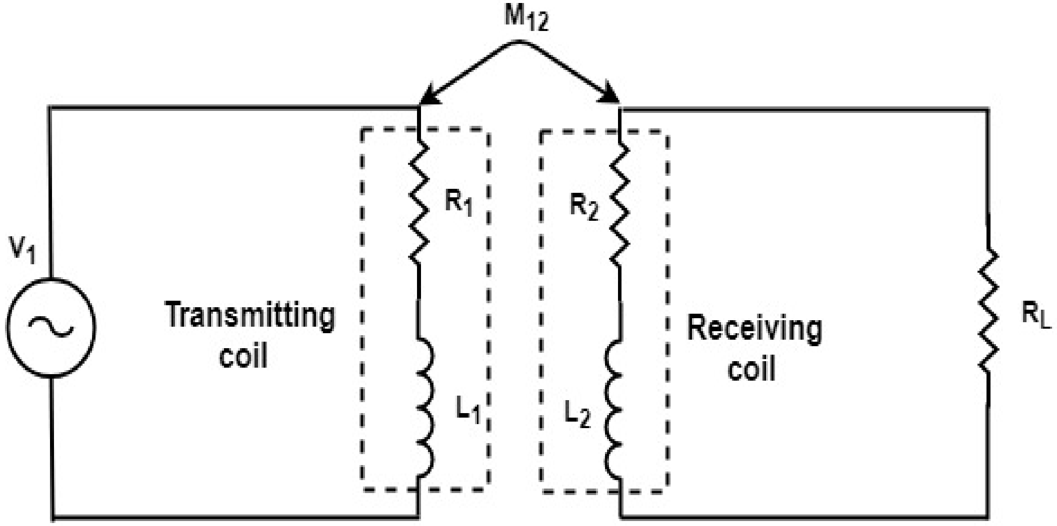


Note: Possible reasons for resistance mismatch could include stray resistance of vector network analyzer's cable and/or physical resistance due to clippers used during measurement.

Inductive Coupling Equivalent Circuit Model

Coils in XFdtd





R_1: Parasitic Resistance of Transmitter Coil

R_2: Parasitic Resistance of Receiver Coil

L_1: Self-Inductance of Transmitter Coil

L_2: Self-Inductance of Receiver Coil

M_{12}: Mutual Inductance

Inductive Coupling Equivalent Circuit Model

Quality Factor of Transmitting Coil: $Q_1 = \frac{\omega L_1}{R_1}$

Quality Factor of Receiving Coil: $Q_2 = \frac{\omega L_2}{R_2}$

Quality Factor of Receiving Coil and Load: $Q_{2L} = \frac{\omega L_2}{R_2 + R_L}$

Mutual Inductance: $M = K\sqrt{L_1 L_2}$

Power Transfer Efficiency: $PTE = \frac{K^2 Q_1 Q_{2L}}{1 + K^2 Q_1 Q_{2L}} \cdot \frac{R_L}{R_L + R_2}$

ω = angular frequency

K = coupling coefficient

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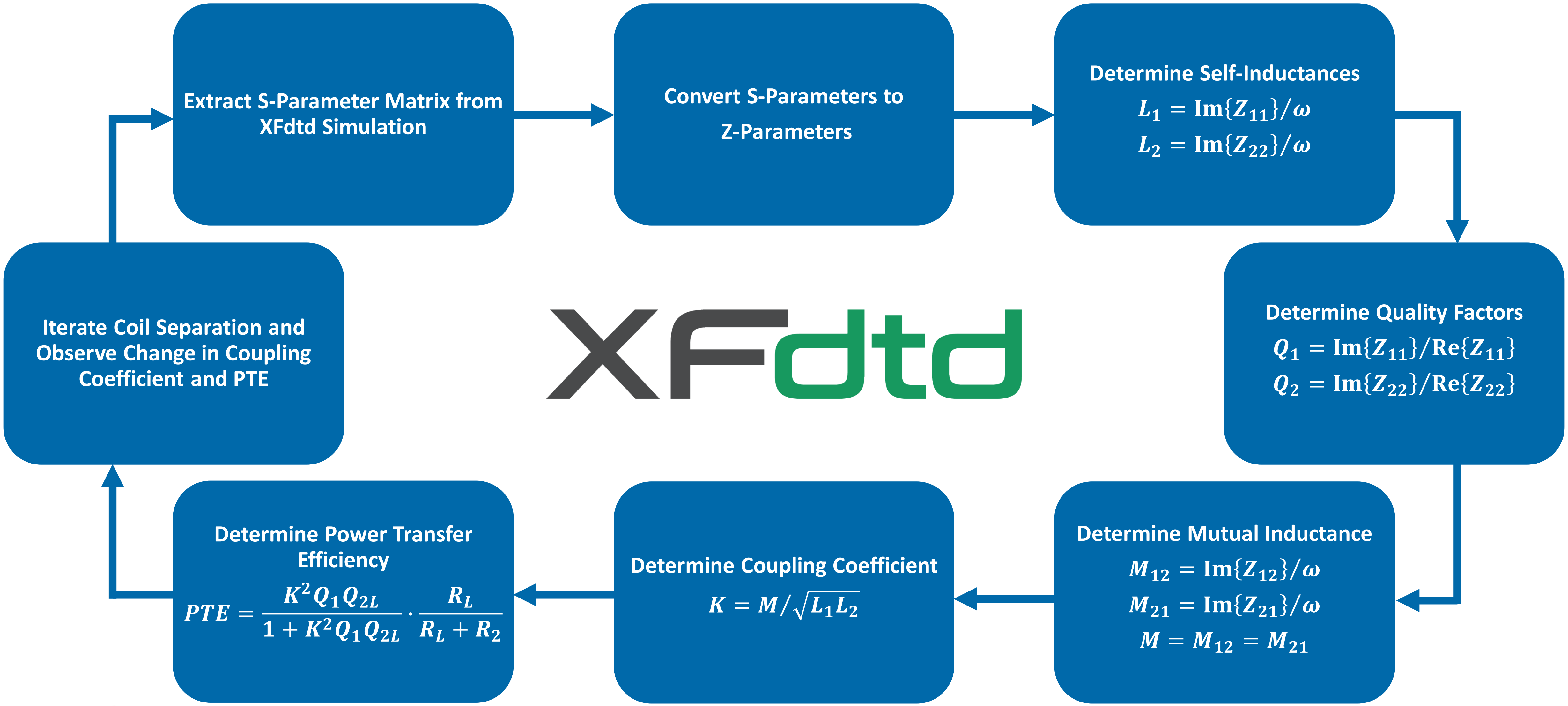
XFdtd Analysis of Wireless Power Transfer



