ELEC2070 2023
Laboratory Worksheet – Week 6 and 7:
Transient Response of Circuits with Inductors and Capacitors

***Abstract*— First and second order circuits with energy storing elements are the simplest building blocks of complicated circuits that are used in everyday electronics. In this session, simple capacitor and inductor circuits are investigated in response to switching dc input.**

I. INTRODUCTION

Circuit analysis with capacitors and inductors require differential equations instead of simple algebraic equations. The behaviour of the circuit includes its natural (transient) response to switching, and its forced (steady state) response to dc (or ac) sources.

In the laboratory, a square wave signal can conveniently be used to represent a continuously switching dc input and the circuit response can be measured with an oscilloscope. Three different circuits are investigated in this laboratory session of two weeks: first-order capacitor and inductor circuits and a second-order circuit.

Natural response of the first-order circuits is an exponentially decaying function with a single time-constant. Second-order circuits have two natural frequencies and they can oscillate, exchanging the stored energy between the two energy storing elements. The time constants of these circuits will be calculated and measured. Do up to Section VII in week 6. Leave LTspice and second order circuits to Week 7. Of course, you can always do more. You will be setting up circuits and doing actual measurements in this laboratory.

II. PRELIMINARY WORK

Week 6: Study the lecture notes and the textbook/s [1-2] to become familiar with the concepts of capacitors, inductors and circuits with energy storage elements and switches.

1. In your logbook, write the general voltage and current equations of capacitor and inductor elements. Which quantity (current or voltage) can change (or cannot change) instantaneously in capacitors and inductors
2. How do capacitors and inductors behave in dc circuits if there is no switching?
3. For the circuits in Fig. 1 and Fig. 2, assume the dc sources turn on at $t = 0$, $v(0) = 0$ for the capacitor and $i(0) = 0$ for the inductor. Use the summary of first order circuits in the textbook Table 8.12-1 [1] or the formula sheet [3] to write the time dependent voltage and current expressions.

Week 7: Study the lecture notes and the textbook/s to become familiar with the concept of "unit step function" (Section 8.6 in [1] or Figure 4.27 in [2]).

4. Write an expression for the current source in Fig. 3 (b) so that Fig. 3 (a) and (b) are equivalent.

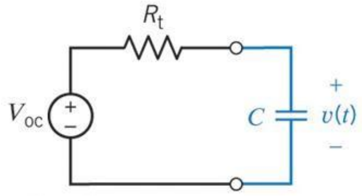

Fig. 1. First-order circuit with capacitor

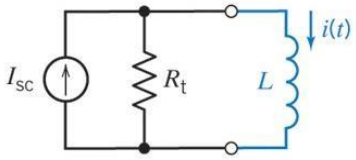

Fig. 2. First-order circuit with inductor

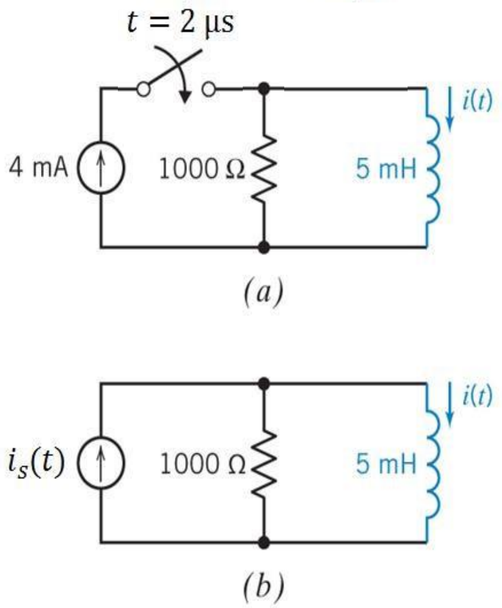

Fig. 3. First-order circuit with switch

III. TIME MANAGEMENT

Look through the whole worksheet before you start and plan your time so that you can complete the work in two weeks. Write your plan in your logbook. At the end of the two weeks compare your actual times to your initial estimates.

