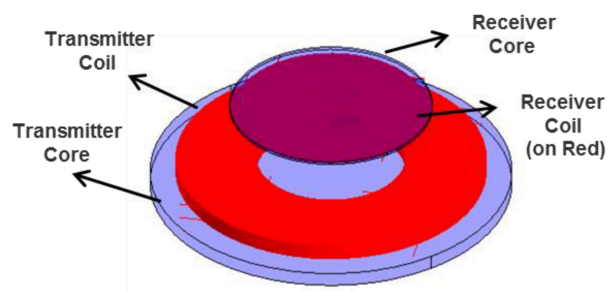
Wireless power transfer

3D Application Note Summary ***(Qualified with Delaunay mesher and User memory mode)***

This application note deals with the modeling of a wireless power transfer with Flux 3D.

Keywords

Applications	Flux main functions	Post-processed quantities
• Steady State AC Magnetic	• Local mesh control • Non meshed coil (3D) • Circuit coupling	• Magnetic quantities • Circuit quantities • Inductance computation

Studied device	
The studied device, represented in figure opposite, is a wireless power transfer (WPT) system. It consists of two circular coils and two ferrite cores which represent the transmitter and receiver inductors.	

Note: This model is based on the demo kit DC2386A by linear technology. It features two different boards for the transmitter and the receiver. There are many transmitter and receiver coils that can be used with DC2386A demonstration board. In this case study, the transmitter coil is circular spiral coil from Würth Elektronik (Wurth 760308100110) with reported inductance value of 24 µH. The receiver coil has 47 µH inductance value and it is from TDK (TDK WR282840-37K2-LR3). All the components of the demo kit will be ignored and only the parts related to WPT system will be modeled.

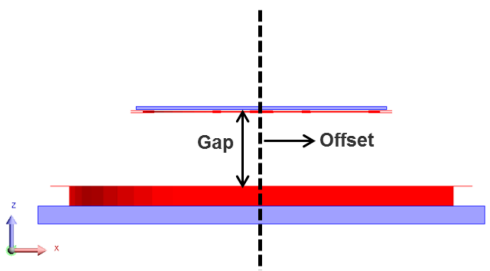
In practice

Open example = Open Flux + Run the pyFlux command file

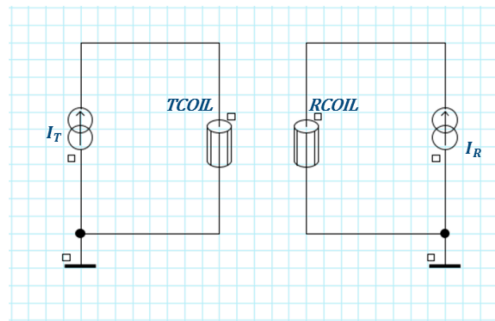
- Recommended memory configuration (standard): 1000 MiB Num + 50 MiB Char + 300 MiB GUI
- Computation time: 7 min < t < 45 min [64 bit - 16 GB RAM - 2.2 GHz]

Example 1: Self and mutual inductance computation

The objective is to calculate self-inductance of each the transmitter and receiver coils and the mutual inductance and coupling coefficient between them based on the gap and offset between the coils.



Coils arrangement (Nominal case Gap = 8.25 mm, Offset = 0)



Electric circuit setup

Three different scenarios were solved for:

- Computation of transmitter coil inductance (L_T)

$$L_T = \frac{\Phi_T}{I_T} = 23.82\ \mu H,\quad with\ \ I_T = 1\ \ Arms\ \ and\ \ I_R = 0$$

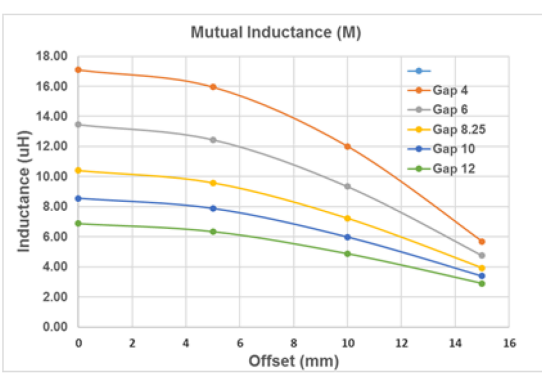
- Computation of transmitter coil inductance (L_R)

