Lab 10
First-Order Time-Domain Simulation with CircuitLab

Objectives – in this lab you will

- use CircuitLab to perform a Time-Domain simulation of a first-order circuit
- create and edit circuit schematics and simulations
- plot a first-order circuit response (time waveform) in CircuitLab and MATLAB

Key Prerequisites

- Chapter 7 (First Order Circuits)

Required Resources

- PC with internet access.

Additional resources

- http://www.docircuits.com/blog/
- http://www.docircuits.com/learn/
- https://www.circuitlab.com/blog/
- https://www.circuitlab.com/forums/

This lab extends our use of CircuitLab into the simulation of First Order Circuits, namely the analysis of their transient behavior in response to a change in circuit parameters (a switch thrown, etc). In transient analyses, we determine voltages and currents as functions of time. CircuitLab can perform this kind of analysis, called a Time-Domain simulation, in which all voltages and currents are determined over a specified time duration.

Vocabulary

All key vocabulary used in this lab are listed below, with closely related words listed together:

Transient response
Time-domain Simulation
Switch settings

Discussion and Procedure

Part 1. Time-Domain Analysis in CircuitLab

As an introduction to transient analysis, let us simulate the circuit in Figure 1, available at https://www.circuitlab.com/circuit/22jt73/lab10demo1/, by plotting the voltage v(t) and the current i(t) for the capacitor.

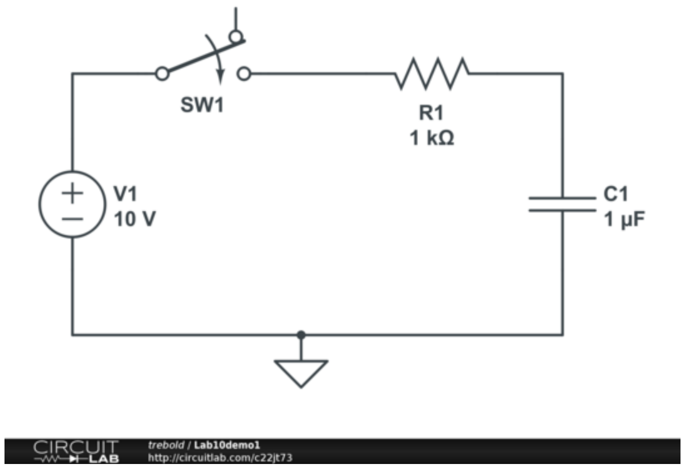


Figure 1

1. Bring up the circuit in the CircuitLab editor by clicking on the link above.

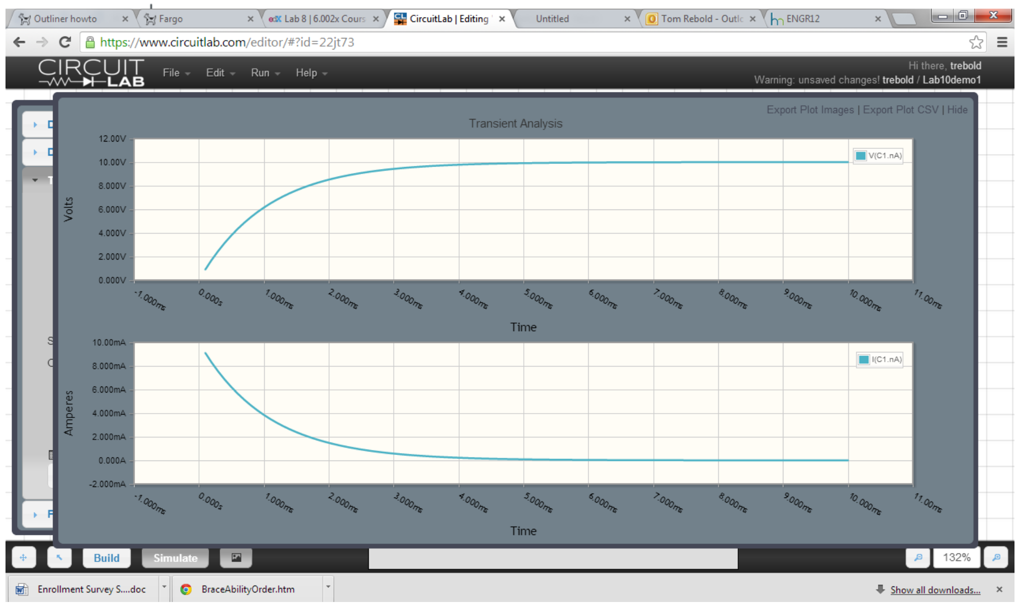
2. Double click the switch element and observe its properties. Note that you can set the switch resistance (normally R=0) and the time the switch closes (normally t=0). Also, if you need a switch that is normally **closed** and **opens** at t=0, you would just connect your circuit to the top and left wires.

