EE1002 Lab4: First-order Transient Circuits (Online experiment)

I. OBJECTIVES

1. To understand the step response of *RC* and *RL* circuit.
2. To calculate the voltages of the step response of an *RC* circuit.
3. To calculate the voltages of the step response of an *RL* circuit.

II. EQUIPMENT AND MATERIALS REQUIRED

1. Computer
2. Browser
3. Online simulator Circuit-Sandbox
   (https://spinningnumbers.org/circuit-sandbox/index.html)

III. PROCEDURES

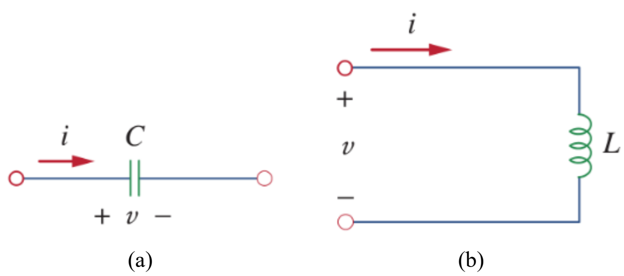

Fig.1. The current and voltage of (a) capacitor and (b) inductor.

The current-voltage relationships of a capacitor (Fig.1(a)) and inductor (Fig.1(b)) are given by

$$i = C\frac{dv}{dt} \text{ and } v = L\frac{di}{dt}.$$

A first-order *RC* or *RL* circuit can be modeled by a first-order differential equation. First, we study an *RC* circuit using Kirchhoff's Law, followed by a study of an *RL* circuit.

Part I: Step Response of an *RC* Circuit

The step response is the output of a circuit for a sudden input of a DC-voltage or DC-current source. In Fig.2(a), the capacitor voltage of the *RC* circuit is given by

$$v(t) = v_s\left(1 - e^{-\frac{t}{\tau}}\right) \quad (t \geq 0)$$

where $\tau = RC$ is called the ***time constant*** of the circuit. It can be easily shown that $v(\tau) = 0.632v_s$. Therefore, the time constant can be obtained by finding the value of t such that $v(t) = 0.632v_s$. This is illustrated in Fig. 3, where the input step signal is zero and v_s for $t < 0$ and $t > 0$, respectively.

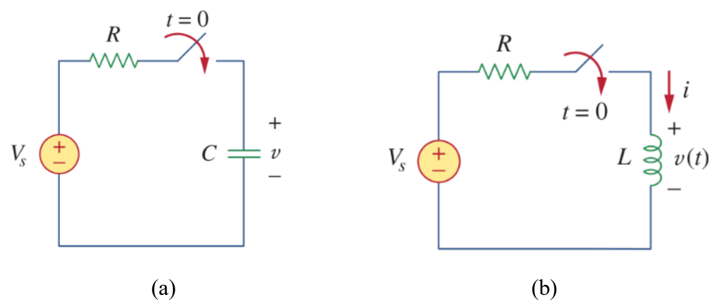

Fig.2. First-order circuits with step input voltage. (a) *RC* circuit. (b) *RL* circuit.

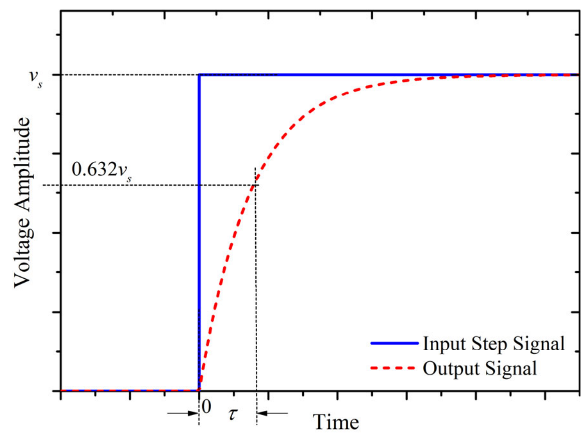

Fig.3. Method to determine the time constant τ from the transient step response of an *RC* circuit

1. Build a circuit as shown in Fig. 4.

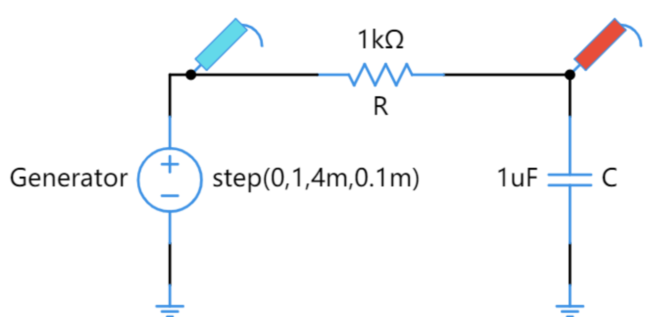

Fig.4 Circuit configuration for the first-order RC simulation

In "step(0,1,4m,0.1m)", "step" means that the input signal is a step signal; "0" means that the initial value of the step signal is 0; "1" means that the amplitude of the step signal is 1; "0.004" means that the input signal has a delay of 4 millisecond; "0.1m" means that the rise time of the input step signal is 0.1 millisecond, where the rise time is the time taken by the input signal to increase from 0 V to the steady state value of v_S. Ideally, the rise time should be zero, meaning that the input signal increases from 0 to v_S in no time (which is, of course, not possible in the real world).