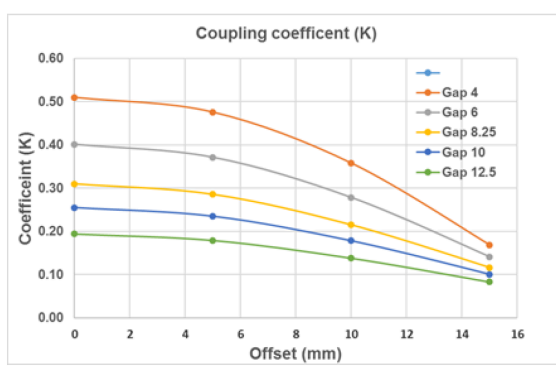
$$L_R = \frac{\Phi_R}{I_R} = 47.58\ \mu H,\quad with\ \ I_T = 0\ \ and\ \ I_R = 1\ \ Arms$$

- Computation of mutual inductance (M) and coupling coefficient (K) for different gaps and offsets

$$M = \frac{\Phi_R}{I_T},\quad with\ \ I_T = 1\ \ Arms\ \ and\ \ I_R = 0$$

$$K = \frac{M}{\sqrt{L_T \times L_R}}$$



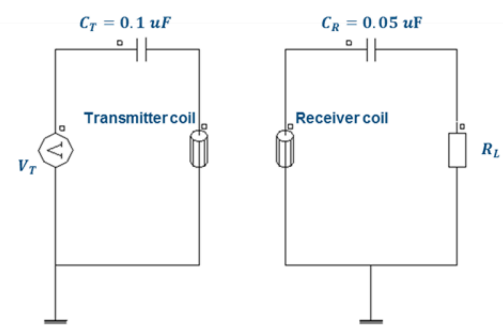


Example 2: Resonant coupling with nominal gap (8.25 mm and no offset)

To improve the power transfer system a capacitor can be added in series to form (LC) circuits with transmitter and receiver coils. At the resonant frequency of the LC circuit, the reactive power will oscillate between the inductor and capacitor, canceling their impedance with respect to the source and leaving only the resistive load, which allow more current (power) to be delivered to the load and improve the overall efficiency of the system. The resonant frequency of series LC circuit can be calculated as:

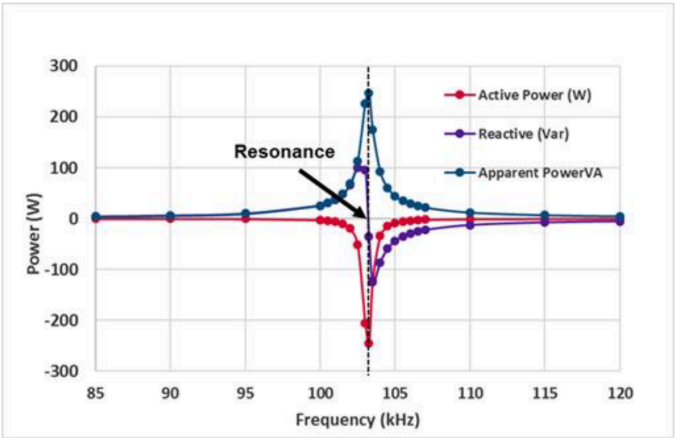
$$f_0 = \frac{1}{2\pi\sqrt{L \times C}}$$

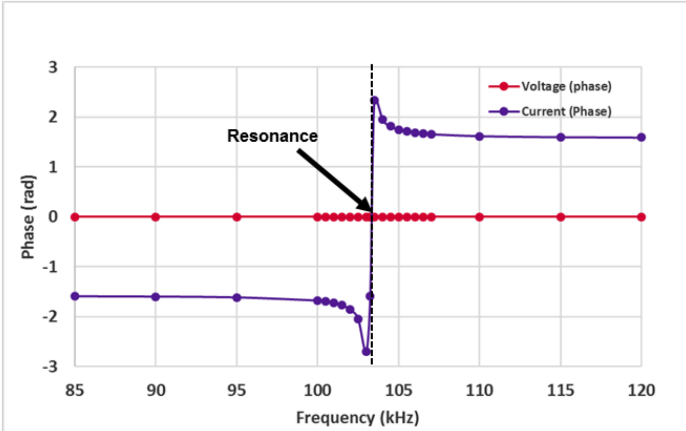
- C_T was set to 0.1 μF
- Resonant frequency is 103.28 kHz
- C_R set to 0.05 μF to match the resonant frequency of the transmitter circuit



