EXPERIMENT E21: SIMULATION OF STEP RESPONSE OF RC, RL AND RLC CIRCUITS

Related course: KIE1005 (Circuit Analysis I)

OBJECTIVES:
To investigate the step response of RC, RL and RLC circuits

EQUIPMENT:
PC/Laptop with OrCAD PSpice software or any circuit simulator software

INSTRUCTIONS:
1. Follow the procedure in this lab sheet
2. Paste your results into a Word document
3. Every student must submit the experiment results (in PDF) and the simulation files (in OrCAD PSpice) to the lab course Spectrum before the deadline (refer to Spectrum)

REFERENCES:
Refer to the main references of KIE1005

TESTS:
TEST 1: Step response of RC circuit
TEST 2: Step response of RL circuit
TEST 3: Step response of RCL circuit

INTRODUCTION:

The step response of RC, RL and RLC circuit involves determination of the transient and steady state solutions of the circuit. Since the energy storage elements such as inductor or capacitor do not permit instantaneous change in the energy, the transient part of the solution makes a smooth transition from one energy level to another. Thus, a gradual change takes place from the initial level until the new steady-state level is reached. Step input to a circuit represents a disturbance appearing in the circuit.

The dynamic characteristics of simple systems can be described by first order (RC and LC circuits) or second order (RLC circuit) differential equations. The characteristic equation for the second order RLC circuit can be expressed by:

$$\frac{d^2v}{dt^2} + 2\alpha\frac{dv}{dt} + \omega_0^2 v = 0 \qquad (1)$$

$$\alpha = \frac{R}{2L}\,(\text{for series RLC}), \alpha = \frac{1}{2RC}\,(\text{for parallel RLC})\text{ and } \omega_0 = \frac{1}{\sqrt{LC}}\,(\text{natural frequency})$$

$\omega = 2\pi f$, where f = frequency in Hz and ω = frequency in rad/s.

The step response of series and parallel RLC circuits can be:

- Overdamped when $\alpha^2 > \omega_o^2$ or $\zeta > 1$
- Underdamped when $\alpha^2 < \omega_o^2$ or $\zeta < 1$
- Critically damped when $\alpha^2 = \omega_o^2$ or $\zeta = 1$

where the damping factor, $\zeta = \alpha / \omega_o$

The time constant for the first order RC and RL circuits can be calculated using:

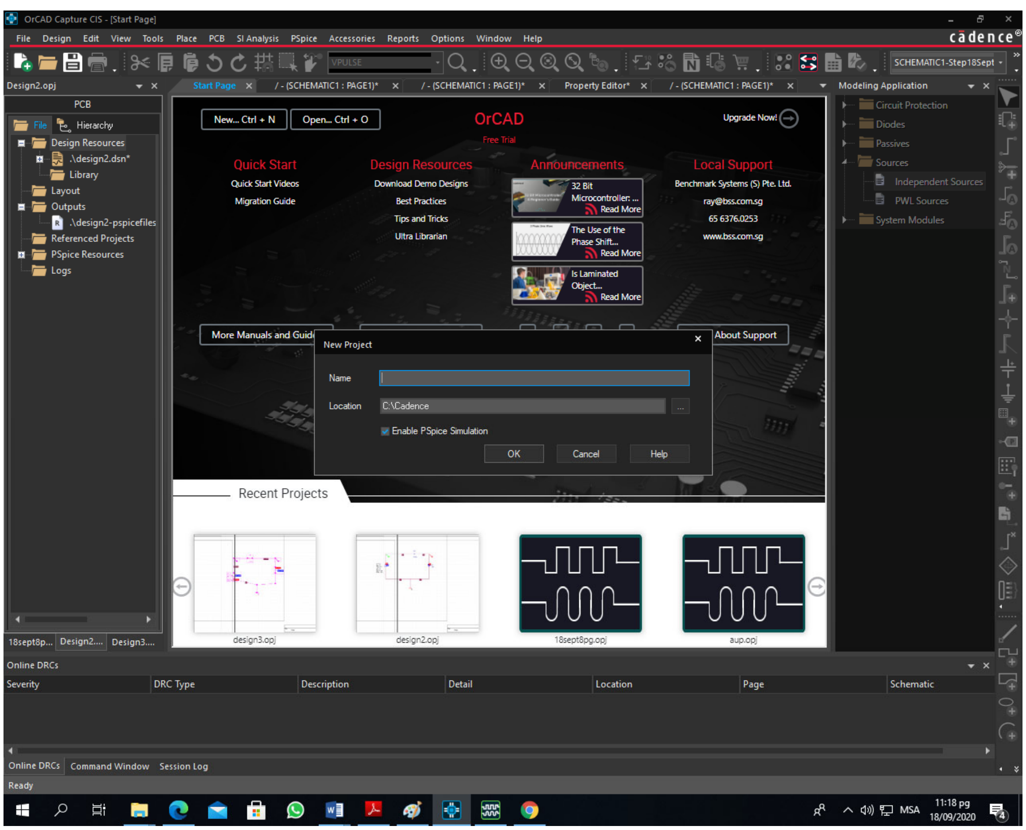
$$\tau = RC\,(\text{for RC circuit}),\ \tau = L/R\,(\text{for RL circuit}) \qquad (2)$$

