Mechatronics

Introduction to Analog and Digital Electronics: Laboratory Exercises 1 & 2

There is an electronics revolution taking place in the industrialized world. Electronics pervades all activities. Perhaps the most important technological development in the second half of the 20th century is the development of solid-state electronics and all the technological changes that this development made possible. While the details of the field of electronics are changing very rapidly, the fundamental laws describing the operation of electronic devices and the methods of analysis used to understand electronic circuits change only slowly, if at all, and so the emphasis here is on the fundamentals and the basic vocabulary used in electronics.

A good working knowledge of electronics has four distinct elements:

- knowledge of the basic physical laws that apply to the operation of electronic devices, including basic circuit analysis laws
- knowledge of circuit analysis techniques, i.e., the mathematical techniques used to understand the operation of circuits, including computer simulation of electronic circuits
- knowledge of the state of the art in electronics in order to answer the challenge "design a ..." or "build a ...."
- mastery of the vocabulary of electronics which is essential for reading the electronics literature

Of these four, only the third element changes very rapidly.

The goal in the first two laboratory exercises is to provide a balanced approach to these elements of electronics as they relate to mechatronic system design.

Laboratory Exercise #1, Analog Electronics, Part A: Resistors, Capacitors, DC/AC Circuits, RC (Filter) Circuits, Lead/Lag Controllers, Input/Output Impedance, Loading Effects

Introduction:

This lab is a review of the two most fundamental electronic components, the resistor and capacitor, together comprising essential building blocks of both analog and digital circuitry. Kirchhoff's and Ohm's laws provide the means of analyzing and constructing analog circuits using these components. The basic circuits covered, voltage dividers, RC (filter) circuits, lead/lag controllers, you will put together in this laboratory exercise. You will learn about input / output impedance and loading effects, two of the most important concepts for any mechatronics engineer to know. You will also begin to learn, through analysis and experimentation, the relationship between the time domain and the frequency domain.

Obviously, much of this is a review in the basics nearly all of you have, at one point or another, already seen. Yet it is precisely for this reason that it is so important that you master these basics, particularly from a design point of view. In addition, as elementary as voltage dividers and RC filters are, they are in fact two of the most useful and applicable circuit fragments to know as a mechatronics engineer, since a host of common electronic devices are based on them.

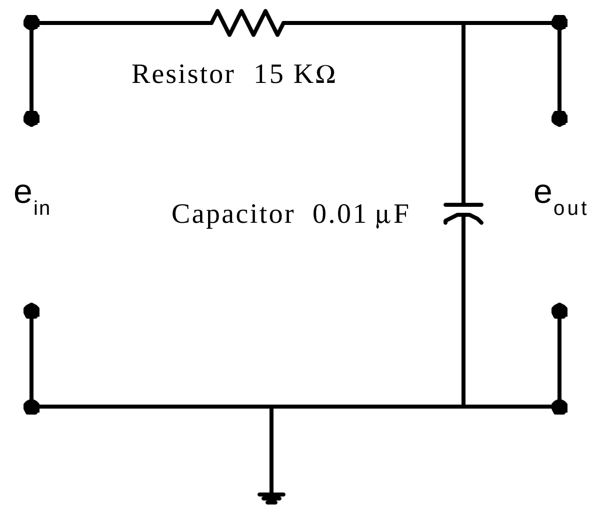
This lab will also quickly familiarize you with the use of the following standard electronics equipment: multimeter, function generator, oscilloscope, powered breadboard.

Laboratory Procedure:

- Using the multimeter, measure all resistors and capacitors. Note values. Note tolerances.

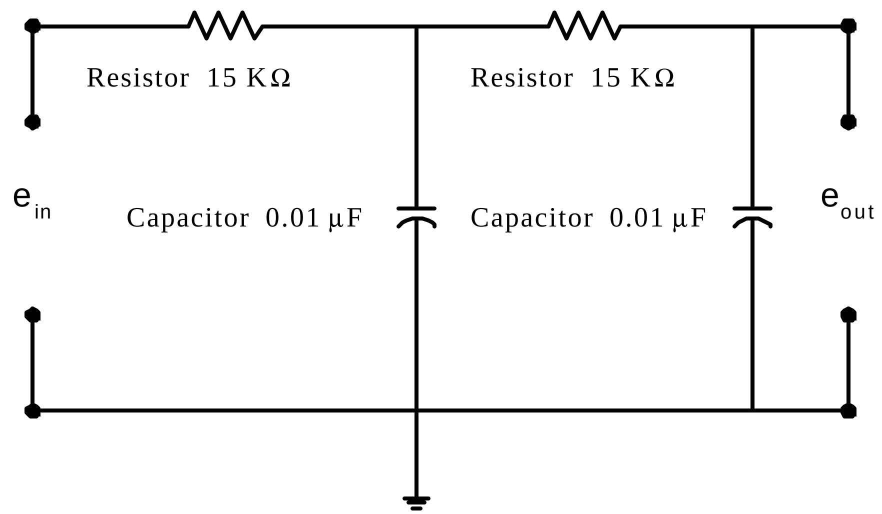
- Using the multimeter, check +15 V, -15 V, and +5 V on the powered breadboard. Using the multimeter, check the connectivity on the breadboard.

