Experiment BT-6B: RL Circuits

Equipment Required

PC or Mac Computer

IX-TA-ROAM recorder, USB cable, power supply

A-BMET-B BMET Trainer Board

C-DIN-BB DIN to Breadboard Cable

C-BNC-BB BNC to Breadboard Cable

A-BMET-EC Electronic Components Set

Jumper Wires

Setup

1. Connect the C-DIN-BB Cable to port A5 on the TA-ROAM. Use extender cables for the yellow and brown leads.
2. Connect the C-BNC-BB Cable to the S1 (LV Stimulator) port on the TA-ROAM.

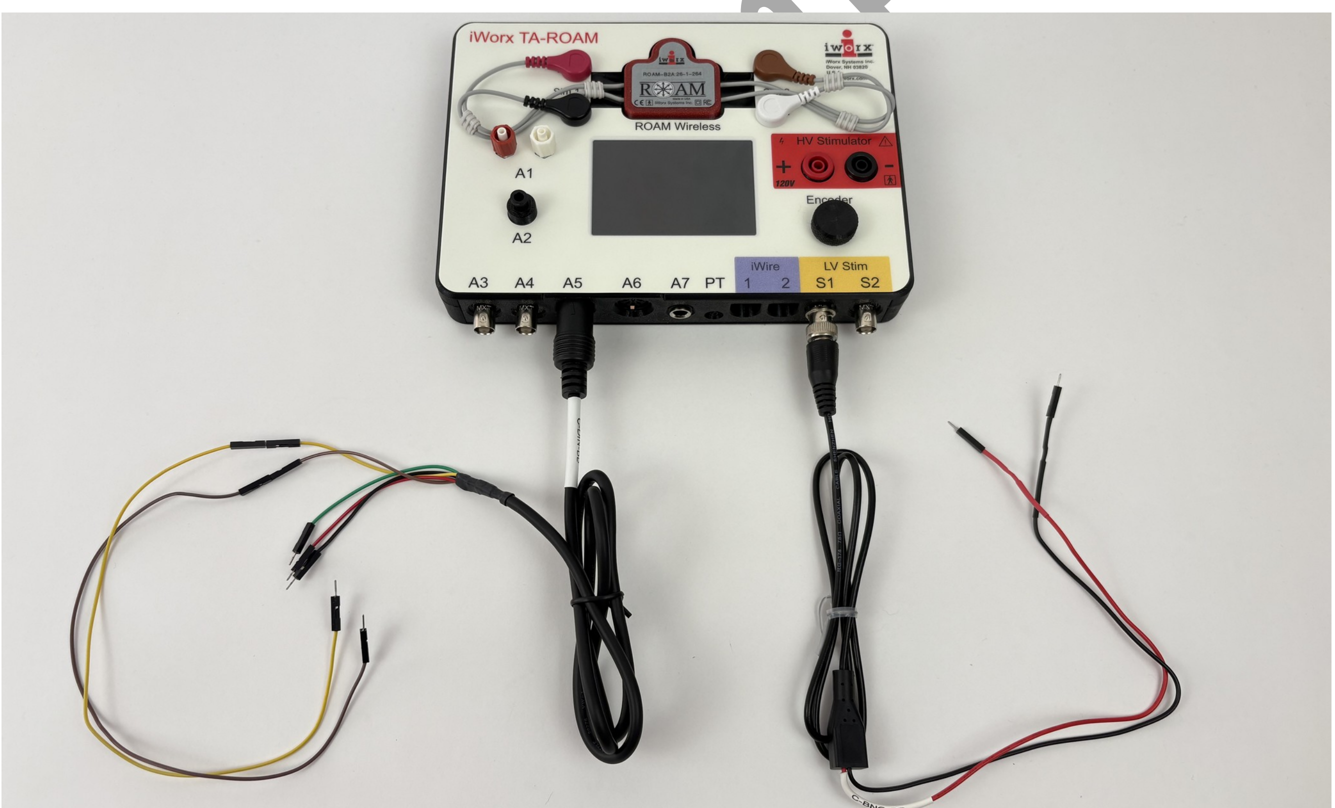

Figure BT-6B-S1: IX-TA-ROAM, C-DIN-BB cable (port A5), C-BNC-BB cable (S1).

