EE1002 Lab4: First-order Transient Circuits (Online)

I. OBJECTIVES

1. To get familiar with transient *RC* and *RL* circuits using an online simulator.
2. To understand the step response of *RC* and *RL* circuits.
3. To study the step responses of *RC* and *RL* circuits.

II. EQUIPMENT AND MATERIALS REQUIRED

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

III. THEORY

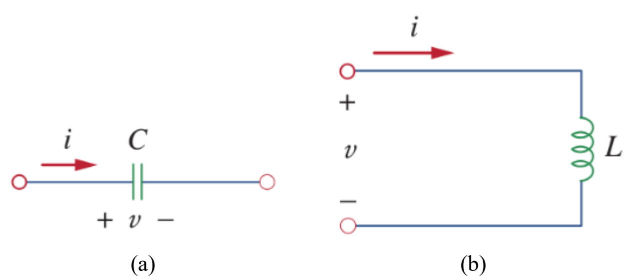

Fig.1. The currents and voltages of (a) capacitor and (b) inductor.

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. We will first study an *RC* circuit and then an *RL* circuit.

Part A: Step Response of an *RC* Circuit

(a) BASIC THEORY

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 τ can be obtained by solving $v(\tau) =$

$0.632v_s$. This is illustrated in Fig. 3, where the input step signal is zero and v_s for $t < 0$ and $t > 0$, respectively.

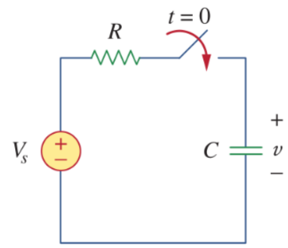

Fig.2. First-order *RC* circuit with a step input voltage.

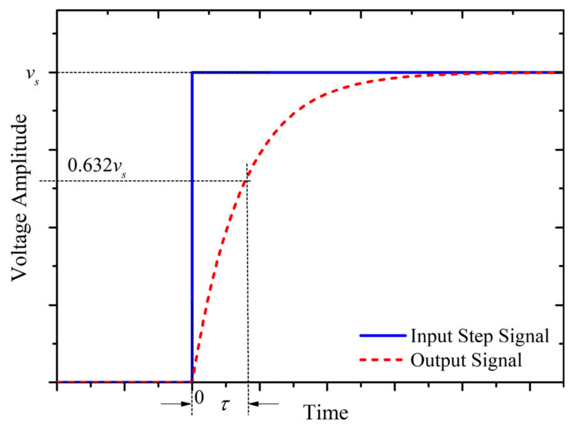

Fig.3. Method to determine the time constant τ from the transient step response of an *RC* circuit.

(b) PROCEDURE

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

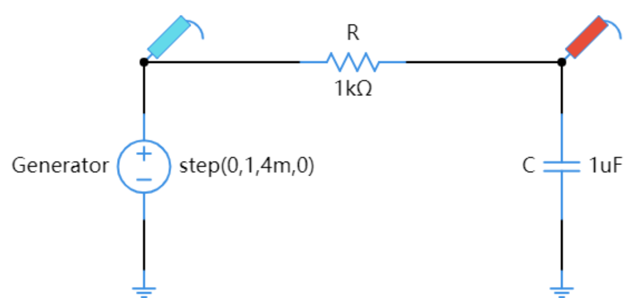

Fig.4 Circuit configuration for the first-order RC simulation with voltage source

In "step(0,1,4m,0m)", "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; "4m" means that the input signal has a delay of 4 milliseconds; "0" means that the rise time of the input step signal is 0 millisecond (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 voltage 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):

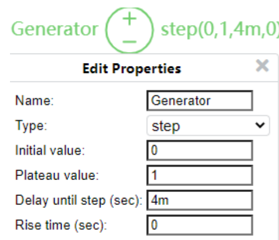

Fig.5. Settings of the voltage source

4. Now, you can run the simulation by clicking 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 results and then fill in Table I with the calculated and simulated data.

Table I

R/C	100kΩ/1uF	50kΩ/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 curves should be shown in the report.*

6. Change the DC voltage generator to the DC ***current generator*** as shown in Fig. 6. In this case, two “Current Probes” are connected in the circuit to measure the currents. Do the steps as similar to Steps 1-5 above and fill in Table II with the calculated and simulated data.

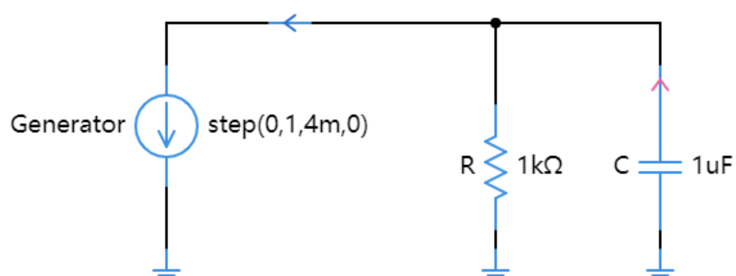

Fig.6 Circuit configuration for the first-order RC simulation with current source

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 that 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.

