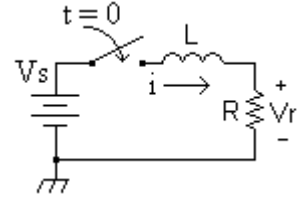


Experiment 19: RL Transient Response

Forced Response

The properties of “inductance” and “inductors” are complementary to the properties of “capacitance” and “capacitors”. Inductors store energy in a magnetic field while capacitors store energy in an electric field. Inductors have an inertia to a change in current while capacitors have an inertia to a change in voltage.

An RL circuit's current response to a step voltage is of the same form as the RC circuit's voltage response to a step voltage. Also, the RL circuit's natural current response is of the same form as the RC circuit's natural voltage response.



The equation for the current as a function of time for the circuit on the right is given by:

$$i(t) = I_f \left(1 - e^{-\frac{Rt}{L}} \right)$$

The current I_f is the circuit current at $t = \infty$, or $I_f(\infty)$ (a final condition). Initial current is 0.

An important parameter of the RL circuit is the time constant: $\tau = \frac{L}{R}$.

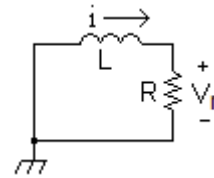
Natural Response

The amount of energy stored in the inductor can be calculated using the equation below. In the SI system, energy, W , has units of Joules, current, I , has units of Amperes, and inductance, L , has units of Henries.

$$\text{Inductor energy: } W = \frac{1}{2} LI^2$$

I_i is the inductor current at $t = 0$ in the circuit on the right, or $i(0)$.

Inductor current, $i(t)$, for $t \geq 0$ is given by: $i(t) = I_i e^{-\frac{Rt}{L}}$



Objectives

The step and natural response of an RL circuit will be measured and compared to calculations. The generator voltage stays constant long enough for the circuit to reach "steady state" (about 5 time constants in this experiment).

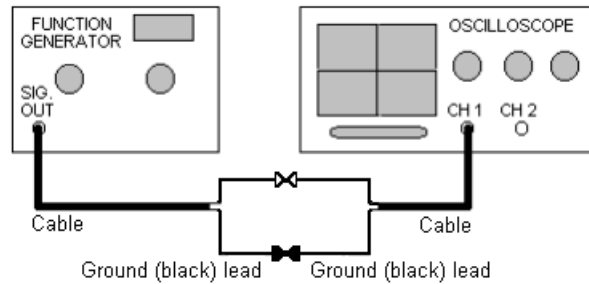
When the voltage changes from 0 V to 8V, the circuit's forced response will be observed. When it changes from 8V to 0V, the circuit's natural response will be observed.

Procedure

Equipment and Parts

Oscilloscope, Function Generator, and Breadboard
Resistors: 1000Ω, 5%. Inductor: 10mH, 5%, air core (J.W. Miller 70F102AI).

1. Connect the instruments shown. Set the generator to 10kHz. Adjust the *AMPLITUDE* and *OFFSET* controls to obtain a 0 to 8V square wave.
2. Turn on the oscilloscope. Set the *TRIGGER MODE* to *AUTO*.
3. Set the input for channel 1 only, *INPUT COUPLING* to *GND*.



You should see a straight line on the screen. Adjust the *VERTICAL POSITION* control to center the trace on the screen vertically.

4. Re-adjust the oscilloscope's *VERTICAL POSITION* control so that the trace fits between the bottom and top of the screen.

Set the *INPUT COUPLING* switch to *DC*, and the *VOLTS/DIV* switch to *1V/DIV*. Set the *TIME/DIV* switch to *10µSec/DIV*.

5. Set the oscilloscope *TRIGGER SLOPE* to negative (falling edge) and *TRIGGER LEVEL* controls to obtain a stable trace.

Waveform should begin at the top of the screen (+8V), and after $50\mu\text{s}$ (5 horizontal divisions) it should go to the bottom of the screen (0V).

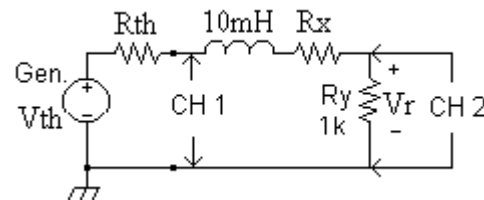
6. Connect the RL circuit to the function generator as shown below on the right. Be sure to leave channel 1 of the oscilloscope connected to the function generator.

The function generator is shown below as a Thevenin equivalent circuit. V_{th} is the "no load" generator voltage and R_{th} is the generator's internal resistance.

Connect channel 2 of the oscilloscope so that it is across the 1K resistor to measure V_r , as shown below.

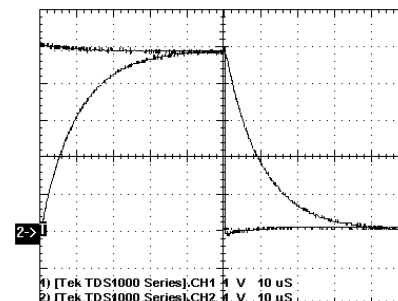
R_x is the DC resistance of the inductor, which must be measured with an ohmmeter. Measure and record the value of R_x .

