

## Inductance

**Reading assignment**

Popović and Popović, Chapter 15

Connor and Salon, VII-19 → VII-25 and VIII-12 → VIII-14

**Software** snoid.m and associated files**Problem 1 - self-inductance, analytical calculation**

Consider a solenoid with  $N$  turns, length  $l$ , and radius  $a$ . If we ignore fringing effects, the flux density inside a solenoid is  $\mathbf{B} = \mu_0 n I \mathbf{a}_z$  where  $n = N/l$ . As previously calculated in Lesson 3.4, the flux through a single turn of the solenoid is  $\psi = \int \mathbf{B} \cdot d\mathbf{s} = \mu_0 n I \pi a^2$ . Assume the current in this problem is given by  $I = I_0 \cos(\omega t)$ .

- What is the flux linkage through all  $N$  turns,  $\Lambda = \sum \psi_i$ ?  
(The summation is over the number of turns).
- What emf,  $\int \mathbf{E} \cdot d\mathbf{l}$  is induced around the solenoid (include all turns)?
- The "voltage" across an inductor is the emf (with care taken about signs). Find the solenoid inductance by substituting the absolute value of the emf in part b. for the voltage in  $V = L dI/dt$ .
- Calculate  $L = \Lambda/I$  and compare with your answer to part c.
- Calculate numerical values for  $\mathbf{B}$ ,  $\psi$ , emf, and  $L$  when  $N = 26$ ,  $I = 100$  mA,  $l = 16$  mm, and  $a = 2.5$  mm. Use these values in the experiment and simulation below.

**Problem 2 - Self and mutual inductance - numerical simulation Computer code overview**

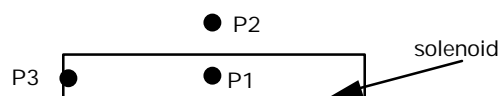
A set of MATLAB .m files will be used to calculate the magnetic field and inductance of a solenoid including fringe effects. To run the code in JEC 4107:

- Copy the solenoid folder on the server to "c:\fw1".
- Start MATLAB
- >> cd c:\fw1
- >> snoid
- Follow the menu prompts. The data file is already set-up.

**Calculations**

Note: snoid performs calculations only for integer multiples of 1 cm. This problem has a mm scale so the data file models a solenoid 10 times larger than actual. Because of this, the true  $\mathbf{B}$  is 10x larger than the code result, the true  $\mathbf{A}$  is the same as the code, and the true inductance, is 10x smaller than the code results.

- What is the inductance of the solenoid? Compare with the results from Problem 1.
- Plot the magnetic flux lines.
- Determine  $\mathbf{B}$  at points P1 → P3 (see figure below). Compare the values for P1 and P3 with problem 1e. P2 is 2.5 mm outside the solenoid. (see next page)



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d. Estimate the flux through some of the loops (in the center and on the ends) and compare with the numerical value in part 1e.

Is the flux intercepted by a finite length solenoid larger or smaller than you would estimate using an infinite length solenoid approximation? Is the inductance larger or smaller? (Is this the same or different than fringe field effects on capacitance?)

Outline how you could numerically calculate inductance if the code didn't already calculate it.

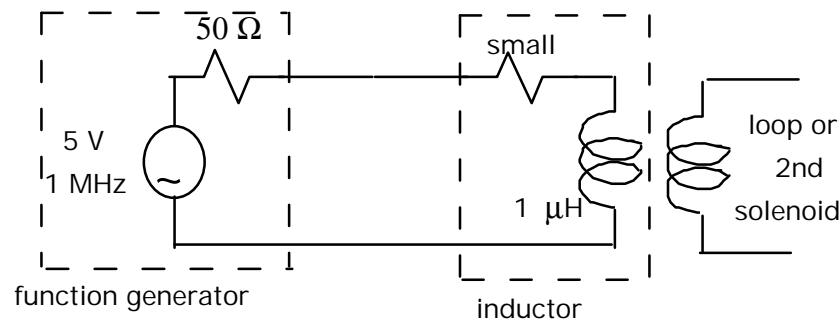
**Problem 3 - Mutual inductance Experiment**

a. Obtain 2 solenoids and some magnet wire. Use the magnet wire to make a multiple turn loop that fits snugly around the solenoid. The solenoid and magnet wires are coated with a non-conducting enamel.

b. What will be the mutual inductance between your loop and a solenoid be when the loop is:

- 1) wrapped around the center of the solenoid
- 2) placed side-by-side with the solenoid (centered about point P2)

c. Set up the circuit below.



d. Use your mutual inductance values from part b. and determine the voltage that will be induced on the pickup coil for both cases. Note that the 50 Ω output impedance of the function generator dominates, so the current is approximately 0.1 A as we have been using. *You should both calculate and measure the voltage.*

e. Make measurements with various positions and orientations for the pickup coil and/or the other solenoid as the secondary. Observe changes in both phase and amplitude. Are they consistent with what you expect?

Some suggested experiments:

- 1) Slide the wire off the end of the solenoid.
- 2) Rotate the coil while outside the solenoid.
- 3) Compare two solenoids side by side with 2 solenoids end to end.
- 4) Adjust the orientation of the cabling as well as the coils.
- 5) Use just the oscilloscope cable as your pickup coil.
- 6) Vary frequency. (Look at the voltage ratios).
- 7) Does the voltage across the secondary fit  $V_2/V_1 = N_2/N_1$ ? What other inductance is in the problem?