Table II

R/C	100kΩ/1uF	50kΩ/1uF	10kΩ/1uF	5kΩ/2uF	1kΩ/1uF
Calculated τ *					
Simulated τ **					

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** *The simulated results should be shown in the report.*

Part B: Step Response of an RL Circuit

(a) BASIC THEORY

Fig. 7 shows a simple *RL* circuit. The inductor voltage of the 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. The time constant τ can be obtained by solving $v(\tau) = 0.368\, v_s$, as shown in Fig. 8.

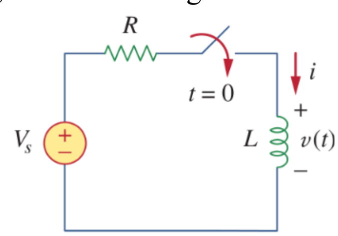

Fig. 7. First-order *RL* circuit with a step input voltage.

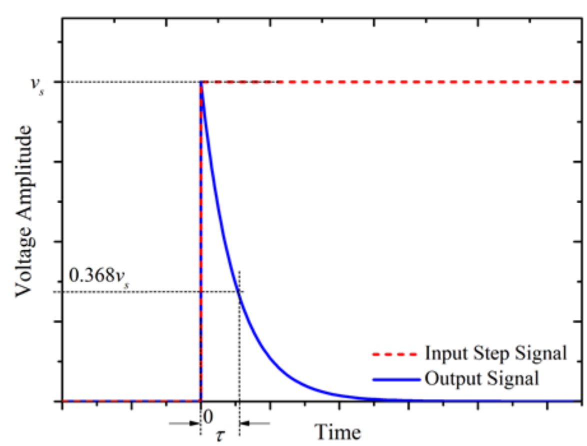

Fig. 8. A method to determine the time constant of the transient step response of an *RL* circuit.

(b) PROCEDURE

1. Build a circuit as shown in Fig. 9.

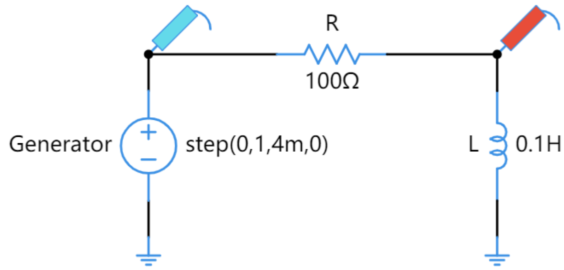

Fig. 9. Circuit configuration for the first-order RL simulation with voltage source.

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 voltage 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).

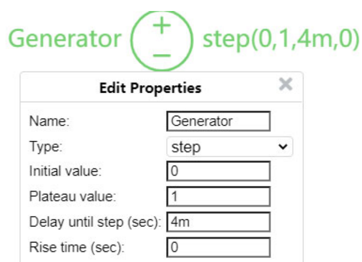

Fig. 10. Settings of the voltage source

4. Now, you can run the simulation by clicking the icon "TRAN". In the "TRAN" solver, two "Voltage Probes" should be put at the two ends of the resistor, as shown in Fig. 9. You should find a suitable stop time (for example 0.02s) for your simulated results.

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

Table III

R/L	500Ω/0.5H	350Ω/0.3H	250Ω/0.2H	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.*

6. Change the DC voltage generator to the DC ***current generator*** as shown in Fig. 11. two "Current Probes" are connected in the circuit to measure the currents. Repeat steps similar to Steps 1-5 above and fill in Table IV with the calculated and simulated data.

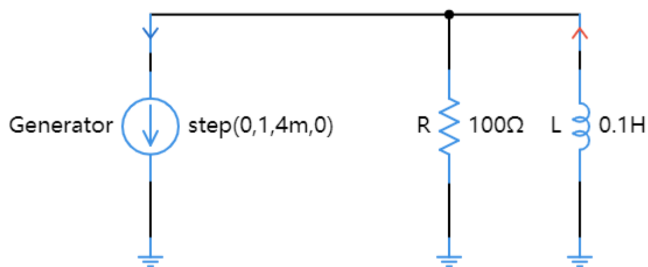

Fig. 11 Circuit configuration for the first-order RL simulation with current source.

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.

Table IV

R/L	500Ω/0.5H	350Ω/0.3H	250Ω/0.2H	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. What is the physical meaning of the time constant in terms of the final output value?

2. For each of the *RC* and *RL* circuits,
(i) What is the effect of *R* on the output voltage and current;
(ii) change the input step signal to a square signal, as shown in Fig. 12. Show and discuss your finding; and

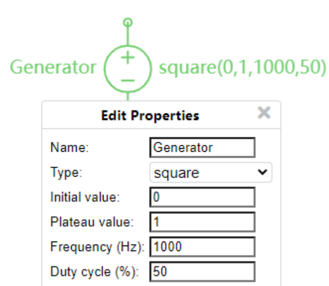

Fig. 12. Setting of the square signal.

3. compare and discuss the results between the voltage-source and current-source cases.

VI. 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.