Inductive Power Transfer Shumeng Wang 5297087

1. Description of the component

Currently, the idea of contactless power transfer becomes popular, as a new method of transmitting power wirelessly. The inductive power transfer (IPT) is one of the solutions, which is composed of an inverter, a rectifier, two coupling coils and compensation circuits on each side.

Name	Value
Operating frequency	100kHz
Load voltage (DC)	40V
Load received power	40W

Due to the requirements shown above, the suitable application will be wirelessly charging tablet.

2. Material

Litz wire will be used to minimize skin effect and proximity effect at operating frequency. The skin depth in cylindrical conductor of 100kHz will be 0.21mm, and the recommended strand diameter is 0.071mm. Given the current density of 5A/mm^2, so we select

Name	L1	L2
Strand count	135	45
Nominal resistance	0.0333Ω/m	0.0979Ω/m
Wire outer diameter	~1.2mm	~0.8mm
Served type	Single served	

The film capacitors are used, which is relatively stable, and able to achieve the estimated capacitance in the order of magnitude of e-8F.

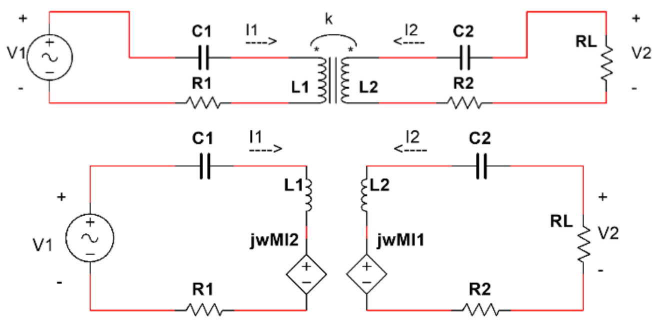
3. Analysis

Rectifier and inverter

The rectifier and inverter are considered to be full-bridge and ideal.

$$V_2 = \frac{\pi}{2\sqrt{2}} V_{load,DC};\ I_2 = \frac{2\sqrt{2}}{\pi} I_{load,DC};\ V_{source,DC} = \frac{\pi}{2\sqrt{2}} V_1$$

Circuit topology



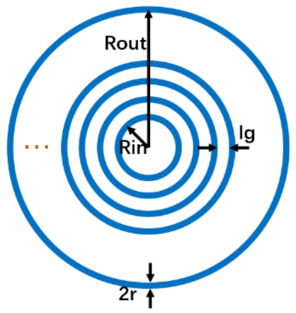
The original circuit and the decoupled equivalent circuit are shown on the left. Thus, we can apply KVL to obtain the following equations.

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{j\omega C_1} + j\omega L_1 + R_1 & j\omega M \\ j\omega M & \frac{1}{j\omega C_2} + j\omega L_2 + R_2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Resonance compensation

$$\frac{1}{j\omega C_1} + j\omega L_1 = 0;\ \frac{1}{j\omega C_2} + j\omega L_2 = 0$$

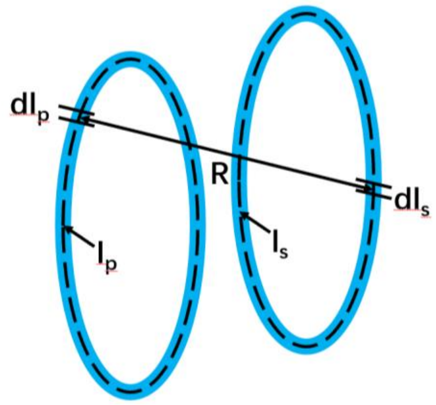
Dimension of coils



The coils can be regarded as concentric circles. The primary and the secondary coil are designed to be identical for simplicity. All key parameters are shown below. Notably, the inner and outer radius are measured from the center to the middle contour of the wire.

Name	Value
Inner radius	40mm
Number of turns	20
Outer radius	66.6mm
Vertical distance	20mm
Horizontal misalignment	0

Mutual inductance (Neumann's equation)



$$A = \frac{\mu_0 I}{4\pi} \oint_l \frac{dl}{R};\ \Phi_m = \int_S B \cdot dS = \int_S \nabla \times A \cdot dS = \oint_{l'} A \cdot dl'$$

$$M = \frac{\Phi_m}{I} = \frac{\mu_0}{4\pi} \oint_{l_{pi}} \oint_{l_{sj}} \frac{dl_{pi} dl_{sj}}{R}$$

$$M_{tot} = \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{\mu_0}{4\pi} \oint_{l_{pi}} \oint_{l_{sj}} \frac{dl_{pi} dl_{sj}}{R}$$

Self-inductance (modified Neumann's equation)

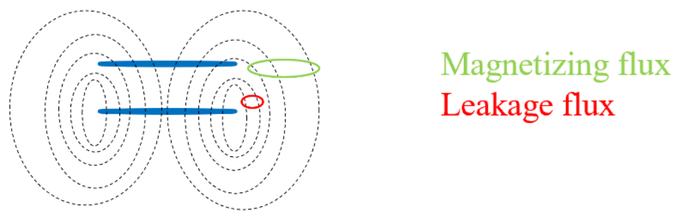
For any arbitrary closed-loop wire.

$$L_i \approx \frac{\mu_0}{4\pi} \oint_{l_{i,in}} \oint_{l_{i,out}} \frac{dl_{i,in} dl_{i,out}}{R}$$

The mutual inductance of series turns also should be considered.

$$L_{tot} \approx 2 \sum_{i=1}^{N} \sum_{j=i+1}^{N} \frac{\mu_0}{4\pi} \oint_{l_i} \oint_{l_j} \frac{dl_i dl_j}{R} + \sum_{i=1}^{N} L_i$$

Calculation results of the parameters (by MATLAB)



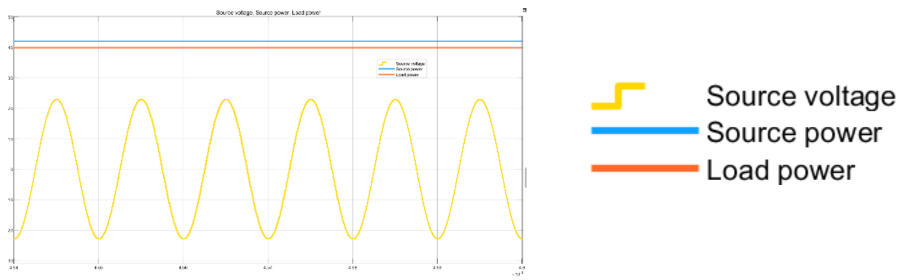
Name	L1	L2
Mutual (magnetizing) inductance	27.36μH	
Self-inductance	58.18μH	58.73μH
Leakage inductance	30.82μH	31.37μH
Coupling coefficient k	0.47	
Compensation capacitance	43.54nF	43.13nF
Coil resistance	0.22Ω	0.66Ω

Power analysis

$$V_{source,AC,peak} = 22.71V;\ V_{source,DC} = 17.84V$$

$$P_{loss} = I_1^2 R_{coil1} + I_2^2 R_{coil2} \approx 2.02W;\ \eta = \frac{P}{P_{loss} + P} \approx 95.2\%$$

Simulink simulation



4. Conclusions

In a nutshell, with the supply voltage 17.84V (DC), which is consistent with common power adapters for a tablet, this IPT system reached wirelessly transferred power of 40W and efficiency of 95.2%, and the coil size is appropriate to fit in a tablet.

5. References

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