Simulating Simple Electrostatic Capacitors

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***Abstract*—This lab focuses on measuring the inductance of a rectangular coil of wire. The coil is modeled to be representative of a standard circuit board coil. The inductance was measured parametrically to understand the impact of trace width.**

I. Introduction & Methods

Lab setup was probably the most time-consuming portion of the process. Before taking any measurements, the model circuit board coil had to be created. This was done by drawing a path for the trace to follow, and then dimension was provided to create a trace with a rectangular cross section.

Due to a simpler geometry, measuring a coil following a rectangular path is less computationally intensive than measuring one with a circular path. To work with the computational restrictions imposed by the virtual machine's limited resources, the rectangular path was the obvious choice. It also happens that most PCB design packages default to eight trace directions, so rectangular path coils are somewhat common in the real world.

Every dimension of the coil plays some role in its inductance—its reaction to a changing current. The coil, as seen in figure 1 has the dimensions shown in table I. Width and height are the width and height of the rectangular section of the coil, terminal is the length of the terminals, via is the vertical via distance for bringing the second terminal back outside the coil. Trace is the width of the trace, thickness is the thickness of the trace, dist is the distance between parallel traces, and pitch is the distance between the centers of parallel traces.

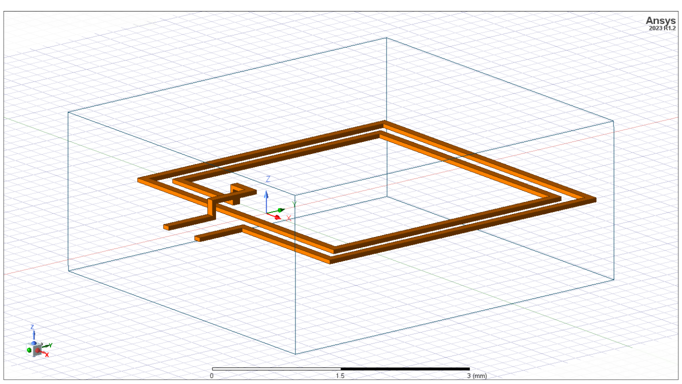

Fig. 1. Final coil design

After constructing the coil, a box of air, just larger than the coil, was created. Getting the box to fit properly around the coil took some messing with, but the final positioning and dimensions cab be seen in table II. This box of air defined the region over which the magnetic field was analyzed.

II. Results & Analysis

A 1[A] current was passed through the coil, and the magnetic field was analyzed inside the box of air. In doing so, the inductance of the coil could be found. Using the coil dimensions in table I, the inductance was found to be 22.822[nH]. Given that it is a small coil with only two windings, a small, but non-zero inductance is expected.

TABLE I
Initial coil dimensions

Dimension	Magnitude	Units
Width	4	mm
Height	4	mm
Terminal	700	μm
Via	200	μm
Trace	200	μm
Thickness	50	μm
Dist	100	μm
Pitch	trace + dist	–

TABLE II
Air box dimensions

Dimension	Magnitude	Units
X Position	-width/2 - trace	–
Y Position	-1.3	mm
Z Position	-1	mm
X Size	2 × trace + width	–
Y Size	length + trace + terminal	–
Z Size	2	mm

Analyzing equation 1, the inductance of the coil is directly proportional to magnetic flux. Therefore, inductance can be increased by either making the loop area larger or by increasing the number of turns of the coil.

$$L = \frac{\Phi_M(i)}{i} \tag{1}$$

The goal of this lab was to determine the effect that trace width had on inductance. Originally, the trace width was increased from 100[μm] to 300[μm] at 100[μm] intervals to decrease analysis time, but the result of this simulation was too low resolution to make out any distinct patterns. To mitigate this, the range was increased to extend up to 400[μm] with a finer step value of 10[μm]. This drastically increased the resolution, and the results can be seen in figure 2.

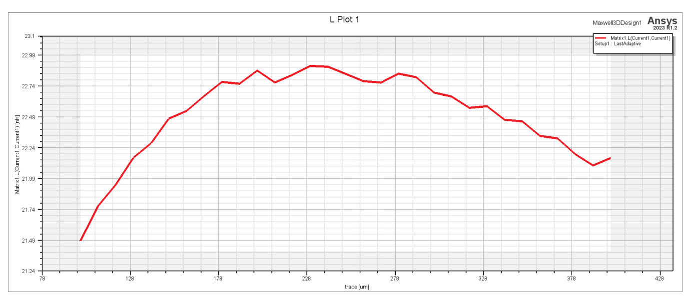

Fig. 2. Inductance as it relates to trace width

The magnetic field produced by the coil will add around parallel wires and cancel out between the wires. This means that as the coils get wider, the magnetic field has a smaller area to travel through. The net effects of the current in the coil can be seen in figure 3.

III. Conclusions

Looking closer at figure 2, increasing the trace width had a positive effect up until about 230[μm] before levelling off

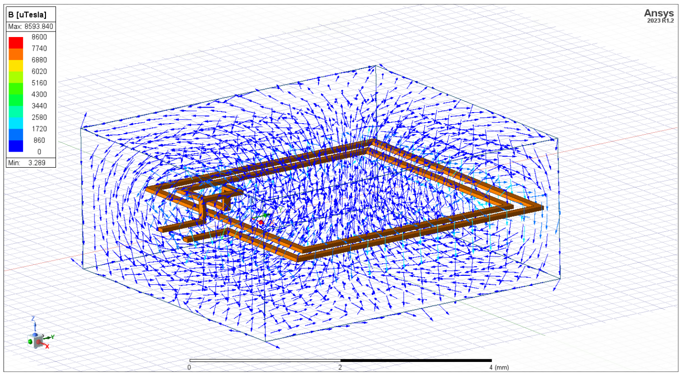

Fig. 3. Magnetic field around the coil

and trending downwards. Since the coil is made of copper and not a perfect conductor, it has some resistance. Therefore, increasing the trace width will increase cross-sectional area and thereby decrease resistance. This possibly explains why the inductance increases as resistance goes down.

However, as the traces get wider without increasing the size of the coil, the area of magnetic flux must decrease. This is because the area that contributes the most to the magnetic flux is inside the coil. This combination of behavior could explain the increase and decrease of inductance as a function of trace width.

Making an inductor on a circuit board therefore poses a few challenges. Firstly, the current must be limited as the trace width impacts inductance. Second, the number of windings is limited by the area given to the coil. Typically, inductors are mounted components that use all three dimensions allotted. This is because they are defined by their geometry and can often be quite difficult to make compact.

The PCB inductor has its benefits, however. If the required inductance is small, it can be quite easy to put together a PCB inductor to use as a small antenna. Unfortunately, this design takes up a lot of board space and makes the center more or less unusable. For this reason, a better, more compact design should probably be used for most applications.