IV. LOGBOOKS AND PARTICIPATION MARKS

Participation marks are given to each student at each laboratory session following the marking rubric published on iLearn. The marks cover punctuality, positive engagement, and logbook recording of each session. All students should have their work assessed and attendance marked by their tutor before leaving each laboratory session.

V. First Order Circuit with Capacitor

5. Draw a circuit diagram with an ac signal generator input (voltage source) outputting a square wave function with 0.5V peak to peak output with 0 DC offset. What would the amplitude of this wave be?

6. Pick two resistors and one capacitor between the ranges of 100 Ω to 1 MΩ and 1 pF to 0.1 mF and design a first order circuit using the square wave generator as the source. Calculate the time constant of the circuit considering the internal resistance of the signal generator. You need a time constant between 0.1 μs and 1 ms to be able to measure it well with the oscilloscope.

7. If you choose the period of the square wave approximately 10-time constants, you can assume most transients decay and circuit reaches steady state at the end of each half period. Choose an appropriate frequency for the square wave for your circuit.

8. Calculate the initial conditions and write expressions for the capacitor voltage (as a function of time) for each half period separately.

9. Look up on some electronics distributors for resistors and capacitors of the same value as you selected for your circuit (RS Online, Mouser, Digikey) Have a look at all of the filter fields and how to access datasheets. What tolerances do you find? What values could your time constant take as a maximum and minimum with these tolerance values? Which type of capacitors are you unable to use in your circuit and why?

10. Consult the textbook/s, lecture notes or the internet to find a method to measure the time constant. Hint: The capacitor discharges 63% of its charge after a time of τ seconds.

11. Calculate the time dependent current for the capacitor using Ohm's and Kirchhoff's laws. How could you monitor this using the oscilloscope? (Hint: resistor voltages are proportional to their current $v(t) = R \cdot i(t)$)

VI. First Order Circuit with Inductor

12. Replace the capacitor with an inductor (between 1 nH and 1 H) and repeat the work above and replace the resistors if necessary, to keep the time constant within specifications. Remember to use a series resistor with the inductor to monitor its current (See item 11 above).

VII. LT Spice Simulation

13. Study Section 8.9 and Example 8.9-1 in the textbook [1]. Simulate your two circuits as shown but using either AWR or LTSpice. Plot the voltages and currents and determine the time constant from the plots. Compare to your calculations.

VIII. Second Order RLC Circuit

14. Design a simple underdamped RLC circuit either in parallel or series configuration as in Fig. 4 or 5, using the capacitors, inductors, and resistors from the ranges previously specified and with an observable oscillation period that is between 0.1 μs and 1 ms. Textbook [1] Section 9.6 and Example 9.6-1 explains the conditions for underdamped circuits. Table 9.13-1 summarizes all conditions. You need to have an oscillation period $T_d = 2\pi / \omega_d$ that is smaller than the half period of your input square wave so that you could observe it with an oscilloscope.

15. Calculate out the differential equation for your circuit.

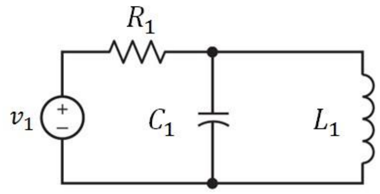

Fig. 4. Simple parallel RLC circuit

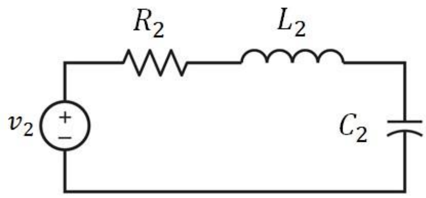

Fig. 5. Simple series RLC circuit

16. Simulate the circuit with LTSpice or AWR to confirm it is underdamped and the oscillations are observable with the square wave input.

IX. Theory

17. List and explain how capacitors and inductors are used in different applications (filters, sensors, storage elements, etc).

References

[1] J. A. Svoboda, R. C. Dorf, "Introduction to Electric Circuits 9th edition," Wiley, 2014.

[2] A. R. Hambley, "Electrical Engineering, Principles and Applications, International Sixth Edition," Pearson, 2014.

[3] O. Sevimli, "ELEC270 2016 Formula Sheet" iLearn, 2017