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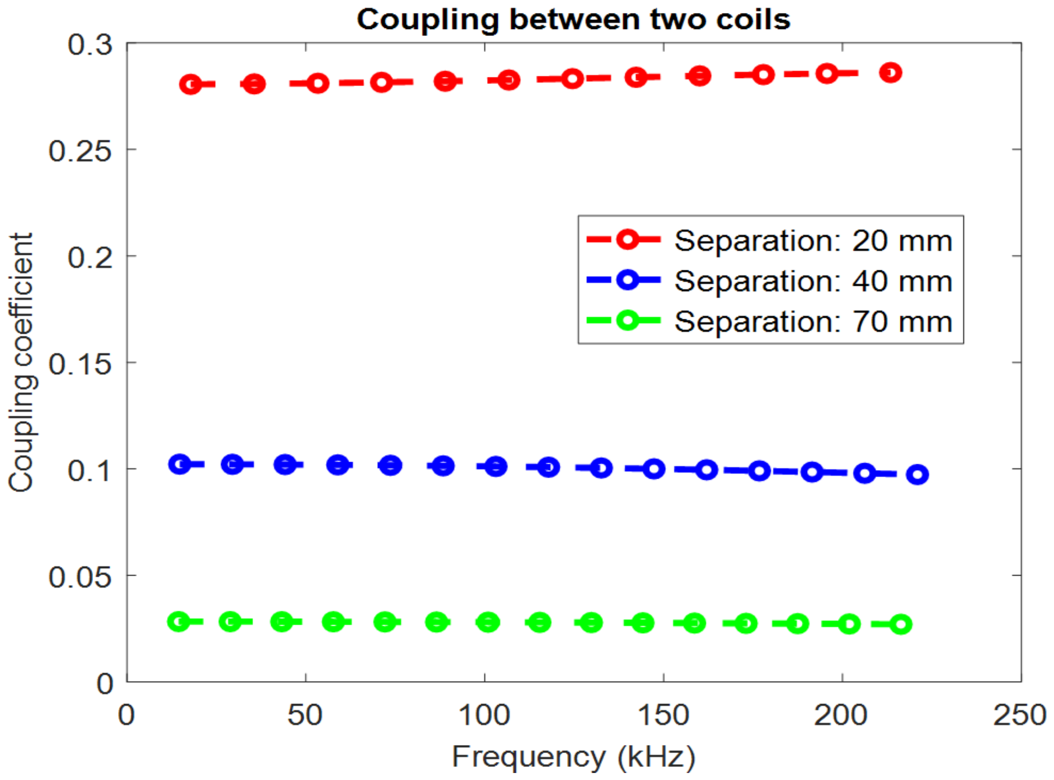
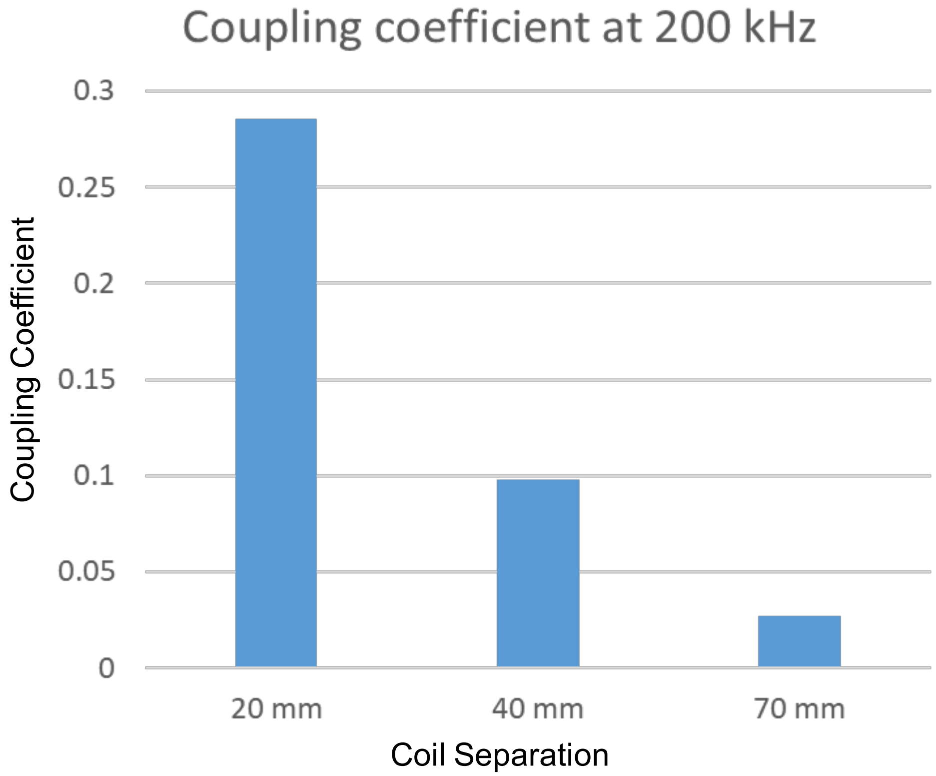
Coupling Coefficient vs. Coil Separation