Experiment BT-6B: RL Circuits and Timing

Background

In previous labs, you explored how voltage, current, and resistance behave in resistive circuits. Resistors respond immediately to changes in voltage and current, meaning that the electrical behavior of a resistor is determined only by its resistance. However, many electronic systems contain components that store energy and respond more slowly to changes in electrical signals.

In the previous RC circuits lab, you investigated capacitors, which store energy in an electric field and oppose sudden changes in voltage. Another important reactive component is the inductor, which stores energy in a magnetic field and opposes sudden changes in current.

When resistors and inductors are combined, they form RL (resistor-inductor) circuits. These circuits are commonly used in filters, power supplies, motor control circuits, electromagnetic systems, and signal-conditioning applications. In biomedical instrumentation, inductive components can be used in filtering circuits and electromagnetic sensing systems.

In this experiment, you will investigate how RL circuits respond to changes in input voltage. You will observe how inductors resist changes in current, compare the behavior of inductors with different values, and examine how real-world inductor characteristics affect circuit behavior.

Theory

1. Inductors Introduction

The most important characteristic of an inductor is that it opposes sudden changes in current. Unlike a resistor, which immediately responds to changes in voltage, an inductor temporarily resists changes in current by generating a voltage that opposes the change.

Inductors are reactive components because they can store and release energy. They store energy in a magnetic field created when current flows through a coil of wire.

The ability of an inductor to store energy is called **inductance** and is measured in henries (H). The relationship between voltage and current in an inductor is:

$V_L = L(dI/dT)$

where:

- V_L = voltage across the inductor (V)
- L = inductance (H)
- dI/dT = rate of change of current (A/s)

This equation shows that a larger change in current requires a larger voltage across the inductor.

The symbol for an inductor is shown in Figure 1.

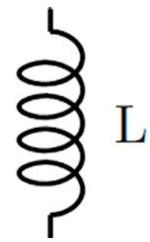

Figure 1. Inductor symbol

2. How Inductors Work

An inductor is made from a coil of conductive wire. When current flows through the coil, a magnetic field forms around the wire. The strength of this magnetic field depends on the amount of current flowing through the inductor.

he energy stored in an inductor is:

E= ½ LI^2

where:

- E = stored energy (J)
- L = inductance (H)
- I = current (A)

When voltage is first applied to an inductor, the current does not immediately reach its maximum value. The changing current creates a changing magnetic field, which produces a voltage that opposes the original change. This is called **self-induced voltage** or **back electromotive force (back EMF).**

As time passes, the current increases and the magnetic field becomes stronger until the circuit reaches steady state.

When the input voltage is removed, the stored magnetic energy is released. The collapsing magnetic field produces a voltage that attempts to maintain current flow, causing the current to decrease gradually rather than stop immediately.

3. RL Circuits

An RL circuit consists of a resistor and an inductor connected together. The resistor controls the maximum current in the circuit, while the inductor controls how quickly the current changes.

When a voltage is applied:

- The inductor initially opposes the increase in current.
- Current begins near zero.
- Current gradually increases until reaching a maximum value.

When the voltage is removed:

- The magnetic field collapses.
- The stored energy is released.
- Current gradually decreases.

The current through an RL circuit follows an exponential response similar to the charging and discharging behavior observed in RC circuits.

4. Time Constant

The time constant of an RL circuit is defined by:

$\tau = L / R_{total}$

Where L is the inductance, and R_{total} is the total resistance (R+DCR).

5. Real Inductors

Unlike ideal inductors, real inductors contain resistance from the wire used to create the coil. This resistance is called DC resistance (DCR).

