Linear Networks Analysis and Synthesis

Lab 1: SSS and Laplace exercise

Circuit lab: Time domain simulations (transient analysis)

Objective

The objective of this exercise is to compare the frequency and Laplace domain analysis and the results obtained with a time-domain circuit simulator. This Lab exercise must be solved individually.

Simulator

The simulator that is proposed is an open source development by Paul Falstad and Iain Sharp.

- Adventages:
  - It runs on any JavaScript enabled browser, on both computers and mobile devices.
  - It is simple and intuitive, with an online manual.
  - It provides generic blocks that are not available in other simulators (generic switches, algebraic operations on voltages and currents, noise generators, ...).
  - A very comprehensive set of examples (index and directions).
- Drawbacks:
  - *Relatively* few circuit models (but more than enough for our purposes).
  - Numerical routines less stable or precise than other simulators (beware of short circuits or open circuits in some particular circumstances).
  - Plots that are powerful but limited configuration capabilities (the mouse pointer acts as a cursor, but, for example, fixed markers are not possible) *The current version allows manual setting of the vertical axis scale.*

Lab instructions

Before the practice

Carry out the theoretical developments of the proposed exercises and bring them with you to the laboratory class. Familiarize yourself with the simulator and all its options. To do this, you can explore the examples given by the authors of the simulator.

Try to check the result of some of the course exercises you have already done from with the simulator. In the presentations used in class and in Aula Global you also have examples of checking results with the Falstad simulator.

Description of the lab

The practice has **two** laboratory sessions and each Lab session has **two** parts:

1. Preparatory homework: theoretical exercise similar to those carried out during the first two topics of the course. **It must be done and submitted before the beginning of the session**.

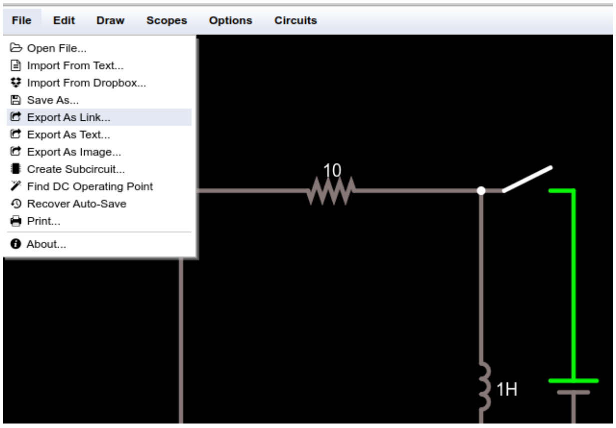

Figure 1: Creating a link to the simulation.

2. Laboratory work: verification of results with the circuit simulator. The agreement between the results in the frequency/Laplace domain and the measurements observed in the simulator must be observed. The guide for this part will be accesible at the beginning of the practical, and the student must answer the questions raised in the guide during the session.

Both parts are evaluated. The weight of each part is detailed in this document or in the practice guide.

The verification of the theoretical result will usually be based on a graph created with the circuit simulator (called `Scope`). The quality of these graphs will be taken into account in the evaluation. In general, please take these recommendations into account:

- If you refer to a graph in the explanation of a result, it must be perfectly clear in the graph what is intended to be shown. If you need to make annotations on the captured image, do so.
- The scales of the graphs must be appropriate for the result to be displayed. Adjust them manually if necessary. For example, if you want to show that the period of an oscillation is 1 ms, the horizontal scale should not be larger than two or three times that value. If you need to use different scales to display a result, add as many plots as you need in your simulation.
- When displaying the voltage and current of a circuit element on a `scope`, the polarity and reference direction respectively depend on how that element is drawn in the circuit.
- The numerical method used by the simulator has only one parameter: the `Time step`. Its initial value is set to 5 µs, and it can be modified in the options menu under `Other options...`. In general, the smaller it is the more accurate the simulation, but also the slower. It is usually sufficient to be 100 times smaller than the duration of the fastest oscillation of the voltages or currents present in your circuit.
- By default, the simulator displays voltage and current graphs. If you do not need both magnitudes, configure the `scope` by right-clicking on each graph to show only the one you need.
- The *assembly* used for the *experimental test* should be shown. It is advisable to include a link to the circuit simulation you have used (the simulator itself generates these links, as can be seen in Figure 1).