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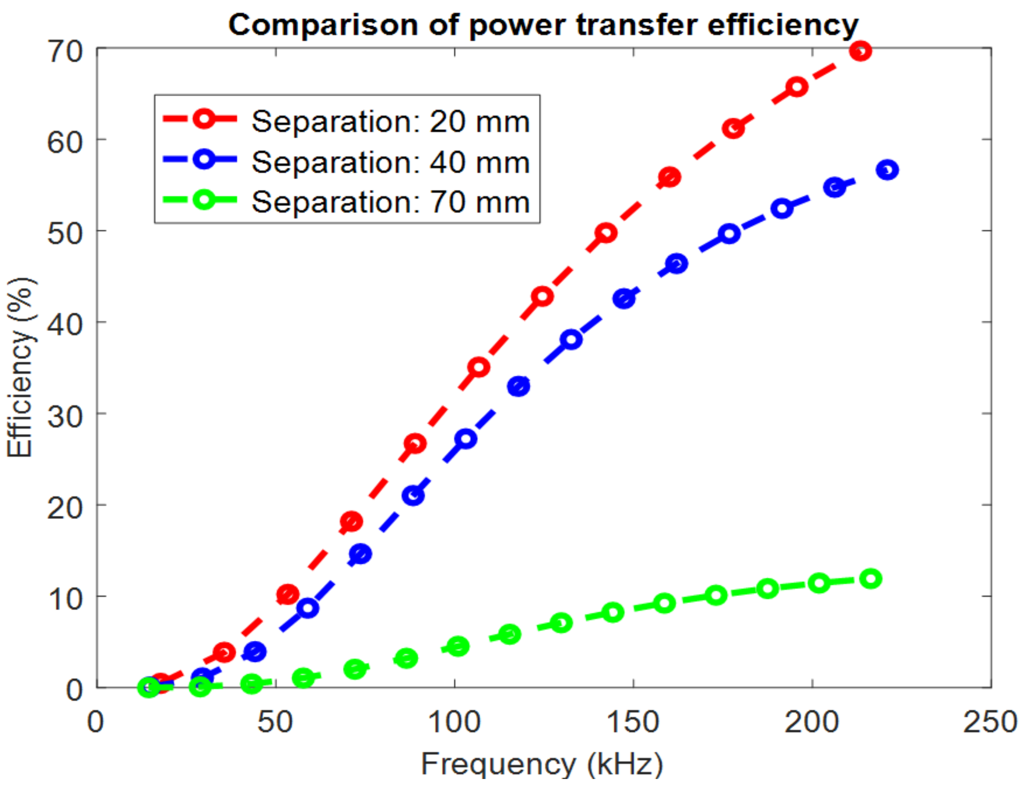
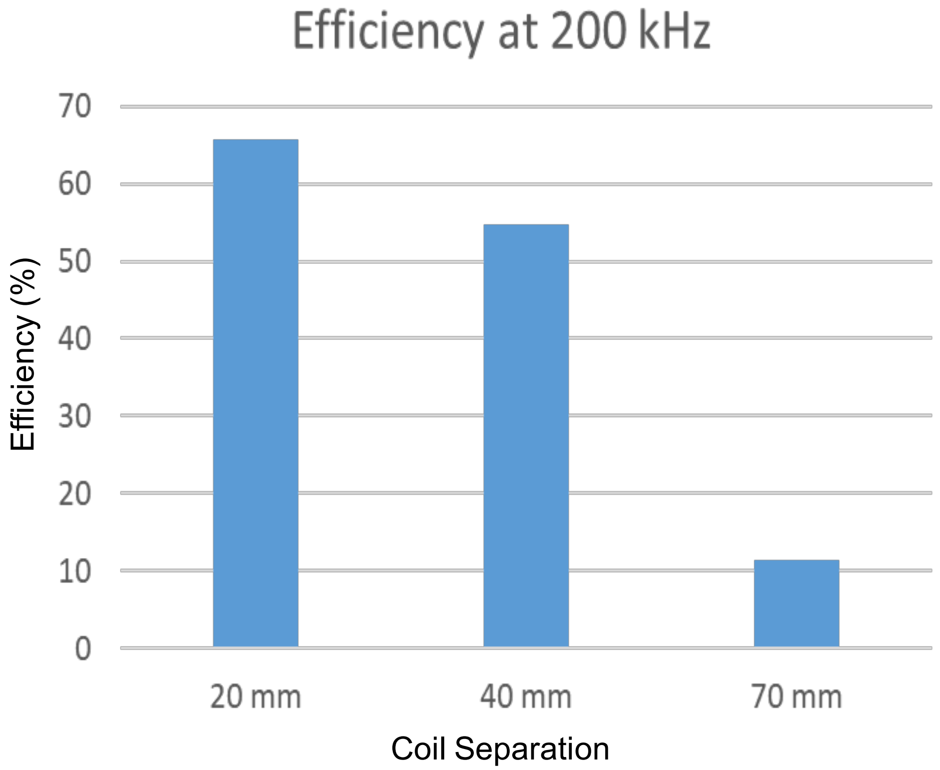
Power Transfer Efficiency vs. Coil Separation