3. Click on the Simulate button and open the Time-Domain Simulation pane.

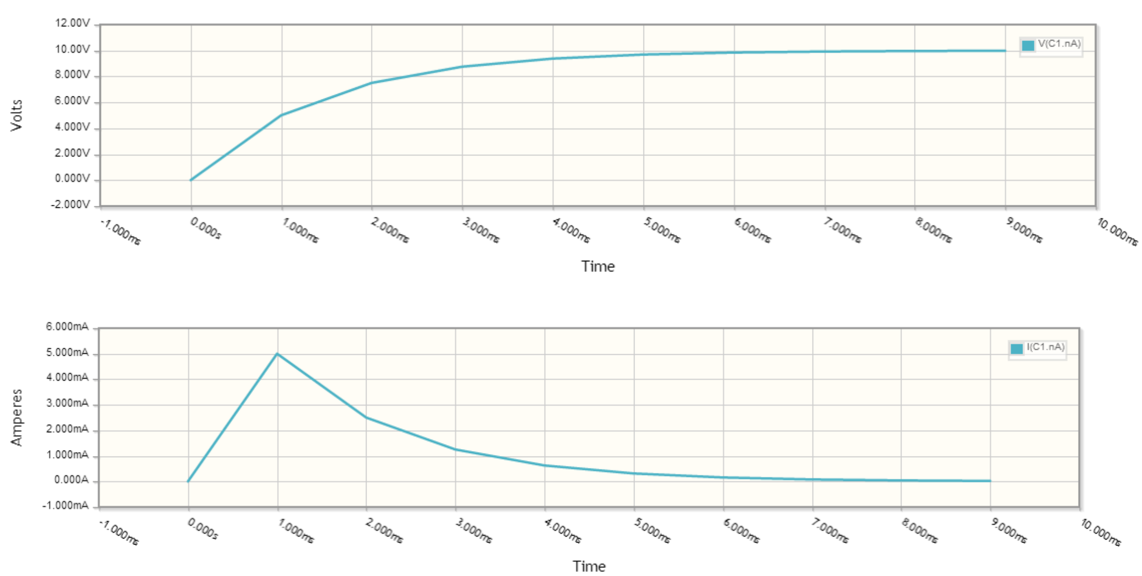
4. To run the simulation, we have to add values for the start time, stop time, and time step (the increment of how often to compute values). Enter 0 for start time, 0.01 for stop time, and 0.0001 for Time step.

5. You will have to indicate what circuit variables to plot. So move the mouse to the top of the capacitor so it turns into a pen/probe, and click the black circle at the node the capacitor attaches to. If you did this right, you will have V(C1.nA) and I(C1.nA) added to the "Outputs" list.

6. Finally, click on "Run Time-Domain Simulation" and you should get a set of plots like the ones below:

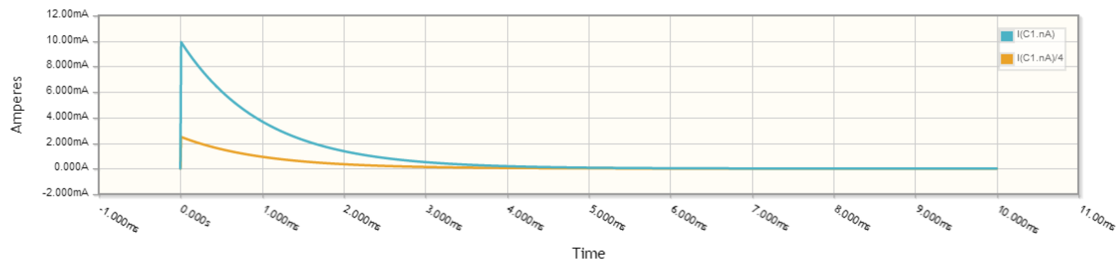


In general, this is quite easy to do in CircuitLab. The only difficulty is in choosing values for stop time and time step. The following images show what can go wrong if the time step is too small (0.001 instead of 0.0001). The curves are more jagged and less accurate.