Evaluation criteria

- Theorical calculations.
- Quality of plots.
- Agreement between theory and simulations, or explanation of discrepancies if they are observed.
- Initiative to study or investigate other aspects of the circuit.
- Format and clarity of your report.

NOTA: Everyone's honesty is trusted to perform this work on an individual basis. If this trust is abused, the students involved will be penalized in accordance with the regulations.

Submission

- The submission of the preparatory homework must be done in Aula Global. It must be a single PDF document with the developments and the final answers. You can also incorporate scanned handwritten sheets to the document. This submission must be done **before the beginning of the Lab session**. For the best convenience, the due date and time is specified in the Aula Global assignment itself.

  Please note that, in any case, the format and clarity of the submitted document will be assessed, so if it incorporates handwritten sheets, please make sure that it is perfectly legible and that the quality of the scan is sufficiently good.

- The submission of the work done during the Lab session will be done at the end of it, and will consist of a single PDF document with the guide of the practice completed with the student's answers. It will also be done through Aula Global. This document must contain screenshots to show the simulated circuits and the graphs obtained.

Session 1

SSS analysis of a Sallen-Key circut

1.1 Preparatory homework [15 %]

The circuit in the figure 2 shows a well-known and widely used circuit often referred to as *Sallen-Key*:

[2 %] 1. In view of the circuit, estimate without calculating the transfer function, the value of $V_o(\omega)/V_g(\omega)$ for $\omega = 0$ and $\omega = \infty$. Recall that the impedance of a capacitor depends on the angular frequency ω of the signal.

[2 %] 2. Assume that the circuit works in sinusoidal steady state and obtain the transfer function defined by the following ratio:

$$H(\omega) = \frac{V_o(\omega)}{V_g(\omega)}$$

[2 %] 3. Find the ratio between the square of the amplitudes of the input $v_g(t)$ and the output $v_o(t)$ for each angular frequency ω. That is:

$$|H(\omega)|^2 = \frac{|V_o(\omega)|^2}{|V_g(\omega)|^2}$$

[3 %] 4. Determine, as a function of R and C, the angular frequency ω in which the amplitude of the output signal $v_o(t)$ is 3 dB lower than the amplitude of the input signal $v_g(t)$. That is, to find the angular frequency ω that verify

$$|H(\omega)|^2 = \frac{1}{2}$$

[4 %] 5. Calculate the current provided by the operational amplifier as a function of V_g, R, C, R_L y ω.

[2 %] 6. The datasheet of the operational amplifier to be used specifies that the amplitude of the output current must always be less than 25 mA. If $R_L = 50\,\Omega$, what is the maximum value that the input signal amplitude can take in order not to exceed this margin when $\omega \simeq 0$)?

NOTE: It is recommended to check with the simulator the results obtained for a particular election of R and C.

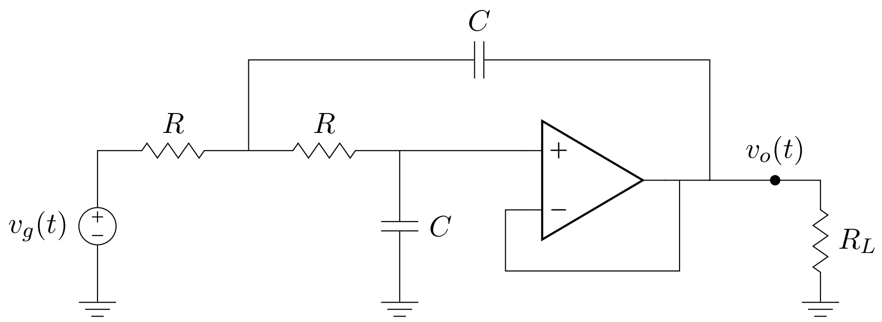

Figure 2: Sallen-Key Circuit.