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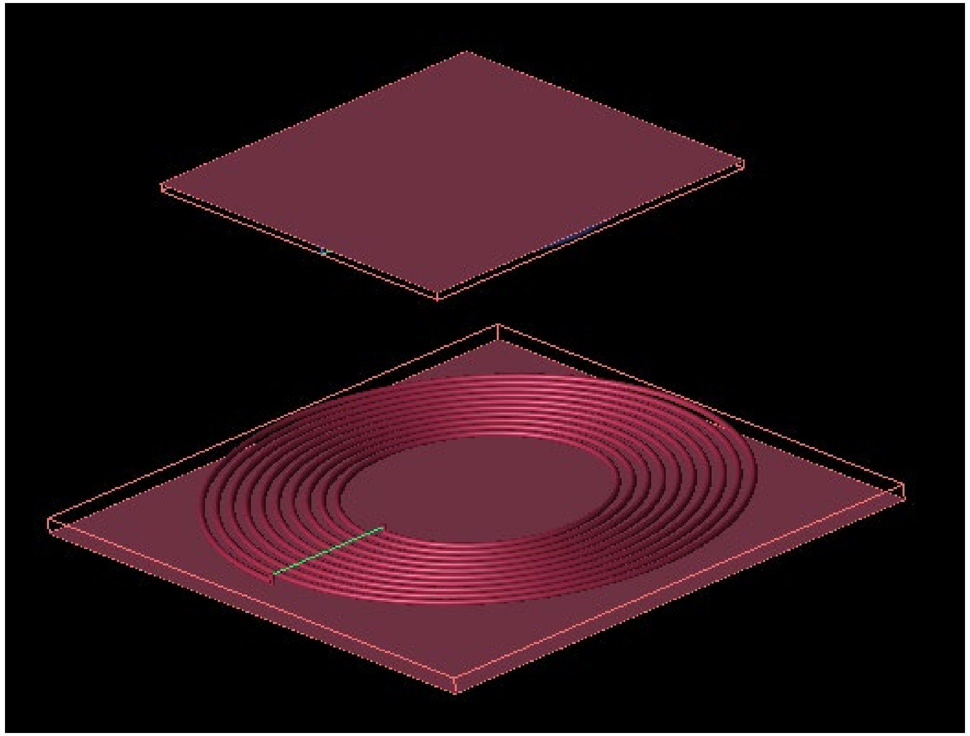
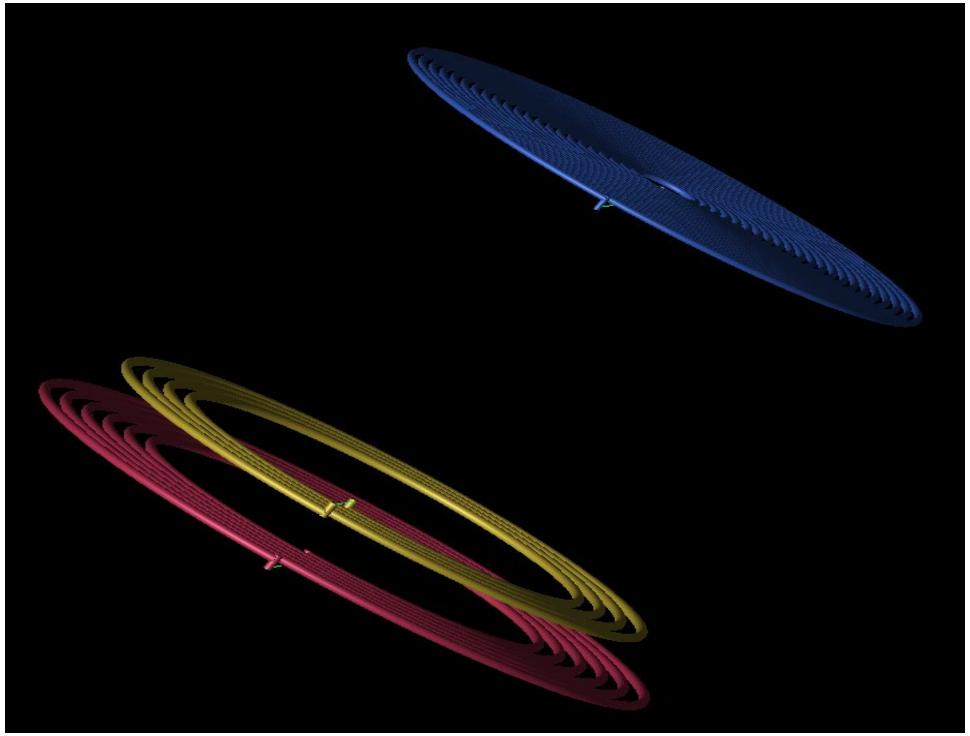
Improving Coupling and Power Efficiency

- Magnetized ferrites can shield magnetic flux and boost mutual inductance.



- Multiple coils can improve flux coupling.



Magnetized Ferrite

A magnetize ferrite is an anisotropic, dispersive, and gyrotropic magnetic material characterized by permeability:

$$\mu = \mu_0 \begin{bmatrix} 1+\chi_m(\omega) & -jk(\omega) & 0 \\ jk(\omega) & 1+\chi_m(\omega) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\chi_m(\omega) = \frac{(\omega_0 + j\omega\alpha)\omega_m}{(\omega_0 + j\omega\alpha)^2 - \omega^2}$$

$$k(\omega) = \frac{-\omega\omega_m}{(\omega_0 + j\omega\alpha)^2 - \omega^2}$$

$$\omega_m = \gamma_m 4\pi M_0$$

$$\omega_0 = \gamma_m H_0$$

Constant:

$\gamma_m = 2.8\ GHz/kOe$ - Gyromagnetic Ratio

Parameters:

α - Damping Coefficient

$4\pi M_0$- Static Magnetization

H_0 - Static Biasing Field

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Magnetized Ferrite

<u>Common Datasheet Parameters</u>

- Real and Imaginary Permeability
- Flux Density
- Applied Field Strength
- Resistivity
- Saturation Magnetic Flux Density
- Resonant Line Width
- Lande Factor

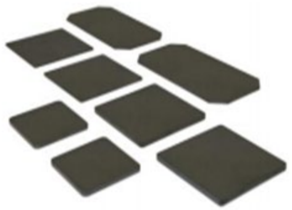
<u>XFdtd Magnetized Ferrite Model</u>

- Applied Field
- Internal Magnetization
- Damping Coefficient
- Biasing Field Direction (Theta, Phi)

Magnetized Ferrite

Laird
Smart Technology. Delivered.

Ferrite Plate
For Resonant Wireless Charging
RP Series



FEATURES ✓RoHS

- Designed and optimized for resonant charging, but can support both magnetic coupling and resonant wireless charging concurrently
- Available in solid ferrite
- High permeability, high Q low loss for resonant charging@6.78MHz
- Wide operating temperature -40℃ to 125℃
- Length and width up to 53x53mm
- Wide range of thickness selection from 1mm to 5mm

