

6.4.2: Non-ideal Inductor Effects

Overview:

Voltage-current relationships for ideal inductors do not always adequately explain measured inductor voltages and currents. In this assignment, we will measure inductor voltages and currents which do not agree well with idealized inductor relationships we have employed earlier. After recognizing the differences between the measured data and our mathematical models, we will use a non-ideal inductor model to better approximate the physical behavior of the inductor.

Before beginning this lab, you should be able to:

- Apply the inductor voltage-current relations to calculate a inductor's voltage from its current and vice-versa
- Use the Analog Discovery's arbitrary waveform generator and oscilloscope to apply and measure time-varying waveforms (Lab 6.2.1)
- Use a math channel on the Analog Discovery to determine the current through a resistor from the voltage drop across the resistor (Labs 6.3.1, 6.4.1)

After completing this lab, you should be able to:

- Model an non-ideal inductor as an ideal inductor in series with a resistor
- Identify some effects of non-ideal inductors from measured data

This lab exercise requires:

- Analog Discovery module
- Diligent Analog Parts Kit
- Digital multimeter (DMM)

Symbol Key:

	Demonstrate circuit operation to teaching assistant; teaching assistant should initial lab notebook and grade sheet, indicating that circuit operation is acceptable.
	Analysis; include principle results of analysis in laboratory report.
	Numerical simulation (using PSPICE or MATLAB as indicated); include results of MATLAB numerical analysis and/or simulation in laboratory report.
	Record data in your lab notebook.

General Discussion:

The basic circuit we will use in this assignment is the same series resistor-inductor circuit used in lab 6.4.1. This circuit is repeated in Figure 1 below, for convenience. As in lab 6.4.1, the inductor voltage can be inferred from the voltage across the resistor and the resistance, as shown below:

$$i_L(t) = \frac{v_R(t)}{R} \quad (1)$$

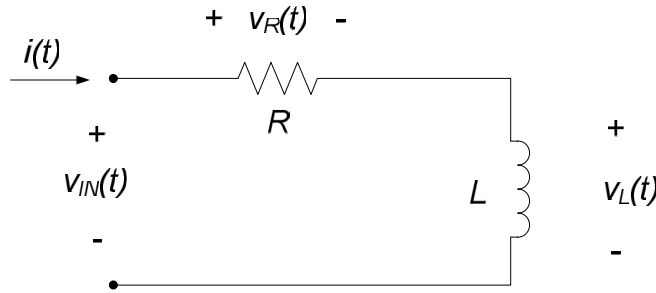


Figure 1. Series RL circuit.

In this assignment, we will apply triangular and square waveforms to the circuit of Figure 1 above. The measured inductor voltage and current resulting from these waveforms will not agree well with the idealized inductor voltage-current relationships we have used to date. In order to interpret the data we acquire in this assignment, we will employ a non-idealized model of the inductor consisting of a series combination of an ideal inductor and a resistor as shown in Figure 2.

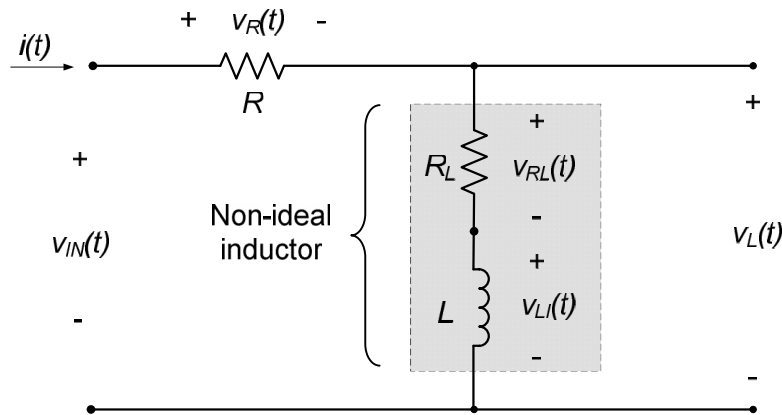


Figure 2. Circuit of Figure 1, with non-ideal model of inductor.

Pre-lab:

In this lab, we will apply triangular and square signals to the circuit of Figure 1¹. The waveforms we will use are shown graphically in Figures 3. In both cases, A is the amplitude of the signal (in amperes) and f is the frequency of the signal (in Hz).

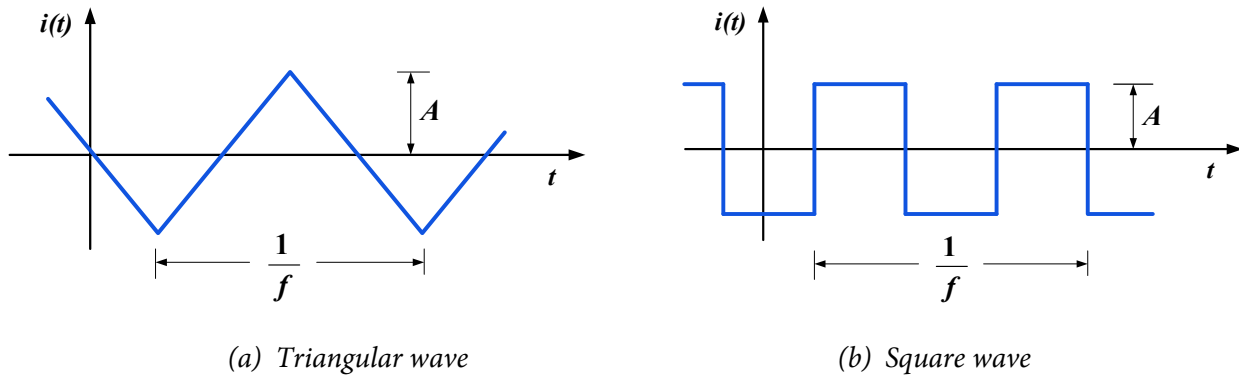


Figure 3. Basic waveforms used in this lab.