Session 2

Relay activation/deactivation transients analysis

2.1 Preparatory homework [15 %]

In this exercise we study the transient effect of the activation and deactivation of the coil present in a relay. Let's think of a microcontroller that activates/deactivates this relay by means of one of its output pins, as shown in Figure 3.

[4 %] 1. Consider that the switch in figure 3 has been open for a long time, and that the microcontroller closes it at an instant we define as $t = 0$. Determine

   (a) $I_L(s)$: current through the coil in the Laplace domain for $t > 0$.

   (b) I_s: stationary value of the current reached after a long time ($t \to \infty$).

   (c) $i_L(t)$: current through the coil in the time domain for $t > 0$.

   (d) If the relay is triggered when the current flowing through the coil is 80 % of the final value I_s, how long does it take for the relay to trigger from the time the microcontroller activates it (switch is closed)?

[5 %] 2. Consider now that the switch in figure 3 has been closed for a long time, and that the microcontroller opens it (puts the output pin in the high-impedance state) at an instant we redefine as $t = 0$.

   Under these circumstances, calculate the voltage on the output pin in the Laplace domain, $V_o(s)$, and in the time domain $v_o(t)$. Interpret the result and comment on whether you foresee any problems in the microcontroller.

[6 %] 3. To avoid the possible problems mentioned in the previous point, a capacitor is connected in parallel with the relay. $C_p = 200\,\mu\text{F}$, as shown in figure 4. Assuming that the switch has been closed for a long time before opening it at instant $t = 0$, determine:

   (a) $I_L(s)$: current through the coil in the Laplace domain for $t > 0$.

   (b) $V_o(s)$: voltage on the microcontroller output pin in the Laplace domain for $t > 0$.

   (c) $v_o(0^+)$: voltage to be supported by the output pin of the microcontroller at $t = 0^+$. Has the problem discussed in section 2 been solved?

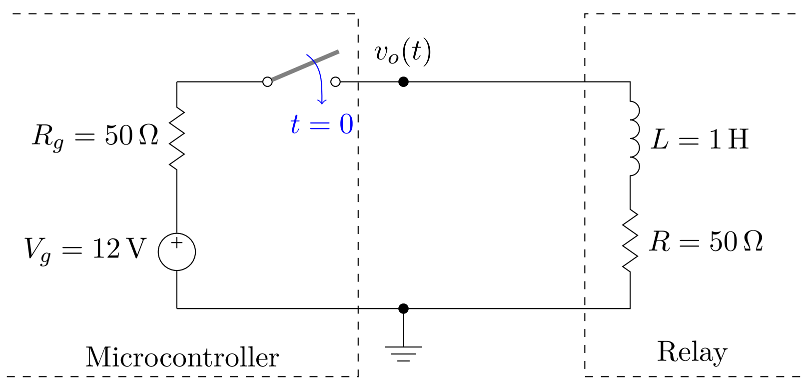

Figure 3: Microcontroller activates the relay at $t = 0$.

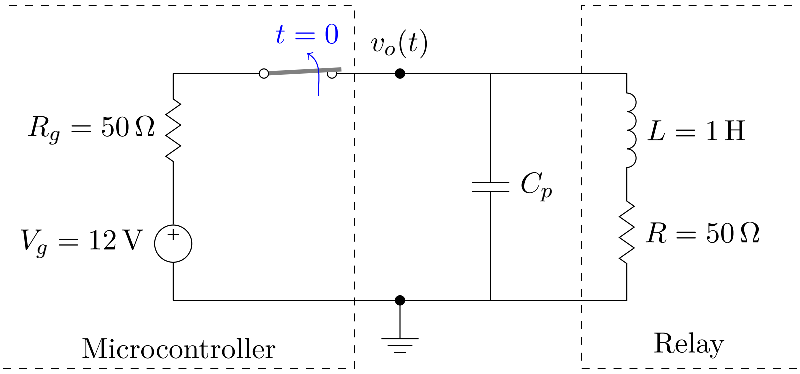

Figure 4: Microcontroller deactivates the relay at $t = 0$.

(d) In view of the equation for the current flowing in the coil, what can be concluded about its behavior? What would you change in the circuit to avoid this effect?