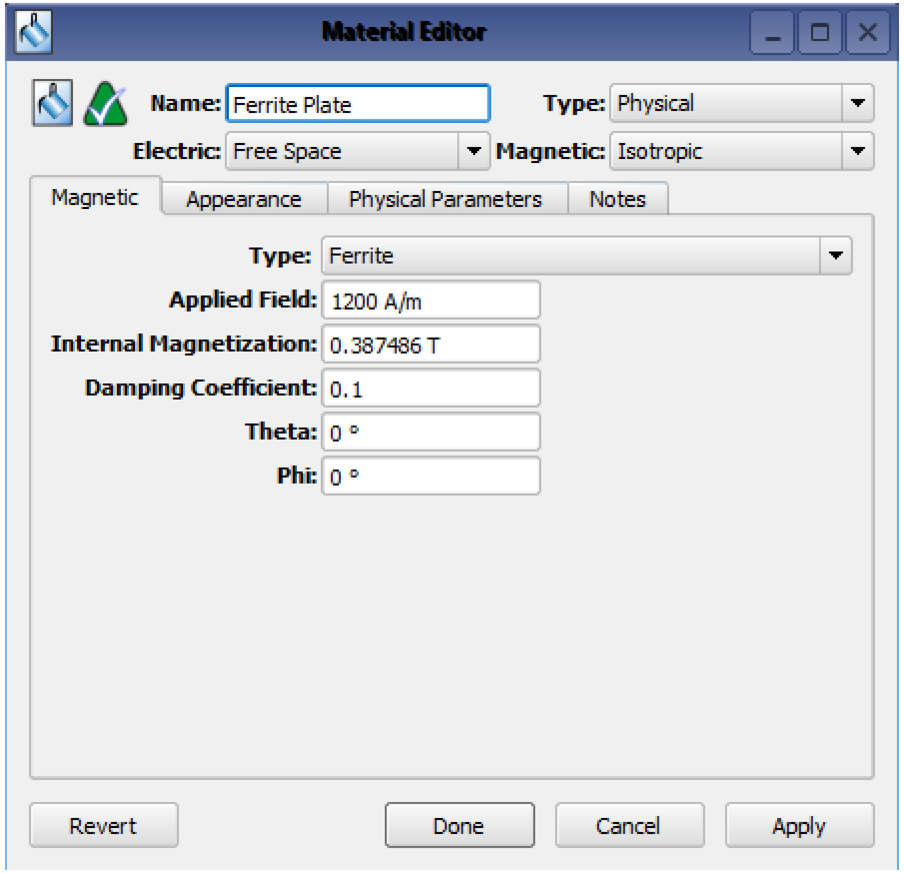
APPLICATIONS

- A4WP or resonant type wireless charger
- WPC and A4WP combo wireless charger for both short distance and long distance charging
- Wireless charger for office ,residential, public area, industrial and automotive applications

MATERIAL SPECIFICATIONS

Property	Symbol	Unit	Value
Real permeability @ 6.78MHz	μ'		250±25%
Imaginary permeability @ 6.78MHz	μ''		10 Max
Flux Density	B	mT [Gauss]	390 [3900]
@ Field Strength	H	A/m [Oe]	1200 [15]
Residual Field Strength	B_r	mT [Gauss]	280 [2800]
Coercive Strength	H_c	A/m [Oe]	100 [1.25]
Curie Temperature	T_c	℃	> 200
Resistivity	ρ	Ω-cm	10^7

Conversion



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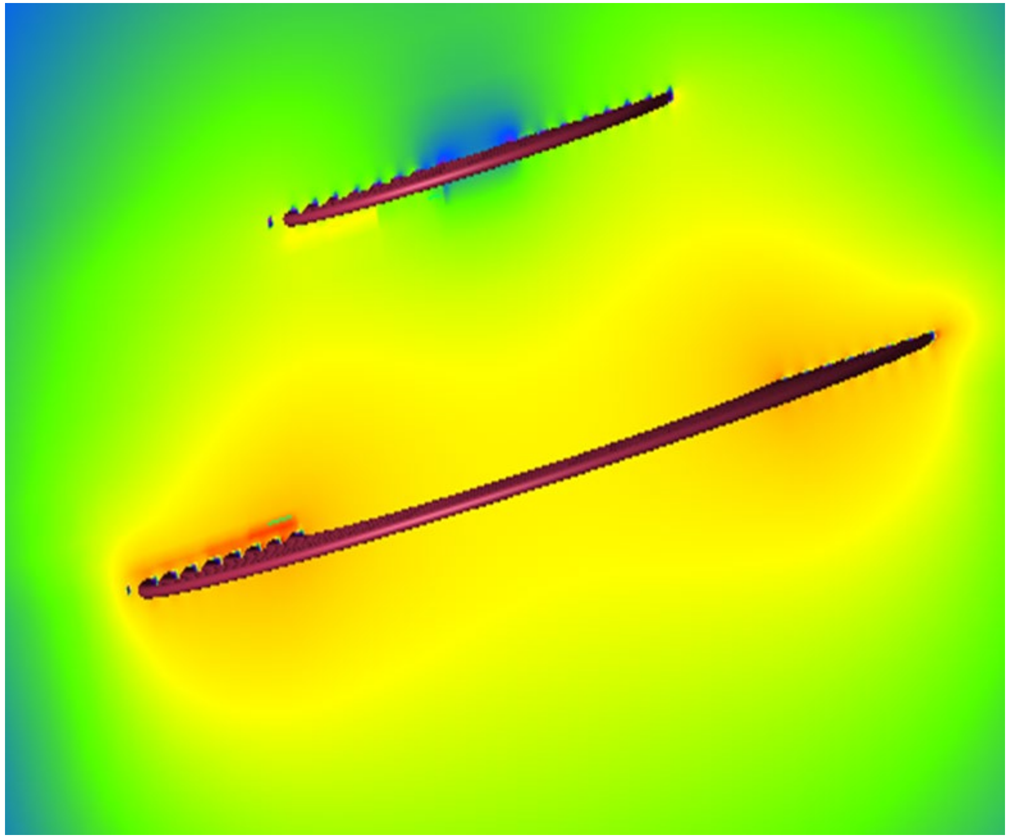
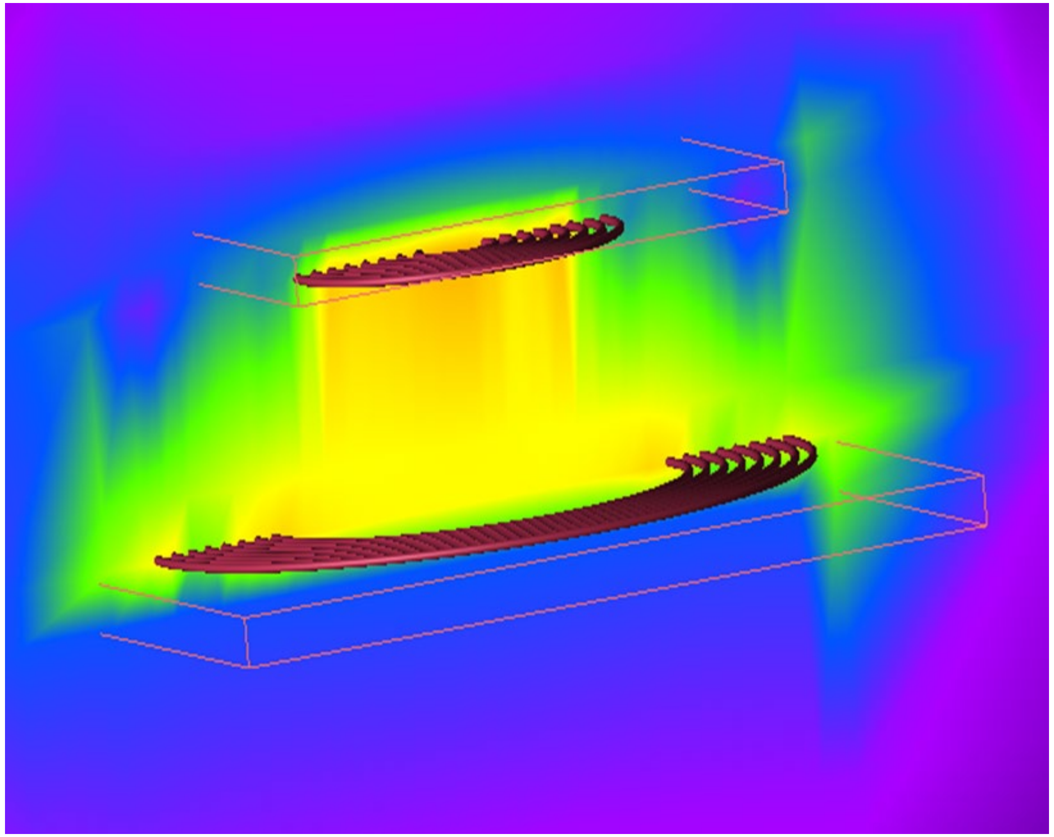
Importance of Magnetized Ferrite