A real inductor can be modeled as:

- An ideal inductor
- In series with a small resistor

The DCR affects the circuit by:

- Reducing the maximum current
- Reducing the voltage across the external resistor
- Changing the circuit time constant

A circuit is considered approximately fully charged or discharged after five time constants.

In this lab, the inductor values you will be working with are:

- 10 mH inductor with ~22 ohms DCR
- 100 mH inductor with ~240 ohms DCR

6. Measuring RC Circuits

When measuring an RL circuit, it is important to consider where the measurement is taken.

In an RC circuit, measuring across the capacitor provides the capacitor voltage directly. However, real inductors contain internal resistance, meaning that measuring across the inductor terminals measures both:

- Voltage across the ideal inductor
- Voltage across the internal coil resistance

For this reason, the voltage across the resistor is used to determine the current response.

Using Ohm's law:

$I = V_R / R$

where:

- I = current through the circuit
- VR = voltage across the resistor
- R = external resistor value

Pre-Lab Questions

1. How does an inductor respond when the current through it suddenly tries to increase? What causes this behavior?
2. What is the time constant of an RL circuit? Write the equation for the RL time constant and identify each variable.
3. An RL circuit contains a 100 mH inductor and a 100 Ω resistor. Calculate the time constant of the circuit. Approximately how long would it take for the circuit to reach steady state?

Experiment BT-6B: RL Circuits and Timing

Exercise 1: Inductor Responses

Aim: To understand how an inductor behaves in an RL circuit and compare the measured response with theoretical predictions.

Approximate Time: 30 minutes

Procedure

Figure BT-6B-S1 shows the circuit that will be created in this lab.

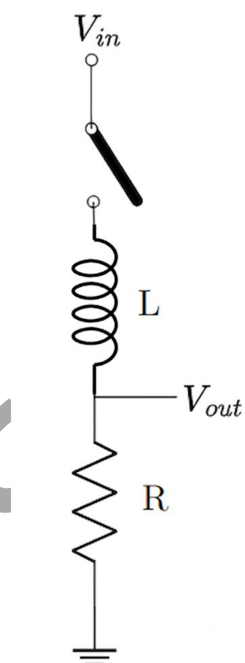

Figure BT-6B-S1: RL circuit with Switch.

1. Locate circuit H on your board.
2. Place switch SW4 in the open (off) position.
3. Add a 100 ohm resistor for RH and 100 mH inductor for LH.
4. Provide an input of 5V using the C-BNC-BB cable.

a) Connect the red pin to INH1.

b) Connect the black lead to one of the GND pins in the Inputs section.

5. Record the voltage using the C-DIN-BB cable.

   a) Connect the + (red lead) to the VCC pin in the Inputs section.

   b) Connect the - (black lead) to the VEE pin.

   c) Connect the ground (green) to a GND pin.

   d) Measure the voltage across the resistor by placing the yellow lead at TPH4 and the brown lead at TPH5.

6. In LabScribe, press the red REC button.
7. Wait 5-10 seconds to record a baseline.
8. Keep the recording going, and now switch SW4 into the closed (on) position.
9. Observe the shape of the voltage curve.
10. Press STOP to stop the recording.
11. Save the data file by clicking File – Save As. Be sure to name the data file appropriately.

Table BT-6B-L1: Data Table for Exercise 1 – Inductor Responses

Data from Charging RL circuit with 100Ω resistor and 100mH inductor				
Value Type	Initial Voltage (_____)	Final Voltage (_____)	Total Charging Time (_____)	Time Constant (_____)
Theoretical				
Measured				
Percent Error (%)				

Data Analysis

1. Position the voltage trace in the center of the window, as shown in figure BT-6B-S2. Use the double display time, half display time, or zoom between cursors icons to center the voltage trace.

Note: The circuit will have a very fast response time, so you will need to zoom in to measure accurately.