PROCEDURE:

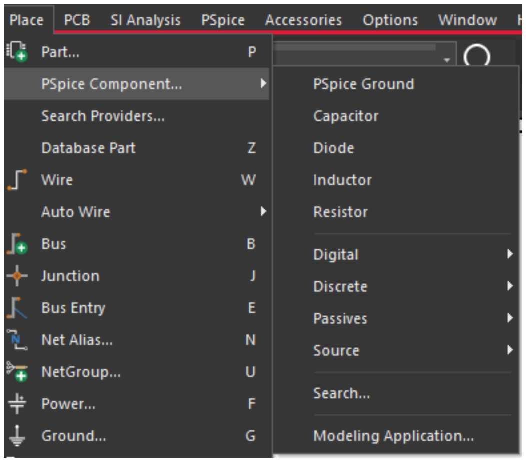
Preparation for simulating simple circuit using OrCAD PSpice

In this part, a simple instruction to build RC circuit will be developed and simulated using OrCAD PSpice to observe the step response at a resistor (you may also use any other software).

1. Create new project from the start page and enable PSpice simulation. (refer to Fig.1 (a)).
2. On PSpsice menu bar, click “Place” → “PSpice Component” (refer to Fig. 1(b)) to select the component blocks and set the value of each components.
3. Select the voltage source component from “Place” → “PSpice Component” → “Modelling Application” → “Sources” → “Independence” → “Pulse or Step” (refer to Fig. 1 (c)).
4. Place the ground and connect all the component to complete the circuit as shown in Fig.1 (d)
5. Start the simulation by clicking PSpice → New Simulation Profile → create. Within the simulation setting GUI, set the run to time value to 10 ms (refer to Fig. 1 (e)).
6. Set the voltage marker at the voltage source and load to measure the V_{in} and V_{out}, respectively (refer to Fig. 1 (f)).
7. Select the run command from the PSpice menu bar and click run for starting the simulation as shown in Fig. 1 (g)



(a)



