Assignment 2

Calculation

By using the online calculator located on `http://deepfriedneon.com/tesla_f_calcspiral.html`, we obtained acceptable inductances for our coils at the coil parameters as given in Table 1. Target parameters were an inner diameter of 50 mm for both coils and inductances of 22 µH for the secondary coil and 100 µH for the primary coil. The diameter of the given Litz-wire is 1.8 mm and we estimated an average wire spacing of 0.5 mm between each winding.

Table 1: Calculated coil parameters

Coil	Windings	Inductance	Outer diameter	Total wire length
Primary	30	101.6 µH	188 mm	11.2 m
Secondary	15	22 µH	119 mm	4 m

Measurements

After winding these coils we obtained the following inductances for the individual coils using an LCR-meter:

Table 2: Measured coil parameters

Coil	Inductance	DC-resistance
Primary	94.5 µH	250 mΩ
Secondary	25.2 µH	65 mΩ

Then, we calculated the coils' mutual inductance and coupling factor via the ostrich approach as given in the Student Manual. [1] This meant measuring the inductance of both of the coils while connected in *series-aiding* and *series-opposing* at a varying distance between the coils. The results are shown in Table 3.

Table 3: Mutual inductance and coupling factor at varying distance

Distance	Aiding inductance	Opposing inductance	Mutual inductance	Coupling factor
0 cm	184.3 µH	58.6 µH	314.2 µH	0.64
2 cm	151.5 µH	86.8 µH	161.8 µH	0.33
4 cm	135.6 µH	100.0 µH	88.9 µH	0.18
6 cm	127.5 µH	107.0 µH	51.2 µH	0.11

By making use of an equivalent circuit we were able to calculate the theoretical power transfer to the load. The equivalent circuit translated to a mathematical relationship is given by

$$\vec{\mathbf{I}}\mathbf{Z} = \begin{bmatrix} I_{source} \\ I_{load} \end{bmatrix} \begin{bmatrix} R_1 + j\omega L_1 & j\omega M \\ j\omega M & R_2 + j\omega L_2 + R_L \end{bmatrix} = \vec{\mathbf{V}} = \begin{bmatrix} V_{source} \\ 0 \end{bmatrix}. \tag{1}$$

Here the internal resistances of the coils are denoted by R_1 and R_2, the mutual inductance by M, the inductances by L_1 and L_2, the voltage source current by I_{source} and the load current by I_{load}. By using this relationship, we tried to approximate the power transfer characterics. The calculated values are given in Table 4.

Table 4: Power transfer simulations

Distance	Source voltage	Source current	Source power	Load voltage	Load power	Efficiency
0 cm	20 V	0.1210 A	2.42 W	4.87 V	2.31 W	96 %
2 cm	20 V	0.0216 A	0.43 W	2.00 V	0.39 W	90 %
4 cm	20 V	0.0069 A	0.13 W	1.04 V	0.11 W	77 %
6 cm	20 V	0.0032 A	0.06 W	0.59 V	0.03 W	53 %

Our equivalent circuit only incorporates the losses of the internal resistances of the coils. We therefore expect the calculated efficiency and source power and consequently current to be inaccurate. Finally, we performed some measurements on the entire converter, including coils, to see how much power could be delivered to a 10.08 Ω load, with a distance of 2 cm between the coils.

Table 5: Power transfer measurements

Distance	Source voltage	Source current	Source power	Load voltage	Load power	Efficiency
2 cm	19.998 V	0.0835 A	1.67 W	2.02 V	0.405 W	24.2 %

As expected, the effiency and source power and current do not match the calculated values. However, the transferred power does match the result of the simulation.

Questions

1. The open and short circuit test is not well suited for the air core transformer, because that method depends on the coupling factor being very high and thus leakage flux being really low. For a ferrite-core transformer this assumption may hold, but for an air core transformer it does not, since the coupling factor decreases very fast, as the distance between the coils increases (this can be seen in Table 3).

2. To determine the mutual inductance of two coils, one can use the series-opposing and series-aiding method. This method makes use of the fact in both a series-aiding and series-opposing configuration, the influence of the inductance of the coils in the total inductance, that means also incorporating the mutual inductance, is the same. Thus, by substracting the measured values of the total inductance in a series aiding and series opposing configuration, one is able to substract the value of the mutual inductance because the influence of the inductances of the two coils is filtered out. However, the mutual inductance and the inductance of the two coils is heavily influenced by external factors. This should be kept in mind.

3. As the distance increases, the coupling factor k decreases. Because the magnetising inductance M is given by $k\sqrt{L_1 L_2}$, the magnetising inductance thus also decreases. Consequently, the leakage inductances L_{L1} and L_{L2} increase, because they are given by $L_{Li} = (1-k)L_i$. This result can also be obtained by arguing that the leakage flux increases by increasing the distance between the coils. An increase in leakage flux corresponds with an increase of L_{L1} and a decrease of L_M.

4. As shown in Table 5, the power transfer of the transformer is very low. This is due to the low coupling factor, especially at higher distances between the two coils.