- **RC Low-Pass Filter Circuit**: R = 15 KΩ, C = 0.01 μF
  ⇒ Derive the ideal transfer function for this system.
  ⇒ Perform MatLab Simulations: plot the step response and frequency response.



⇒ Build in hardware the RC low-pass filter circuit and use the function generator and digital oscilloscope to validate your step response and frequency response predictions in the MatLab simulations.

- **Two identical RC Low-Pass Filters in Series**: R = 15 KΩ, C = 0.01 μF
  - ⇒ Derive the ideal transfer function for this system.
  - ⇒ Perform MatLab Simulations: plot step response and plot frequency response. Note the effect of the second filter loading the first filter.

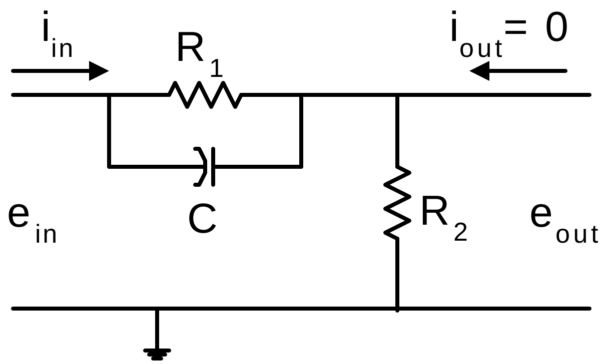


  - ⇒ Build in hardware the RC-RC circuit and use the function generator and digital oscilloscope to validate your step response and frequency response predictions in the MatLab simulations.

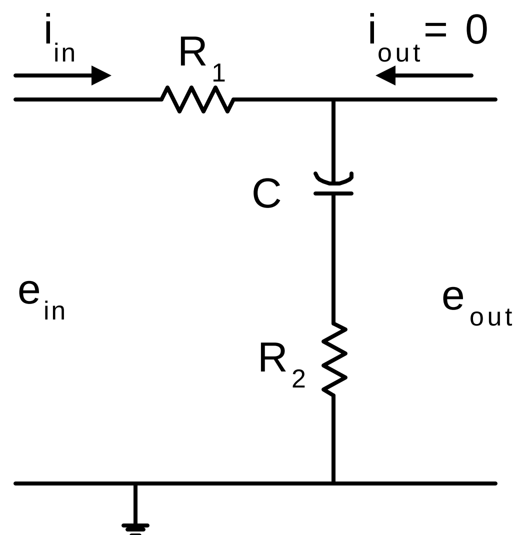
- **Passive Lag Controller**: R_1 = 100 KΩ, R_2 = 11 KΩ, C = 0.1 μF
- **Passive Lead Controller**: R_1 = 100 KΩ, R_2 = 11 KΩ, C = 0.1 μF

⇒ Derive the ideal transfer functions for these systems.

⇒ Perform MatLab Simulations: plot step response and frequency response.



Passive Lead Circuit



Passive Lag Circuit

⇒ Build in hardware the Lead and Lag Controller circuits and use the function generator and digital oscilloscope to validate your step response and frequency response predictions in the MatLab simulations.

Lab Exercise 1A Questions

1. Resistors dissipate power, capacitors do not. Why? Where does the power go?
2. Explain how a passive RC differentiator is exactly the same as a passive RC high-pass filter. What is the criterion for good differentiation? How would you construct a "perfect" differentiator?
3. Explain how a passive RC integrator is exactly the same as a passive RC low-pass filter. What is the criterion for good integration? How would you construct a "perfect" integrator?
4. The following questions apply to the RC Low-Pass filter.
   - ⇒ Draw the circuit and write the Laplace transfer function e_{out} / e_{in} .
   - ⇒ Sketch the unit step response of this system. What is the time constant τ of the system in terms of the system hardware parameters and what does it represent in the time domain ?
   - ⇒ Sketch the frequency response of this system. In the magnitude plot, identify the low-frequency amplitude ratio, the breakpoint frequency and amplitude ratio at that frequency, and the slope of the curve at high frequency. On the phase plot, show the low-frequency value, the high-frequency value, and the breakpoint-frequency value. What is the bandwidth of this system and how is it related to the time constant τ ?
   - ⇒ What is the input impedance for this circuit?
   - ⇒ What is the output impedance for this circuit?
5. Using the expressions for the input and output impedance of the RC circuit, write the expression for the overall transfer function e_{out} / e_{in} of two identical RC circuits connected in series. Do not simplify. Identify the term in the expression that represents the loading effect.
6. Why are the passive lead and lag circuits given their names, i.e., lead and lag?
7. The passive lead circuit is an approximate PD (proportional-derivative) controller? Explain.
8. The passive lag circuit is an approximate PI (proportional-integral) controller? Explain.