Software Packages in Physics 0332481

Session 1:

Simulation of Simple Ideas in Electronics

Foreword

Electronics is today perhaps one of the most exciting branches of applied physics. Even though models used to describe circuit elements are simple, having to deal with complicated circuits with a large number of elements can be very time consuming. On the market, there are many sophisticated software packages that can be used to simulate circuits with a huge variety of elements, and with a large array of tools for analysis, so that an electronics lab can be fully simulated on a PC! In this lab session, you will conduct a very rudimentary simulation of two types of circuits, one made of resistors and batteries, and the other is a typical RC circuit, and then you will conduct a simple simulation concerning Lissajous figures. In what follows, we sketchily review the basics of the theory behind the two types of circuits.

- Note: This session will be introduced as three separate parts. The first two parts are self-contained in physical formulation of the problem, programming, and exercises.

Part 1: Kirchhoff's Rules

Electrical circuits involving batteries and resistors can be analyzed using Kirchhoff's rules:

1. The loop rule:

When any closed-circuit loop is traversed, the algebraic sum of the changes in potential must equal zero.

$$\sum_{\text{loop}} \Delta V = 0 \qquad \text{(S.1.1)}$$

1. The junction (node) rule:

At any junction point in the circuit where the current can divide, the sum of the currents into the junction must equal the sum of the currents out of the junction.

$$\sum i_{\text{in}} = \sum i_{\text{out}} \qquad \text{(S.1.2)}$$

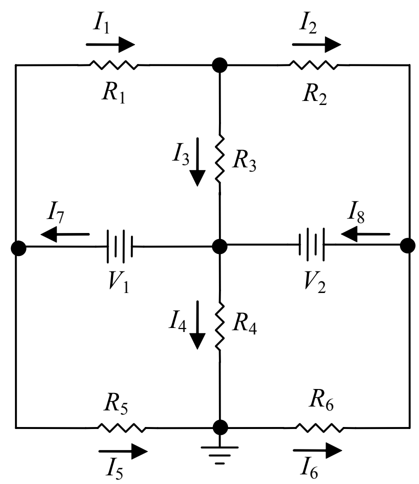

Figure S.1.1

1.1 Hints to Algorithm (Programming)

a. For the circuit shown in figure S.1.1, write four independent loop equations and four independent node equations.

b. Use as inputs:

$V_1 = 15\text{ V},\ V_2 = 10\text{ V}$

$R_1 = 5\,\Omega,\ R_2 = 2\,\Omega,\ R_3 = 8\,\Omega,\ R_4 = 4\,\Omega,\ R_5 = 7\,\Omega,\ R_6 = 3\,\Omega.$

c. Using the ***Mathematica***'s `Solve[]` function, obtain the eight currents.

d. Check that your output is reasonable.

1.2 Questions

a. From what conservation laws do Kirchhoff's rules follow?

b. For the above circuit, how many loops are there? Did you use them all in your analysis? Explain.

c. Are the assigned directions for the current correct?

1.3 Exercises

a. Which resistor dissipates the most power?

b. If we modify the above circuit by lifting the battery V_2 from it, find the current(s).

Part 2: RC Circuits

A circuit containing a resistor and a capacitor is called an *RC* circuit. Using Kirchhoff's rules, one can obtain the charge on the capacitor Q and the current I as functions of time for both charging and discharging of a capacitor through a resistor of resistance R.

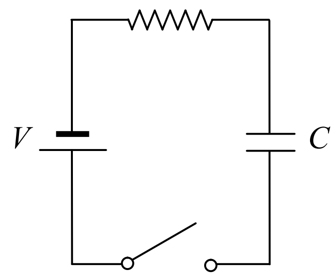

Figure S.1.2

Consider the circuit in figure S.1.2. Assuming that the capacitor is initially uncharged and the switch, originally open, is closed at time $t = 0$, Kirchhoff's loop rule at $t > 0$ gives

$$V = \frac{Q}{C} + i\,R \tag{S.1.3}$$

Starting with the above equation,

a. Show that:

$i(t) = \frac{V}{R}\,e^{-t/\tau}$, and $Q(t) = V\,C(1 - e^{-t/\tau})$, where $\tau = R\,C$ is the circuit's time constant.

b. Plot $i(t)$ and $Q(t)$ as functions of time *on the same graph* to visualize their time dependence. (*Hint: Since i and Q have different units you need to make them dimensionless before drawing them*).

2.1 Hints to Algorithm

a. For the given circuit, recall that in order to obtain an ordinary differential equation with one unknown, say $i(t)$, you will need to use the definition of charge in terms of the current: $Q(t) = \int i(t)\,dt$.

Solve the obtained equation for $i(t)$. (*Hint: See Mathematica's function* **`DSolve[]`**).

Integrate $i(t)$ to obtain $Q(t)$.

b. Use as input values: $V = 10\,\text{V}$, $R = 8\,\text{k}\Omega$, $C = 2.5\,\mu\text{F}$.

Plot $i(t)$ vs. t with well-defined axes. (See the option **AxesLabel**).

Plot also $Q(t)$ vs. t.

Combine *dimensionless versions* the two plots together. (See **Show[]**).

2.2 Questions

a. Is it reasonable for the current (charge on the capacitor) to decrease (increase) with time? Explain physically.

b. Mention an application (practical example) of an *RC* circuit used in our life.

2.3 Exercises

For $R = 8\ \text{k}\Omega$ and $C = 2.5\ \mu\text{F}$:

a. Calculate the time constant for the given *RC* circuit and with one statement, make *Mathematica* display the result as in the form: $\tau =$ ---sec. (See **Print[]**) .

b. Plot the voltage across the capacitor V_C and the voltage across the resistor V_R as functions of time to see if they are reasonable.

Part 3: Lissajous Figures

Lissajous figure can be used in an electronics lab to compare the frequencies of two signals using an oscilloscope; the two signals are made to appear simultaneously with one entering through the *x*-channel, and the other through the *y*-channel.

In order to draw Lissajous figures for two sinusoidal signals using *Mathematica* you need to do a *parametric plot*, such that the *x*-coordinate will represent the *x*-channel, and the *y*-coordinate will represent the *y*-channel. Of course, in doing that, you will have *parametrized* the problem in terms of time.

3.1 Exercise

Find out how *Mathematica* handles parametric plots, and then draw the Lissajous figure resulting from two signals entering an oscilloscope: the one entering the *x*-channel having a frequency 3 times as much as the signal entering the *y*-channel.

3.2 Questions

a. Briefly explain the physical principle behind the Lissajous figures.

b. Briefly explain the concept of parametrization.

Final Word :

- **Do not forget to give physical meaning for each part.**
- **Try to simulate similar topics in electronics.**
- **Mention your suggestions if available.**