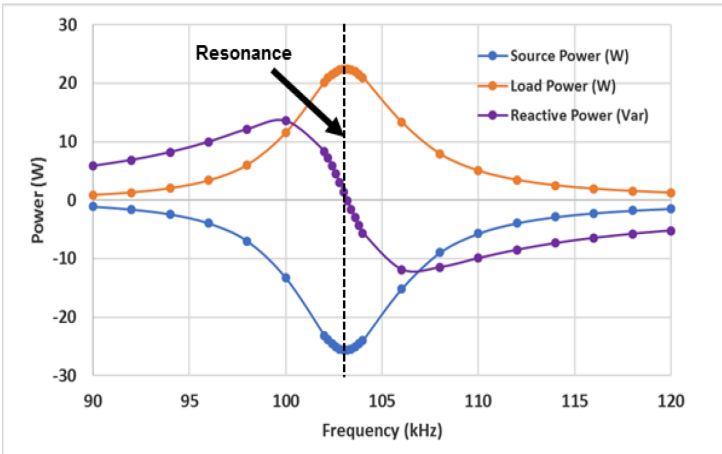
Three cases were considered:

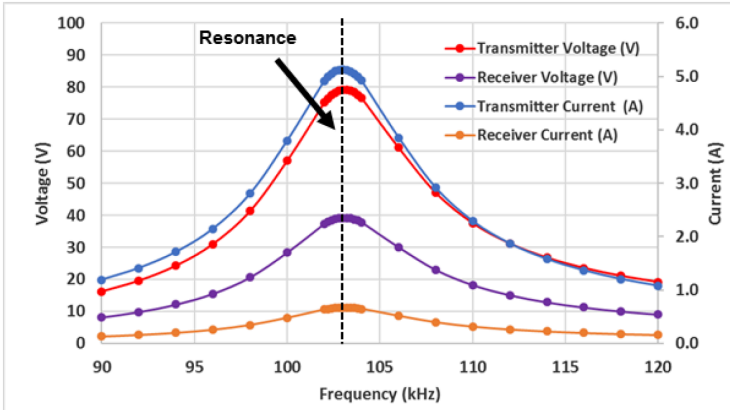
- Unloaded condition, with R_L set to very large value (1E6). The simulation was done by varying the frequency with the voltage supply set to 5 Vrms. The resonant happens when the reactive power is zero and current and voltage for the source are in phase. From the simulation the resonant happens around 103.21 kHz.



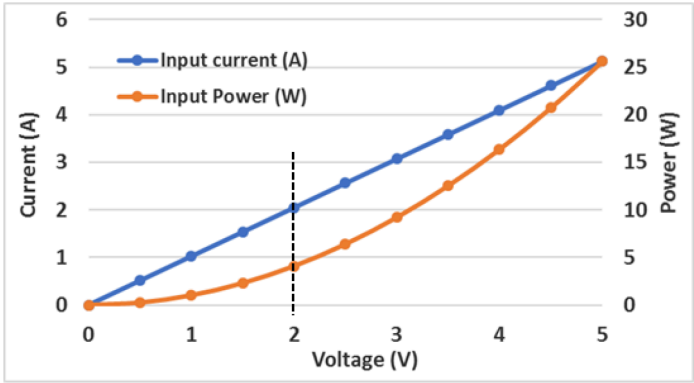


- Loaded condition with R_L set to 50 Ω. The simulation was done by varying the frequency with the voltage supply set to 5 Vrms. The resonance happens at 103.2 kHz, at resonant the active source power is 25.6 W, while the load power is 22.43 W, which indicate an efficiency of 87.6 % for the power transfer.