For the circuit of Figure 1, use the inductor voltage-current relations to overlay sketches of the inductor voltage and the inductor current ($v_L(t)$ and $i(t)$) if the inductor current is:

ANALYSIS

- a. A triangular wave, $i(t)$, with frequency (f) and amplitude (A) as shown in Figure 2(a)

ANALYSIS

- b. A square wave, $i(t)$, with frequency (f) and amplitude (A) as shown in Figure 2(b).

Label your sketch to show the amplitude and period of the inductor current for both of the above cases. Your results may be dependent on the parameters A , f , and L . Be sure that your sketches of voltage and current share the same time axis!

Lab Procedures:

1. Triangular waveform: Construct the circuit of Figure 1 with $L = 1\text{mH}$ and $R = 100\Omega$. Use channel 1 of your oscilloscope to measure the resistor voltage difference, and channel 2 of your oscilloscope to measure the voltage across the inductor. Use channel 1 of your waveform generator (W1) to apply the voltage $v_{in}(t)$ in Figure 1. Set up a math channel to calculate the current through the capacitor per equation (2) in the pre-lab. Set the oscilloscope measurements to provide at least the amplitude of each of the three displayed waveforms.

¹ Please keep in mind that Figures 1 and 2 are actually schematics of the same physical circuit. The difference between the two circuits is simply in the way the inductor is modeled mathematically – in Figure 1 the inductor is modeled as being ideal, while in Figure 2, the inductor is modeled as including a resistance. In Figure 2, we are simply accounting for the fact that any physical inductor will dissipate energy.

DATA

- i. Apply a triangular input voltage with frequency = 1kHz, amplitude = 1V, and offset = 0V to the circuit of Figure 1. Use your oscilloscope to display the data listed above (waveforms corresponding to C1, C2, and M1; measurement window displaying amplitudes of C1, C2, and M1). Export the image of the oscilloscope window, showing the waveforms and their measured amplitudes.

DEMO

- ii. Demonstrate operation of your circuit to the Teaching Assistant. Have the TA initial the appropriate page(s) of your lab notebook and the lab checklist.

DATA

- iii. If the experiment goes according to plan, the measured voltage across the inductor will look something like the waveform shown in Figure 4. This is not (hopefully) what your sketch of your expected response of the inductor voltage that you created in part (a) of the pre-lab looks like (since you were assuming that the inductor was ideal, per the assumptions of Figure 1). We need to revisit our expectations as to how inductors actually behave!

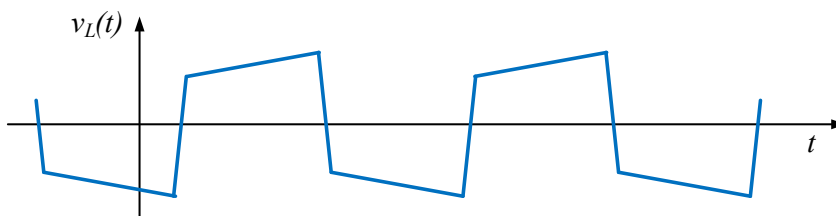


Figure 4. Likely shape of the measured inductor voltage waveform.

DATA

- iv. Now we will examine our measured inductor voltage response in the light of the non-ideal inductor model shown in Figure 2. In Figure 2, the measured inductor voltage is the sum of the “ideal” inductor voltage, $v_{LI}(t)$, and the voltage difference induced by the inductor’s internal resistance, $v_{RL}(t)$. We can still assume that the measured current ($i(t)$, in Figures 1 and 2) is the current through both elements of our non-ideal inductor. Using your digital multimeter as an ohmmeter, measure the resistance of your inductor. Based on your measured waveform of the inductor current from part (b), sketch the voltages internal to the non-ideal inductor, $v_{LI}(t)$ and $v_{RL}(t)$. Sketch the sum of these contributions and compare the result to the measured inductor voltage from part (b) above. Briefly discuss the ideal, non-ideal, and measured inductor voltages.

ANALYSIS

2. Apply a square wave input voltage with frequency = 100 Hz, amplitude = 2V, and offset = 0V to the circuit of Figure 1. Repeat the process of part 1 of the experimental procedures to generate:

DATA

- i. The measured waveforms and amplitudes (as an image of the oscilloscope window).
- ii. A sketch of the expected inductor voltage using an ideal inductor model from the pre-lab. (Since the current is a piecewise constant value, the expected inductor voltage should be a constant, except when the current transitions from one value to another – during this transition, the inductor voltage should go to infinity.)

ANALYSIS

- iii. A sketch of your expected inductor voltage, based on the non-ideal inductor model of Figure 3 and your measured inductor current. Include a brief discussion comparing the ideal, non-ideal, and measured inductor voltage differences.