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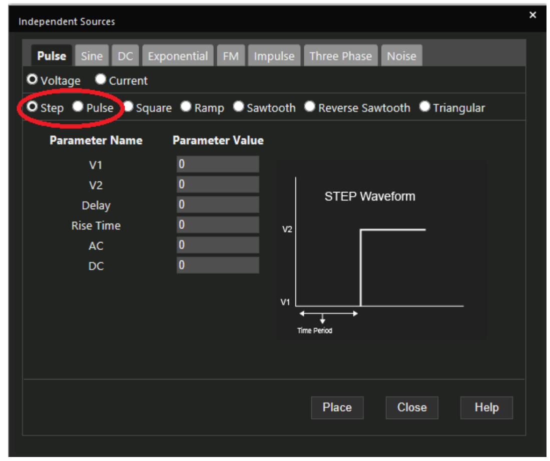
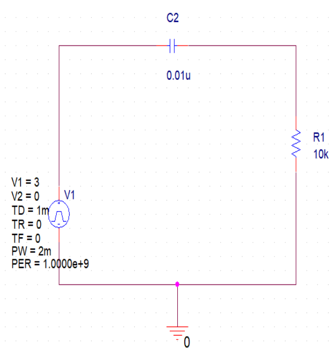
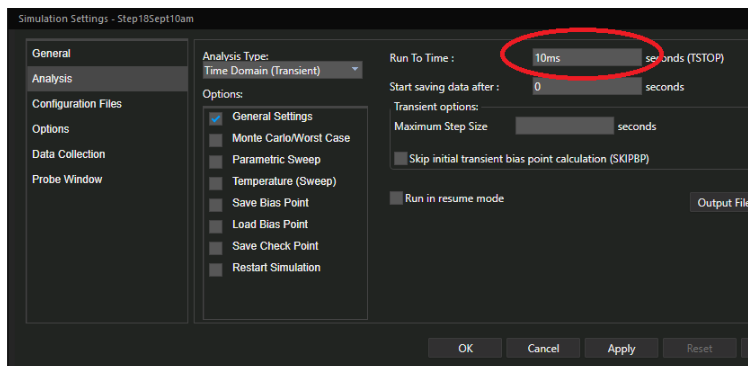


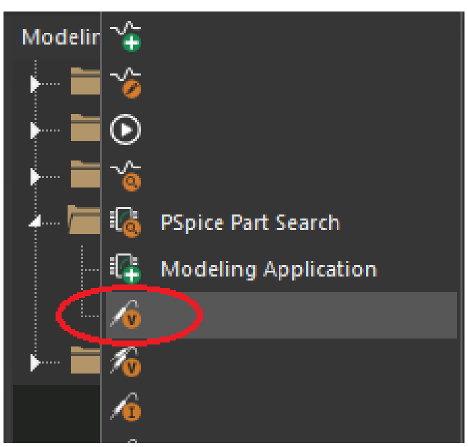
(c)



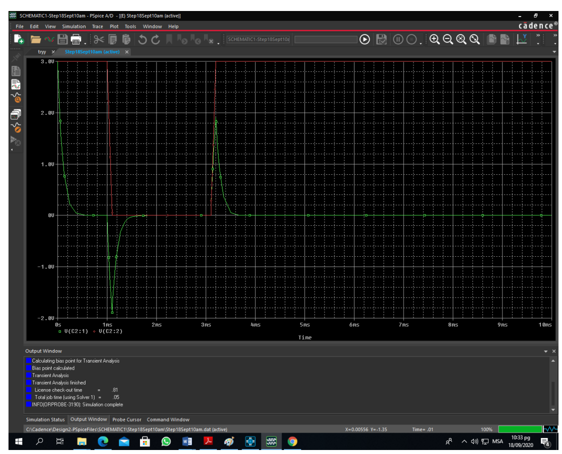
(d)



(e)



(f)



(g)