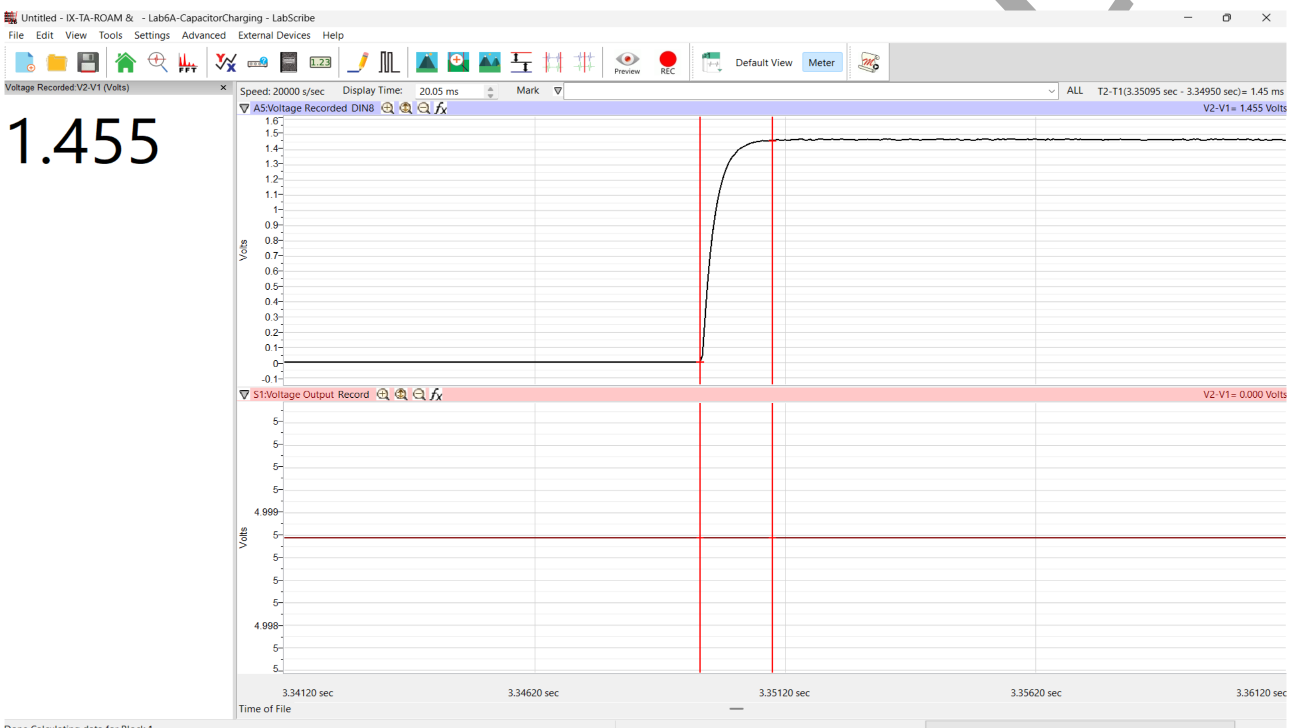

Figure BT-6B-S2: Voltage trace of the output displayed in the Analysis window.

2. Click on the magnifying glass icon to enter into the Analysis window. The Analysis window can be used to simplify measurements.

3. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical functions, Value1, Value2, and T2-T1 should appear in this table. Values for these parameters on each channel are seen in the table across the top margin of each channel.

4. Place the first cursor at the point where the voltage starts to increase. Place the second cursor at the point where the voltage is steady. As you move the cursors, the values at the top of the Voltage Recorded Channel will change. The values of the parameters in the Function Table can be recorded in the on line notebook of LabScribe by typing their names and values directly into the Journal, or on a separate data table.