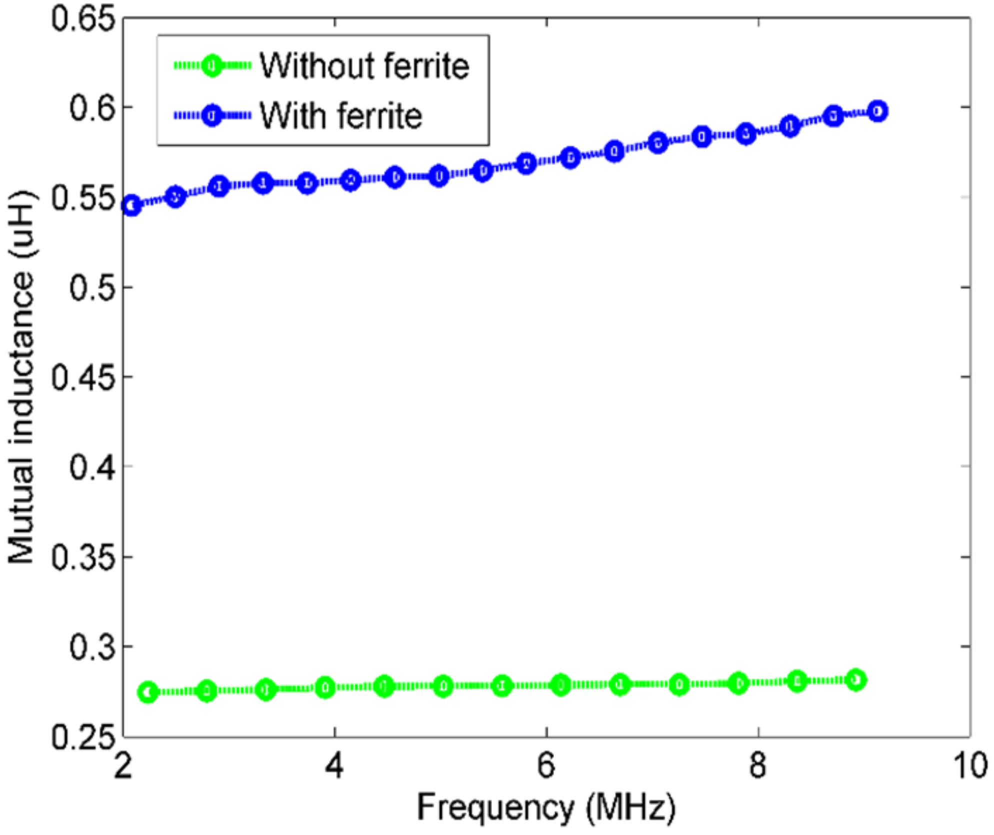
(a)

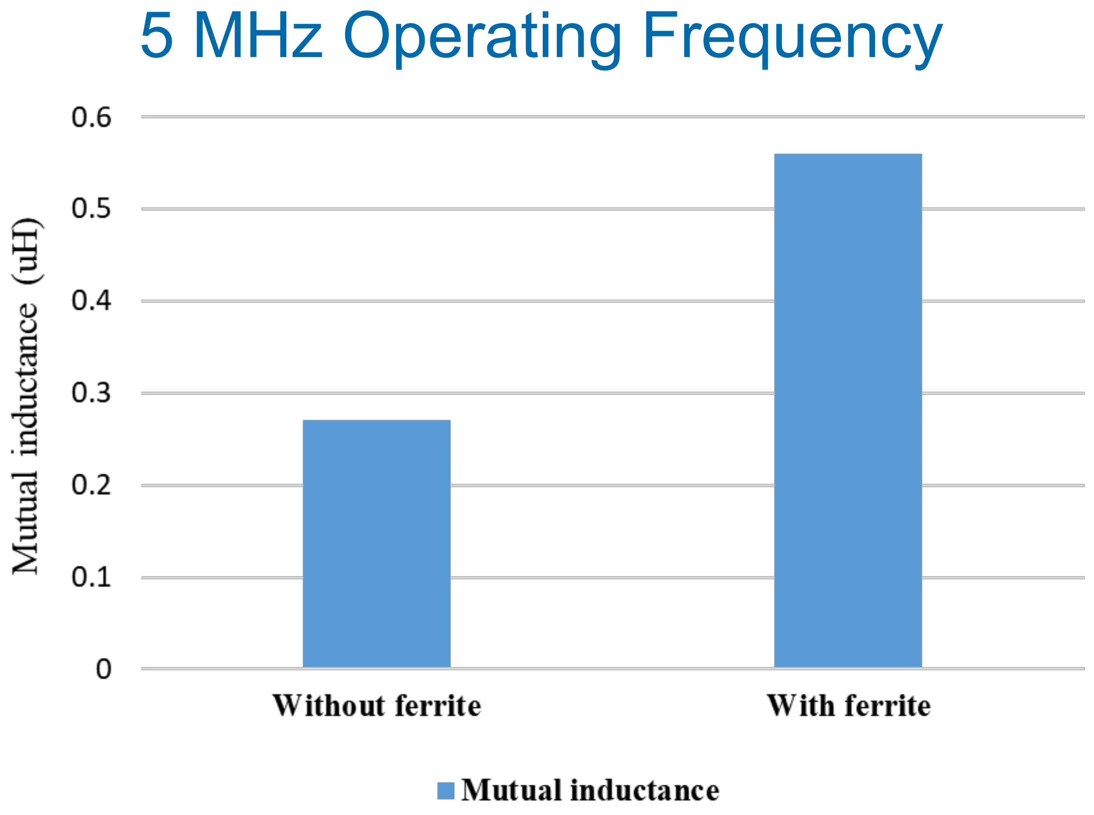


(b)

Magnetic flux density with (b) and without (a) magnetized ferrites in the wireless power transfer design.