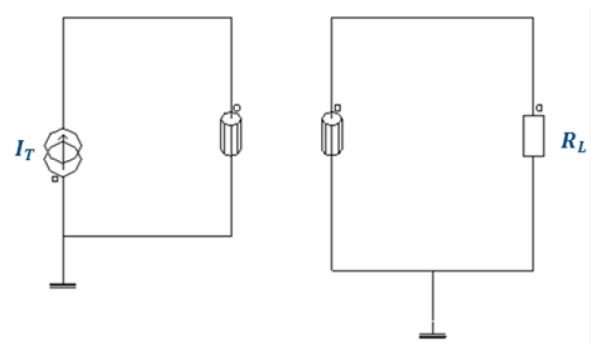
- Voltage variation at the resonant frequency of 103.2 kHz. The objective here is to meet the limitation of the demo kit (2 A and 5 W for input current and power). With 2 Vrms the power and current are within the limitation.



Example 3: Inductive coupling with nominal gap (8.25 mm and no offset)

The objective of this example is to compare the resonant coupling on the previous example with the inductive coupling for the same input power of 4.01 W.

- Circuit setup to be used in this example for inductive coupling



The scenario is defined with variation of the current to meet the input power of 4.01 W. The table gives the results and compare with the case of resonant coupling. The efficiency is more than 5% higher with resonant coupling compared with inductive coupling.

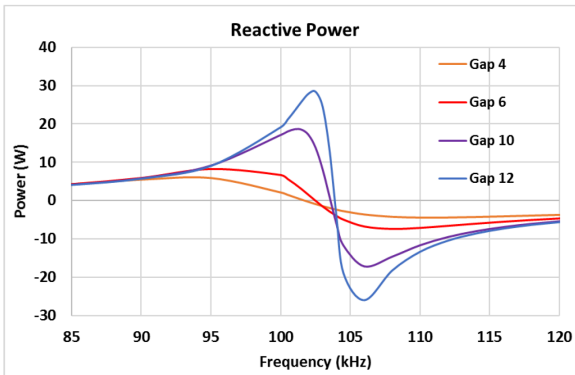
	Resonant Coupling	Inductive Coupling		Resonant Coupling	Inductive Coupling
Input Power (W)	4.01	4.01	Receiver Current (A)	0.27	0.26
Reactive Power (Var)	0	-87.8	Receiver Voltage (V)	15.67	12.96
Transmitter Current (A)	2	2.31	Load Power (W)	3.59	3.38
Transmitter Voltage (V)	31.68	34.9	Efficiency (%)	89.5	84.28

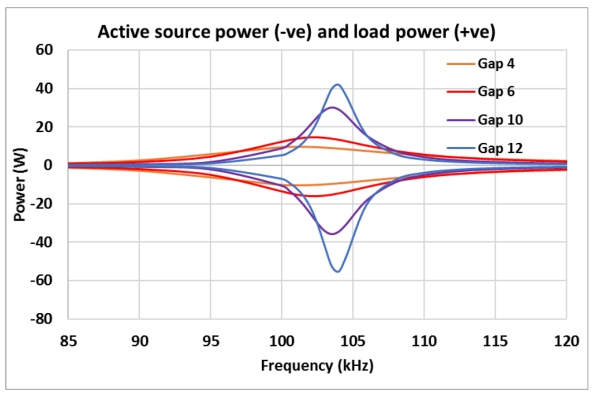
Example 4: Resonant coupling with different gaps (no offset)

The objective of this example is to find the system performance with different gaps from (4, 6, 10, and 12 mm). The circuit setup is the same as in example 2.

Several cases are considered for this analysis:

- For each gap the frequency was varied while the voltage source is 5 Vrms and the load resistance at 50 Ω. From the power plots the resonant frequency of each gap can be identified.





- To meet the limitation on the input current and power, a solving scenario has been created for each gap with voltage variation at the identified resonant frequency from the simulation above. The results are summarized in the table below. Clearly, the power delivered to the load and the system efficiency decrease as the gap increases.

Gap (mm)	Resonant Frequency (kHz)	Voltage (V)	Transmitter current (A)	Transmitter voltage (V)	Source Power (W)	Receiver Voltage (V)	Receiver Current (A)	Load Power (W)	Efficiency (%)
4	101.69	3.45	1.44	22.80	5.00	17.92	0.31	4.67	93.40
6	102.47	2.77	1.79	27.78	5.00	17.57	0.30	4.53	90.60
8.25	103.2	2.00	2.00	31.68	4.01	15.67	0.27	3.59	89.53
10	103.56	1.40	2.00	30.88	2.90	12.65	0.22	2.40	82.76
12	103.8	0.975	2.00	30.69	1.96	10.15	0.17	1.52	75.79