5. The functions in the channel pull-down menus of the Analysis window can also be used to enter the names and values of the parameters from the recording to the Journal. To use these functions:

- Place the cursors on either side of the section of data to be analyzed.
- Transfer the names of the mathematical functions used to the Journal using the Add Title to Journal function in the Voltage Recorded Channel pull-down menu.
- Transfer the values to the Journal using the Add Ch. Data to Journal function in the Voltage Recorded Channel pull-down menu.

6. Measure the following parameters from the Voltage Recorded Channel for the region of data selected:

- Initial Voltage, which is the value for V1.
- Final Voltage, which is the value for V2.
- Charging time, which is the value for T2-T1.

7. Record the values for these parameters in the data table.
8. Click the Save button to save the file.
9. Click on the Main icon in the LabScribe toolbar to return to the Main window.

Questions

1. Calculate the total resistance of the RL circuit. Include both the external resistor and the inductor's DC resistance (DCR).
2. Calculate the theoretical time constant of the RL circuit.
3. How long did it take the voltage to reach approximately 63% of its final value? Calculate this value from the initial and final voltages, and include it in Data Table BT-6B-L1.

Exercise 2: Effect of Inductance

Aim: To understand how inductor values affect the response of an RL circuit.

Approximate Time: 30 minutes

Procedure

1. Replace the 100 mH inductor with a 10 mH inductor.
2. Repeat the procedure from Exercise 1.

Table BT-6B-L2: Data Table for Exercise 2 – Effect of Inductance

Data from RL circuit with 100Ω resistor and 10mH inductor				
Value Type	Initial Voltage (_____)	Final Voltage (_____)	Total Charging Time (_____)	Time Constant (_____)
Theoretical				
Measured				
Percent Error (%)				

Data Analysis

1. Use the double display time, half display time, or zoom between cursors icons to center the voltage trace.
2. Measure the following parameters from the Voltage Recorded Channel for the region of data selected:

- Initial Voltage, which is the value for V1.
- Final Voltage, which is the value for V2.
- Charging time, which is the value for T2-T1.

3. Record the values for these parameters in data table BT-5A-L2.
4. Click the Save icon to save the file.
5. Click on the Main icon in the LabScribe toolbar to return to the Main window.

Questions

1. Calculate the total resistance of the RL circuit. Include both the external resistor and the inductor's DC resistance (DCR).
2. Calculate the theoretical time constant of the RL circuit.
3. How long did it take the voltage to reach approximately 63% of its final value? Calculate this value from the initial and final voltages, and include it in Data Table BT-6B-L1.

Exercise 3: Effect of Resistance

Aim: To understand how changing resistance affects the response time of an RL circuit.

Approximate Time: 30 minutes

Procedure

1. Keep capacitance constant using a 100 uH inductor.
2. Repeat Exercise 1 using a 499 Ω resistor.
3. Observe charging curves for each resistor.

Table BT-6B-L3: Data Table for Exercise 3 – Effect of Resistance

Data from Charging RL circuit with 499 ohm resistor			
Resistor Value (_____)	Theoretical Charge Time (_____)	Measured Charge Time (_____)	Percent Error (%)

Data Analysis

1. Calculate the total resistance of the RL circuit. Include both the external resistor and the inductor's DC resistance (DCR).
2. Calculate the theoretical time constant of the RL circuit.
3. How long did it take the voltage to reach approximately 63% of its final value? Calculate this value from the initial and final voltages, and include it in Data Table BT-6B-L1.

Questions

1. Which circuit charged fastest? Which circuit charged the slowest? Why?

Post-Lab Questions

1. Explain why an inductor opposes changes in current while a capacitor opposes changes in voltage.
2. A circuit contains a 50 mH inductor with a 20 Ω internal resistance and a 330 Ω external resistor. Calculate the expected steady-state current when connected to a 10 V supply.
3. Compare the responses of the 10 mH and 100 mH inductors. How did changing inductance affect the circuit behavior?
4. Real inductors are not ideal components. Describe two ways that internal resistance changes the behavior of an RL circuit.