Mutual Inductance Comparison





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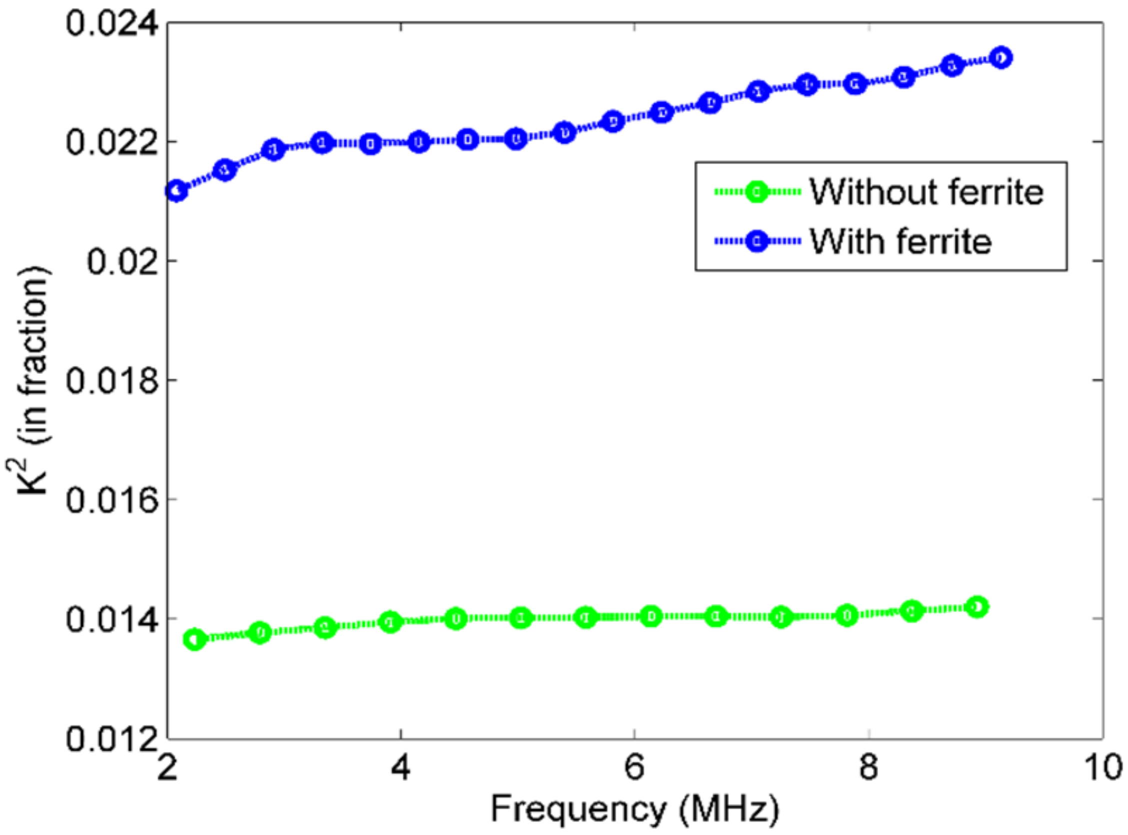
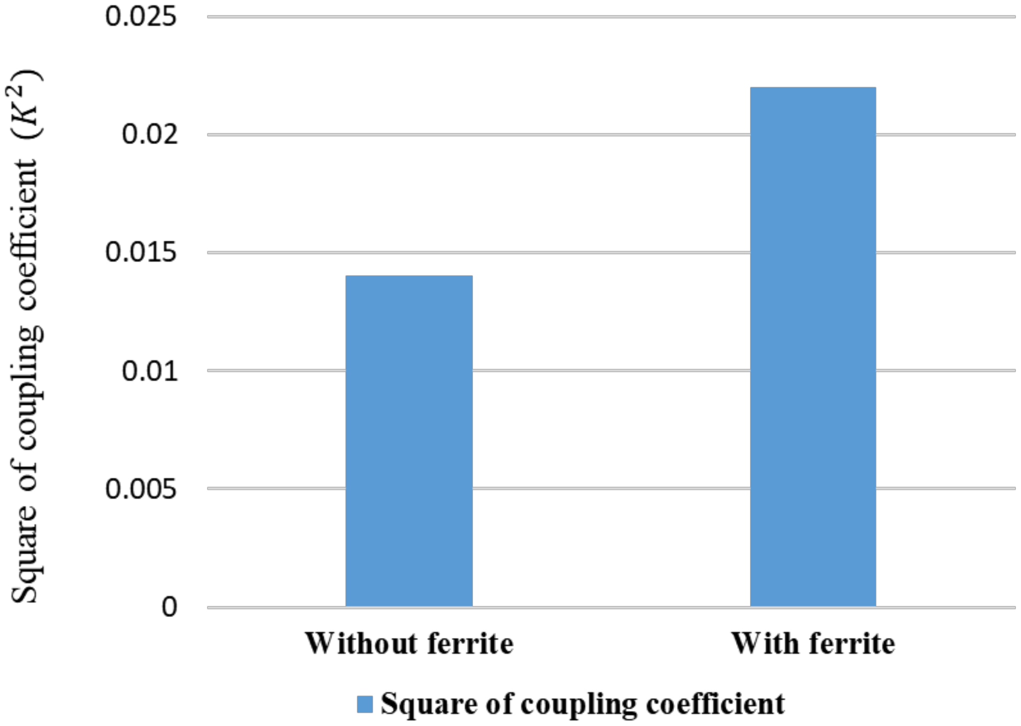
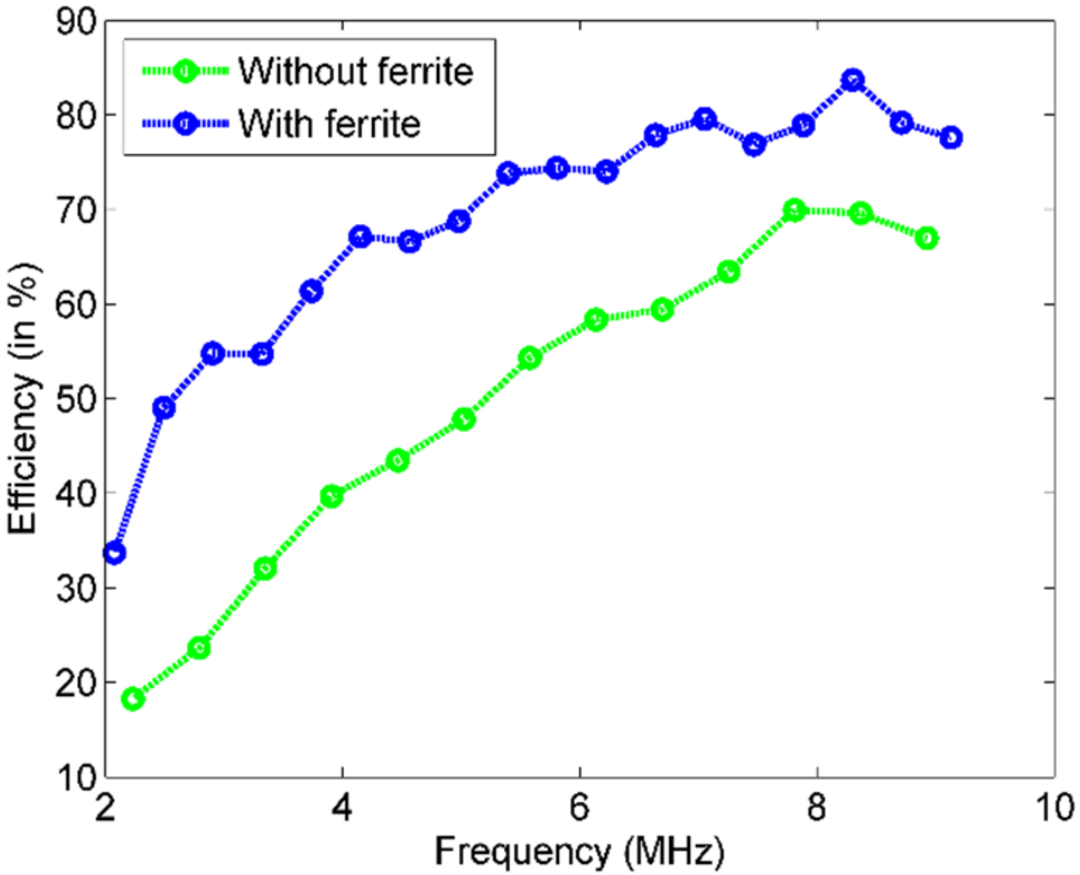
Coupling Coefficient Comparison