7. It is also possible to compute and plot mathematical expressions involving circuit variables. For example, if we want to plot i(t)/4, we could “Add Expression” under Outputs and enter I(C1.nA)/4 in the box. Then when we

run the Time Domain simulation, our current plot will have an extra curve on it for our calculated expression:



Part 2. Plotting transient response curves in MATLAB or FreeMat

For this lab, we will also need to make plots in MATLAB or FreeMat of the results of our analysis. For example, the mathematical solution to $V_C(t)$ and $i_C(t)$ for the above example is:

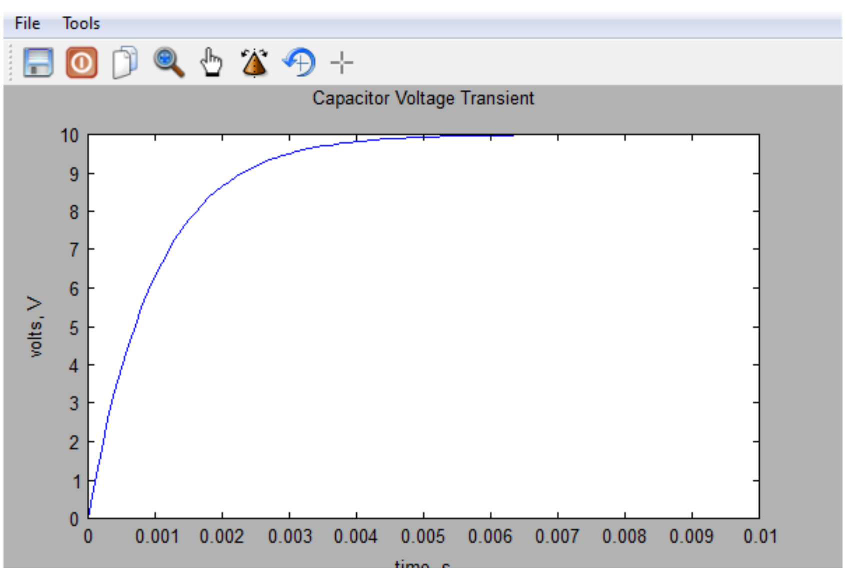
$$V_C(t) = 10 - 10e^{-1000t}, V$$

$$i_C(t) = 10e^{-1000t}, mA$$

In FreeMat, this would be plotted using the following commands:

```
time = 0:0.0001:0.01;
v = 10 - 10*exp(-1000*time);
i =  10*exp(-1000*time);
plot ( time, v )
xlabel('time, s'); ylabel('volts, V');
title('Capacitor Voltage Transient');
```

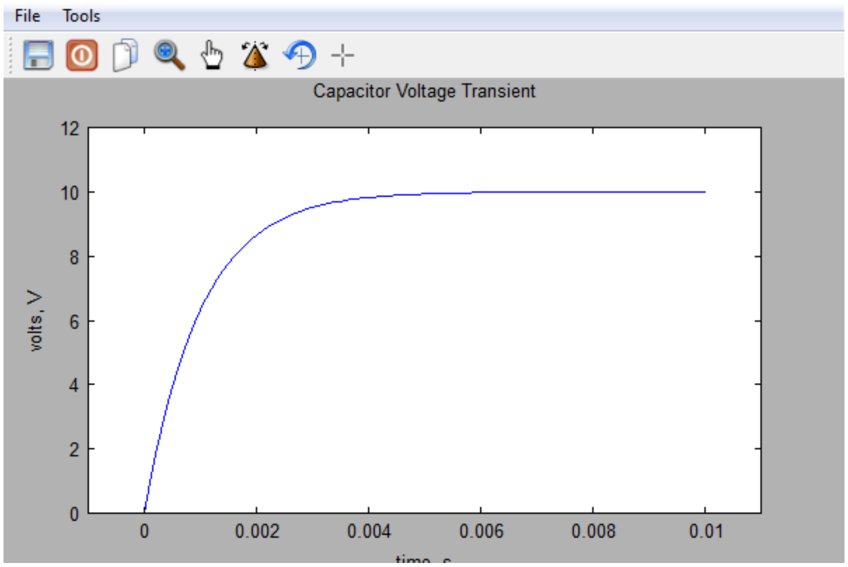
and you would get the following plot:



If you don't like the axis, you can change it by setting the new xmin, xmax, ymin and ymax values:

```
axis([-0.001, 0.011, 0, 12]);
```

which makes the plot look like this:



To plot the current, you would simply type:

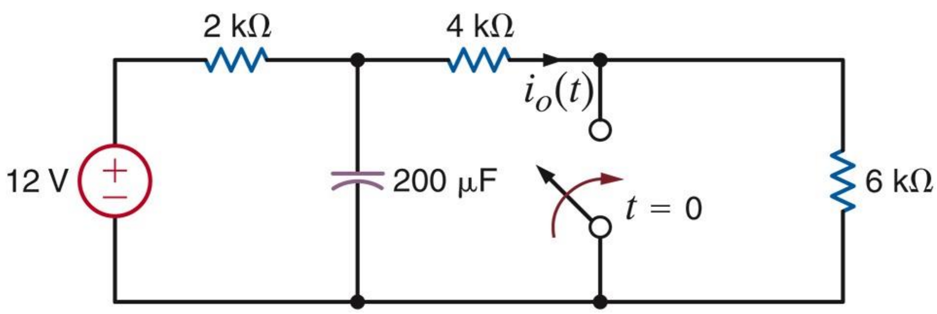
```
plot ( time, i )
xlabel('time, s'); ylabel('current, mA');
title('Capacitor Current Transient');
```

To copy the plot into word, just select Tools>Copy from the plot menu. You can then paste it into your datasheet for the lab.

Part 3. Exercises

Your datasheet must include **ALL** circuit diagrams (from CircuitLab), with all variables clearly labeled, and **ALL** calculations must be clearly shown. In addition, you will need to capture plots (from CircuitLab and FreeMat) for the various exercises and include them in your datasheet.

1) The switch in the circuit below has been opened for a long time and is closed at t = 0. Calculate $i_0(t)$ for t > 0. Plot $i_o(t)$ versus time using FreeMat and include the plot in your report. Now simulate this circuit using CircuitLab and plot $i_0(t)$ versus time. Include this plot in your report as well.



Calculation:

Although the problem requests $i_o(t)$, we initially need to focus on Vc(t) of the capacitor, since that is the controlling variable for this circuit. The following steps will help you arrive at a solution:

a. Initial Voltage across the capacitor:
b. Final Voltage across the capacitor:
c. Equivalent resistance seen by capacitor when the switch is closed
d. Time constant for the response:
e. Use the above to construct the equation for Vc(t):

f. Expression to calculate $i_o(t)$ from Vc(t):

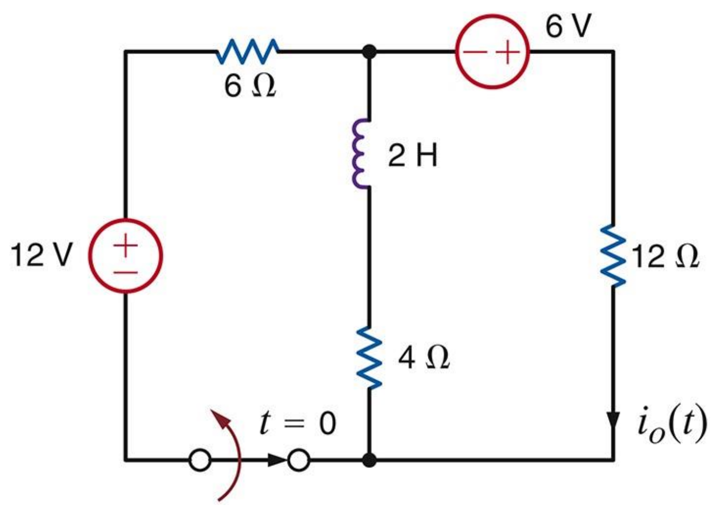
g. Insert the FreeMat plot of $i_o(t)$

h. Insert the CircuitLab schematic for this circuit

i. Insert the CircuitLab plot of $i_o(t)$

j. If there are any disagreements, go back and debug.

2) The switch in the circuit below has been closed for a long time and is opened at t = 0. Calculate $i_o(t)$ for t > 0. Plot $i_0(t)$ versus time using Matlab and include the plot in your report. Now simulate this circuit using CircuitLab and plot $i_0(t)$ versus time. Include this plot in your report as well.



Calculation:

Although the problem requests $i_o(t)$, we initially need to focus on $I_L(t)$ (current through the inductor defined as flowing downward, since this is the controlling variable for the circuit. The following steps will help you arrive at a solution:

a. Initial Current through the inductor:
b. Final Current through the inductor:
c. Equivalent resistance seen by inductor when the switch is open
d. Time constant for the response:
e. Use the above to construct the equation for IL(t):

f. Expression to calculate io(t) from IL(t):

g. Insert the FreeMat plot of $i_o(t)$

h. Insert the CircuitLab schematic for this circuit

i. Insert the CircuitLab plot of $i_o(t)$

j. If there are any disagreements, go back and debug.