R_x : _____



Your display should look like the one on the right, except the amplitude will be 8V peak-to-peak. Notice that the channel 1 waveform voltage is greater at the left side and decreases toward the center. Can you explain this?

Channel 2 displays the "forced" response of the circuit in the left 5 major scale divisions, and the "natural" response in the right 5 major divisions.



- Change the *TIME/DIV* to $5\mu\text{Sec}/\text{DIV}$. Adjust the horizontal position and trigger to observe the forced response only.

The current in the RL circuit can be calculated from the voltage drop, V_r , across the 1K resistor. First measure and record the steady state voltage, V_f , at $t = 50\mu\text{Sec}$. Since the circuit current is proportional to the voltage, V_r , the value of V_r can be calculated as a function of the time constant.

$$V_f = \underline{\hspace{4cm}}$$

Calculate the expected voltage for each time interval below and record in the spreadsheet shown at the bottom of page in column B. The example below is for the forced response.

$$1\tau = V_f(1 - e^{-1}) = V_f(1 - .368) = \underline{\hspace{2cm}} \text{ volts}$$

$$2\tau = V_f(1 - e^{-2}) = V_f(1 - .135) = \underline{\hspace{2cm}} \text{ volts}$$

$$3\tau = V_f(1 - e^{-3}) = V_f(1 - .050) = \underline{\hspace{2cm}} \text{ volts}$$

$$4\tau = V_f(1 - e^{-4}) = V_f(1 - .018) = \underline{\hspace{2cm}} \text{ volts}$$

Record the time of occurrence of the predicted voltages for 1, 2, 3, and 4 time constants after $t = 0$. Record in spreadsheet column C

- Repeat step 7 above for the circuit's natural response. Keep the oscilloscope's *TIME/DIV* at $5\mu\text{Sec}/\text{DIV}$, but change the trigger to observe the natural response.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	RC Forced:							RC Natural:					
2	Tau	Voltage (V)	Meas. Time (us)	Calc. Time (s)	% Error	Current (A)		Tau	Voltage (V)	Meas. Time (us)	Calc. Time (s)	% Error	Current (A)
3	1							1					
4	2							2					
5	3							3					
6	4							4					

Analysis

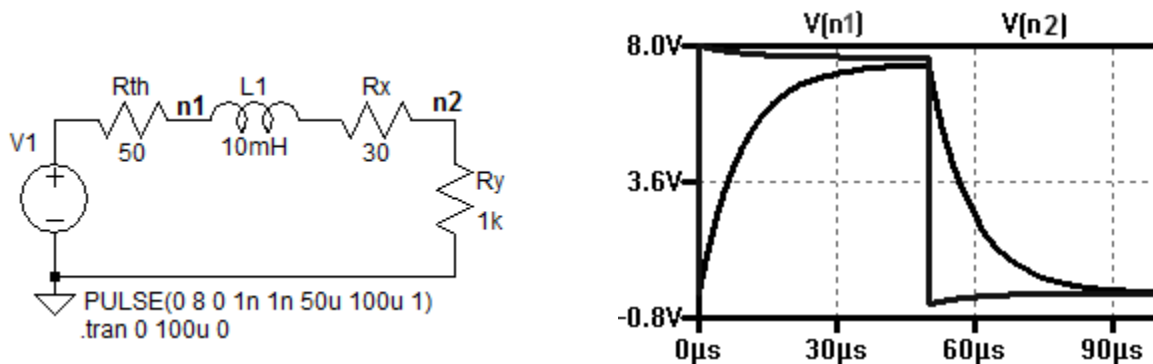
- Calculate the theoretical time constant values and enter the values into the spreadsheet columns D and K. Calculate the percent error values in columns E and L. You can enter the appropriate equations into the cells in row 4 and use "fill down".
- Calculate the circuit's current with the correct polarity for the circuit's step and natural response and put the result into columns F and M. Explain when (or at which multiple of tau) and why the maximum (absolute value) currents occurred.
- Simulate the circuit and plot the inductor voltage and current as a function of time. Refer to the simulation example at the end of this experiment.

4. Compare the measured step and natural response time constants to the simulation results. How do these compare to the calculation: $\tau = L/(R_{th} + R_x + R_y)$?

Lab Report: Include spreadsheet, simulation results, and answers to above questions.

LTspice Simulation Example

The simulation settings for this circuit are the same as for the RC circuit in the previous lab exercise. Note the effect of the function generator's source resistance on the square wave at node N1.



History Note:

Joseph Henry (17 December 1797 – 13 May 1878) an American scientist. Henry discovered the electromagnetic phenomenon of self-inductance. He also discovered mutual inductance independently of Michael Faraday, though Faraday was the first to publish his results. The SI unit of inductance, the henry, is named in his honor. Henry's work on the electromagnetic relay was the basis of the electrical telegraph, invented by Samuel Morse and Charles Wheatstone separately.

[From Wikipedia, the free encyclopedia](#)