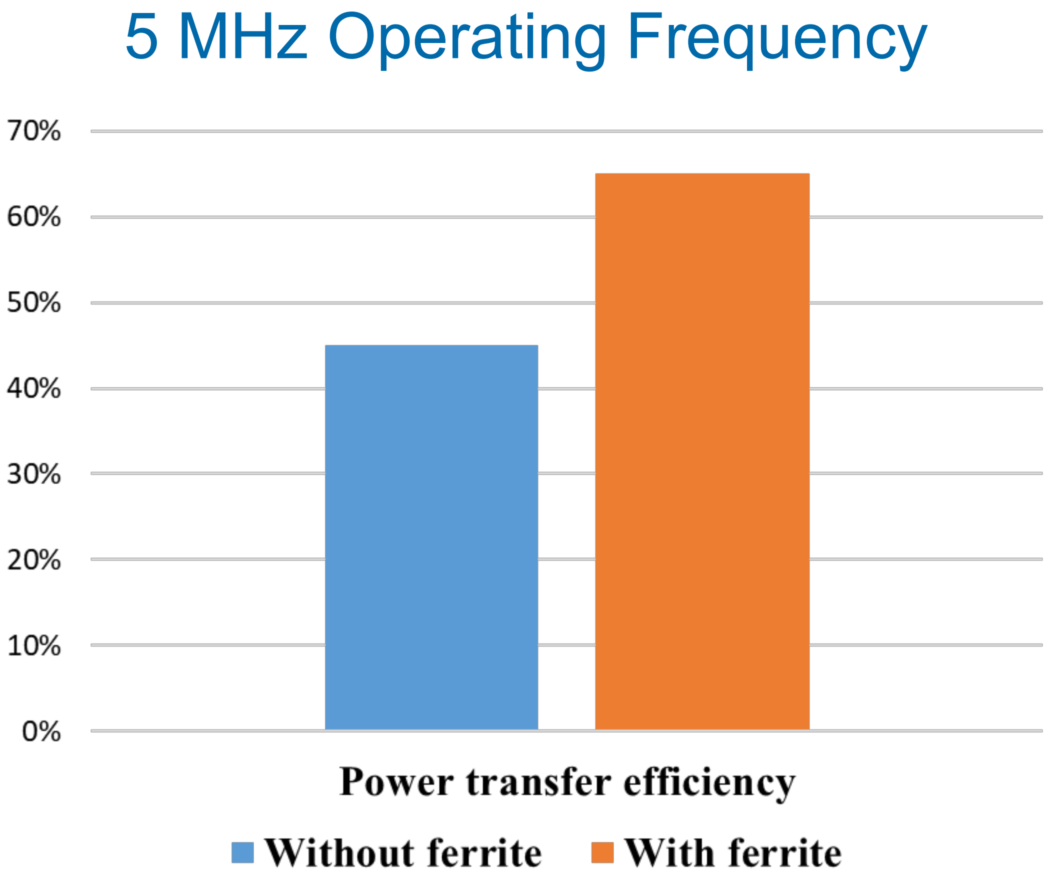


5 MHz Operating Frequency



Power Transfer Efficiency Comparison





Conclusions

- Wireless charging and wireless power transfer is an emerging technology which will undoubtedly see continued growth over the next decade and beyond.
- XFdtd accurately calculated the inductance and resistance of wireless charging coils.
- XFdtd showed that the coupling and power transfer between wireless charging coils predictably decreases as distance between the coils increases.
- XFdtd demonstrated that the use of magnetized ferrites can significantly increase the mutual inductance, coupling coefficient, and power transfer efficiency of wireless charging devices.

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