Figure 1: OrCAD PSpice

TEST 1: Step response of RC circuit

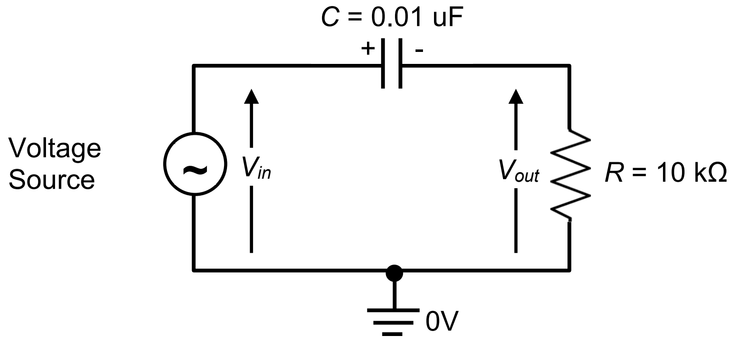


Figure 2: RC circuit

1. Build the circuit as shown in Fig. 2 with R = 10 kΩ resistor and C = 0.01 uF capacitor in series
2. Set voltage marker for measuring the input voltage V_{in} across the voltage source
3. Set voltage marker for measuring the output voltage V_{out} across R
4. Record the output waveform V_{out}. You should see the output waveform, which is the response to input step voltage at both rising and falling edge
5. From the simulated V_{out} curve, measure the RC time constant. Refer to the APPENDIX section on how to determine the time constant from the simulated curve. Then, compare with the theoretical time constant value using Equation (2) (use $\tau = RC$). Are they almost similar?
6. Repeat steps 4 to 5 but only change the resistor R to 1 kΩ in Figure 2. What is the effect on the time constant of RC circuit when R is smaller?

TEST 2: Step response of RL circuit

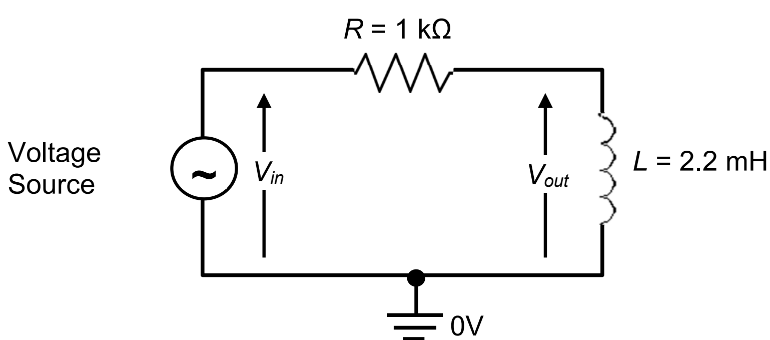


Figure 3: RL circuit

1. Build the circuit as shown in Fig. 3 with R = 1 kΩ resistor and C = 2.2 mH capacitor in series
2. Set voltage marker for measuring the input voltage V_{in} across the voltage source
3. Set voltage marker for measuring the output voltage V_{out} across L

4. Record the output waveform, V_{out}. You should see the output waveform, which is the response to input step voltage at both rising and falling edge
5. From the simulated V_{out} curve, measure the RL time constant. Refer to the APPENDIX section on how to determine the time constant from the simulated curve. Then, compare with the theoretical time constant value using Equation (2) (use $\tau = L/R$). Are they almost similar?
6. Repeat steps 4 to 5 but only change the resistor R to 10 kΩ in Figure 3. What is the effect on the time constant of RL circuit when R is larger?