2. Double click the DC source and edit its properties. Choose "step" in the type, other properties can be set as follows (you can try different values in your simulations):

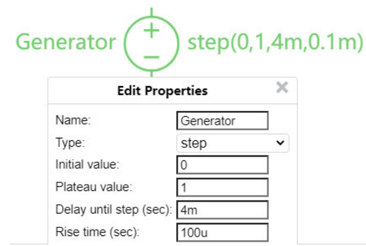

Fig.5. Settings of the voltage source

4. Now, you can run the simulation using the icon "TRAN". In the "TRAN" solver, two "Voltage probes" should be put at the two ends of the resistor, as shown in Fig.4. You should find a suitable stop time (for example 0.02s) to show your simulated traces.

5. Observe the simulated traces and fill in Table I with the calculated and simulated data.

Table I

R/C	100kΩ/1uF	10kΩ/1uF	5kΩ/2uF	1kΩ/1uF
Calculated τ *				
Simulated τ **				

* *You should provide your mathematical analysis and calculation in your Lab Report.*
** *The simulated results should be shown in the report.*

Part II: Step Response of an RL Circuit

As shown in Fig. 2(b), the inductor voltage of the *RL* circuit is given by

$$v(t) = v_s e^{-\frac{t}{\tau}} u(t)$$

where $\tau = L/R$ is the ***time constant*** of the *RL* circuit. According to the equation above, the time constant can be obtained at the time t where $v(t) = 0.368\ v_s$, as shown in Fig. 6.

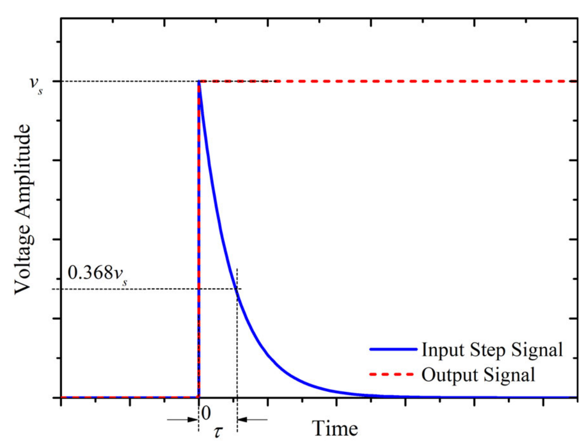

Fig.6. Method to determine the time constant of the transient step response of an *RL* circuit

1. Build the circuit in Fig. 7.

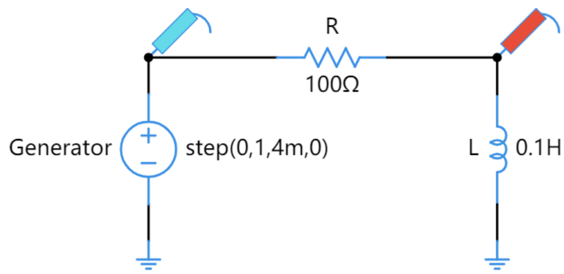

Fig.7. Circuit configuration for the first-order *RL* simulation

For "step(0,1,4m,0)", "step" means that the input signal is a step signal; "0" means that the initial value of the input step signal is 0; "1" means the amplitude of the step signal is equal to 1; "4m" means that the input signal has a delay of 4 millisecond; and "0" means that the rise time of the input step signal is 0 second.

2. Double click the DC source and edit its properties. Choose "step" for the signal type with other properties set as follows (you can try different values in your simulations).

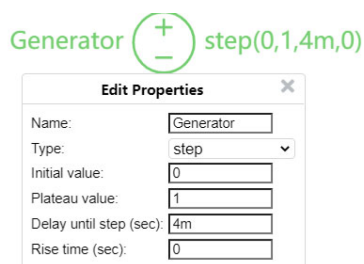

Fig.8. Settings of the voltage source

4. Now, you can run the simulation using the icon "TRAN". In the "TRAN" solver, two "Voltage probes" should be put at the two ends of the resistor, as shown in Fig.7. You should find a suitable stop time (for example 0.02s) for your simulated results.

5. From the displayed simulated results, fill in Table II with your calculated and simulated data.

Table II

R/L	500Ω/0.5H	250Ω/0.25H	100Ω/0.1H	100Ω/0.25H
Calculated τ *				
Simulated τ *				

* *You should provide your mathematical analysis and calculation in your Lab Report.*
** *The simulated results should be shown in the report.*

V. DISCUSSION

1. In Part I, change the value of the resistor and describe its effect on the output voltage.
2. In Part II, change the input step signal to a square signal with a frequency of 1000Hz. Describe the difference between the input and output.

REFERENCES

1. M. O. Sadiku, S. M. Musa and C. K. Alexander, Applied Circuit Analysis, McGraw Hill, 2012.
2. C. K. Alexander and M.O. Sadiku, Fundamentals of Electric Circuits, 5th Edition, McGraw Hill, 2012.

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