TEST 3: Step Response for RLC circuit

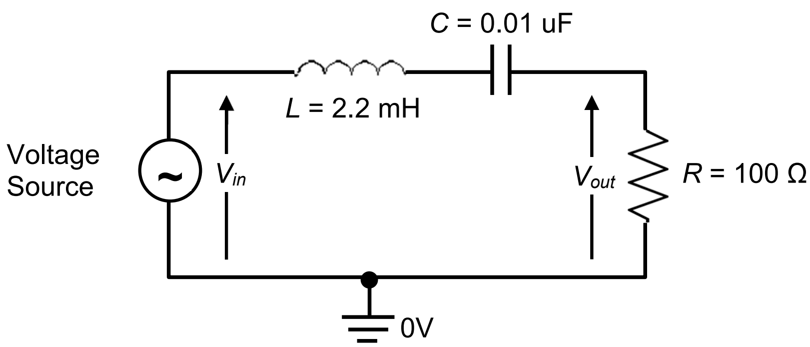


Figure 4: RLC circuit

1. Build the circuit as shown in Fig. 4 with R = 100 Ω resistor, C = 0.01 uF capacitor and L = 2.2 mH capacitor in series. This circuit will give an underdamped response output.
2. Set voltage marker for measuring the input voltage V_{in} across the AC voltage source
3. Set voltage marker for measuring the output voltage V_{out} across R
4. Record the output waveform, V_{out}. You should see the output waveform, which is the response to input step voltage at both rising and falling edge
5. From the simulated V_{out} curve, find the frequency of the oscillation. Please refer to the APPENDIX section on how to determine the frequency of oscillation from the output curve. Hint: First, measure the period T of the oscillation and then, measure the frequency in Hz ($f = 1/T$).
6. Change the resistor to 1 kΩ and repeat step 5 to obtain critically damped output. Save or capture the simulated output waveform.
7. Change the resistor to 10 kΩ and repeat step 5 to obtain overdamped output. Save or capture the simulated output waveform.

DISCUSSION (include them in your lab report):

1. Plot the simulated output voltage, V_{out} vs. frequency from RC and RL circuits in one graph. Discuss the difference of the step response between the circuits.

2. Plot the simulated output voltage, V_{out} vs. frequency from RCL circuit in Figure 4 in one graph. Discuss the differences.

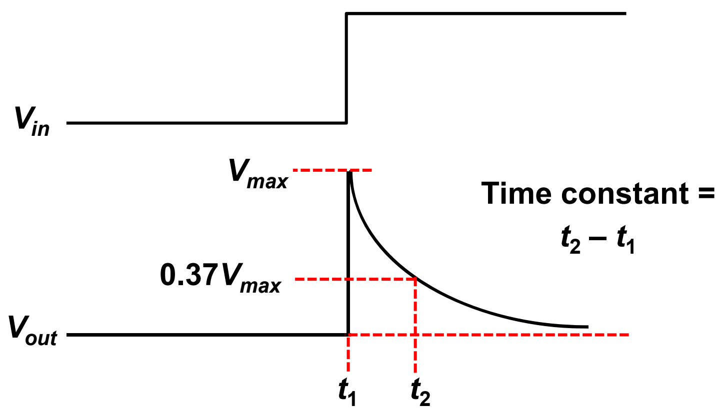
3. For RLC circuit, calculate α and ω_o for underdamped, critically and overdamped case (when R = 100 Ω, 1 kΩ, 10 kΩ respectively). Then, compare between α and ω_o for each case. Do they agree with:
   - $\alpha^2 > \omega_o^2$ for overdamped case?
   - $\alpha^2 < \omega_o^2$ for underdamped case?
   - $\alpha^2 = \omega_o^2$ for critically damped case?

4. If you were asked to carry out actual experiment of Test 1, Test 2 and Test 3***, suggest suitable*** components and devices to be used in the measurement set up. Do you expect the same result will be obtained from actual experiments? Please discuss.

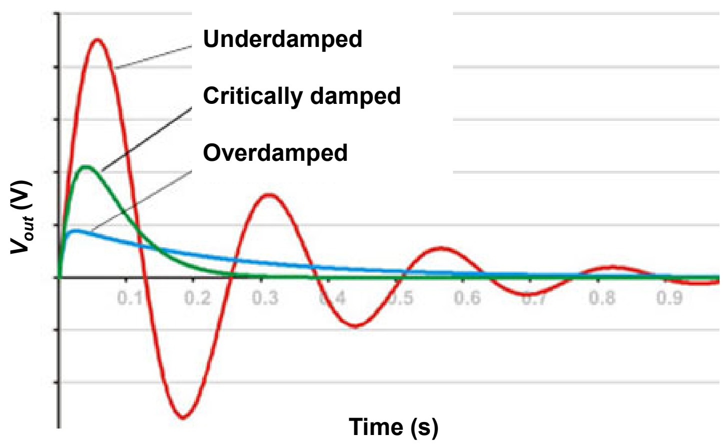
END OF EXPERIMENT

APPENDIX

How to find time constant:



Step response of RLC circuit:



Period *T* of oscillation: