EE 210 Lab Exercise #9:
RC Circuit Transient Response

| ITEMS REQUIRED	EE210 crate, EE210 parts kit, Breadboard
ASSIGNMENT	Lab report due at the beginning of the next lab period
Data and results from all of the numbered, bolded material in the procedure sections must be included and clearly numbered in the data section of the lab report.	

Introduction

The objective of this lab is to study the transient properties of circuits with resistors and capacitors. For a circuit composed of a resistor and capacitor (an *RC* circuit see Figure 1.), the voltage across the capacitor is

$$V_{(t)} = V_o e^{-t/RC}$$

where V_o is initial voltage (initial condition across the capacitor at *t=0*). The time constant τ for this circuit, the time that it takes for the voltage to decay to 37% of its original value is $\tau = RC$. The time constant for different circuits composed of resistors and capacitors along with a small design project will be examined in the following laboratory.
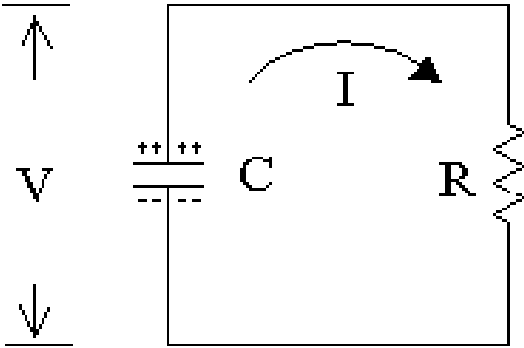
Figure 1. An *RC* circuit.

Exercise 1: Time Constants of Parallel RC Circuits

In this first part of this exercise, an assigned capacitor will be charged to a known potential and then discharged through a resistor and the HP oscilloscope's internal resistance. The time dependence of the potential across the capacitor as it changes from *0 V* to *10 V* will be measured, so that the time constant $\tau = RC$ can be determined. The resistance *R* is the equivalent resistance of the *1MΩ* internal resistance of the oscilloscope (marked on the oscilloscope probe) and the *1MΩ* resistor, and C is the capacitance of the capacitor (*1µf*). Using the same procedure, the effect of capacitors in series and parallel will then be explored.

Exercise 1: Procedure

1. **(1) Analytically determine the time constants of the circuits in Figures 2 & 3.** (remember that the oscilloscope acts as 1MΩ resistor)

2. Connect the power supply, *1µf* capacitor, *1MΩ* resistor, and channel 1 of the oscilloscope as shown in Figure 2.

3. Set the trigger mode to *Single* and the trigger slope to detect a falling slope. Adjust the trigger level to just below the input voltage. When the trigger is set off, the resulting image will "freeze" on the scope for measurement. The trigger is stopped in this state, as indicated in the upper right-hand corner of the screen. The RUN button must be pressed in order to re-activate the trigger for capturing another image.
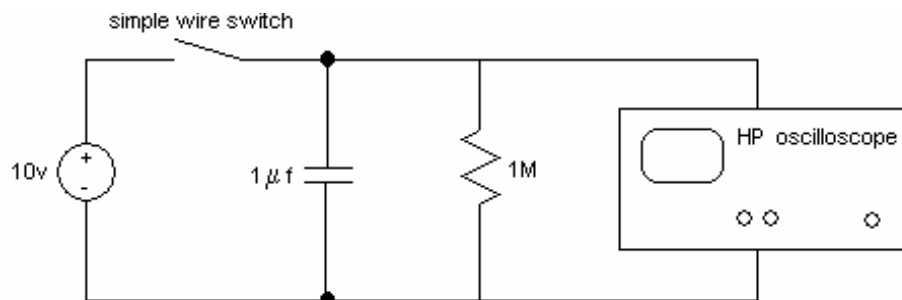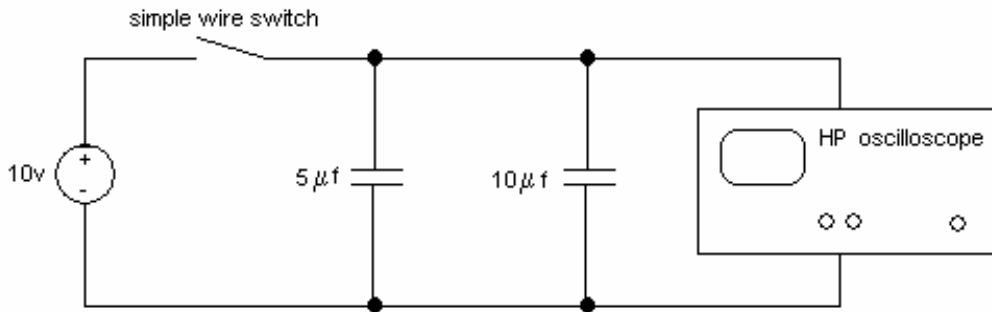

Figure 2. *RC* circuit with HP oscilloscope.

4. Make sure that the oscilloscope is set at an adequate time/division based on the time constant calculated in step 1. Close the switch long enough for the capacitor to reach a constant voltage (at least 5 time constants) then open it. **(2) Using the time and voltage cursors, measure the time constant of the circuit** (the time that it takes for the voltage to *decay* to 37% of its original value). **(3) Provide a printout of one of the trials, including the time constant determined by the cursors.**

5. **(4 & 5) Repeat step 4 for Figure 3 (remember that the relations for combining capacitors in series/parallel are the inverse of the relations for resistors).**

6. **(6) Determine time constant if the capacitors in Figure 3 are in series instead of parallel.**

Figure 3. *RC* circuit with two capacitors and HP oscilloscope.

Exercise 2: Time Constant of a Series RC Circuit Driven by the Function Generator.

In this exercise, both the charging and discharging time constants of an RC circuit will be determined by driving the circuit by a square wave.

Exercise 2: Procedure

1. Return the trigger mode of the oscilloscope to normal.

2. Let C= *0.1μf* and R=*3kΩ.* Construct the circuit given in Figure 4. **(7) Determine the time constant of the circuit, neglecting the resistance of the oscilloscope and function generator.**
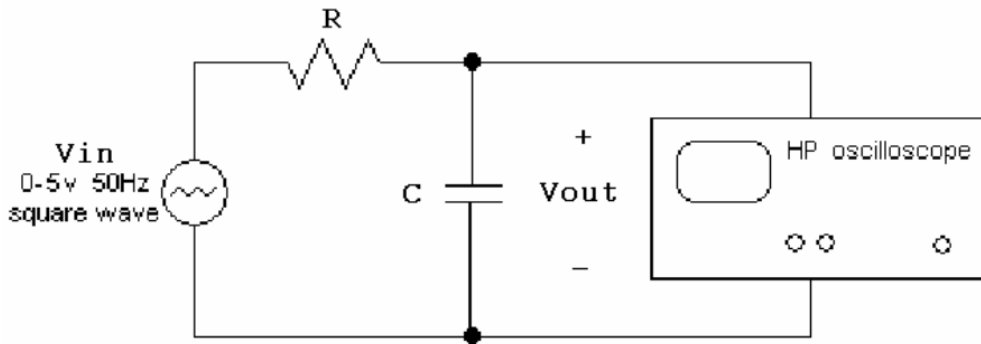
Figure 4. Series *RC* circuit.

3. Simultaneously monitor Vin and Vout of the circuit using the oscilloscope. Notice that Vout has an exponential characteristic on both the rising and falling edges. The decaying characteristic should follow the equation used earlier and the rising characteristic should follow:

$$V_{(t)} = V_o(1 - e^{-t/RC})$$

Notice that the charging time constant will be defined as the time that it takes for the voltage to increase to 63% of its final value.

4. From the plot**, (8) determine both the charging and discharging time constants of the circuit. (9) Make a printout of the oscilloscope display including Vin and Vout.**

5. Gradually increase the frequency of the input voltage. **(10) Note what happens to the amplitude and shape of the waveform displayed on the oscilloscope at high frequencies.**
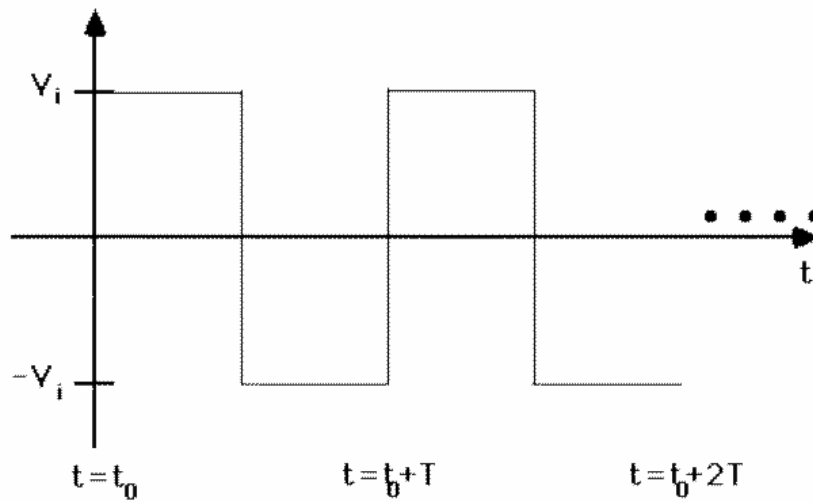
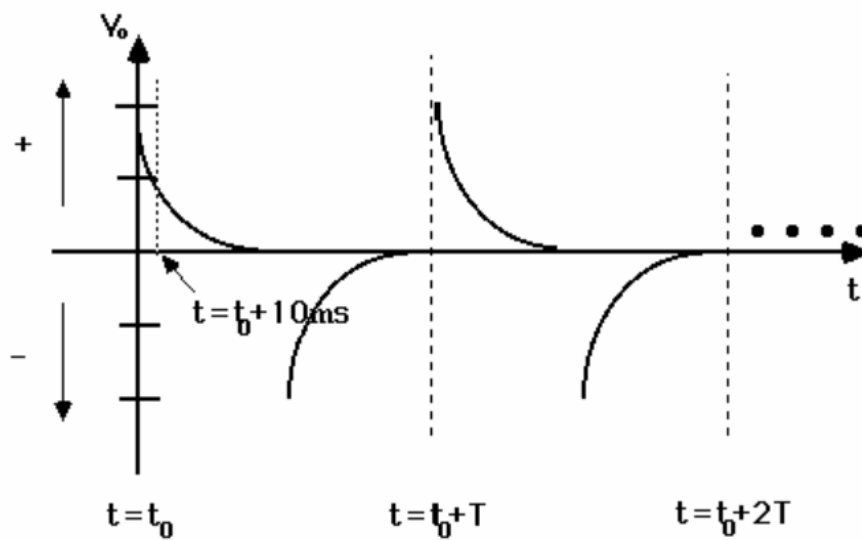# Exercise 3: Design Problem

Exercise 3: Procedure

Design a circuit using only resistors capacitors in series which, when connected as in Figure 5 and for the input shown in Figure 6, produces an output voltage as shown in Figure 7. The design should use the design criteria listed below.
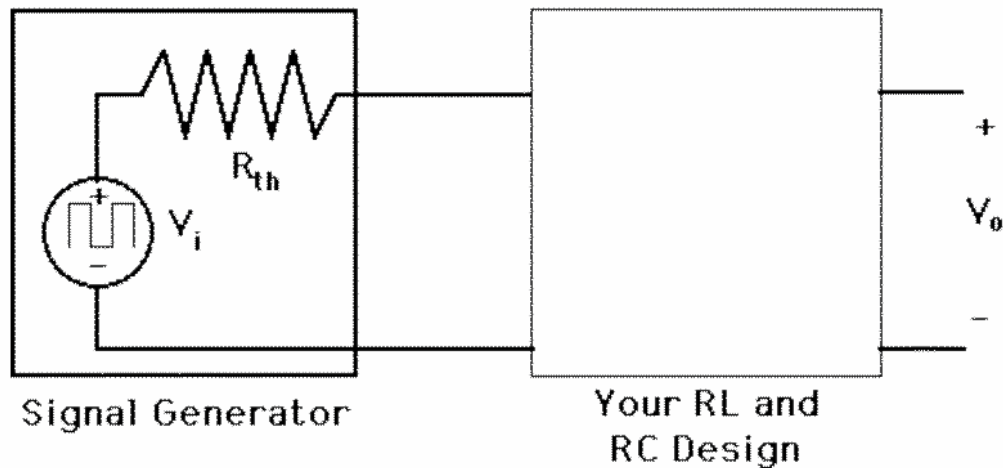
Figure 5. Schematic of the design.

Figure 6. The input pulse train.

Figure 7. Desired circuit output.

Design Criteria:

1) Consider R and V_i as design variables.

2) Let T (the period) be approximately *250 ms*.

3) Use $C = 0.1 \mu F$ in the RC design

4) Require $V_0(t_0+10\ ms) = 3.5\ V$ and $V_0(t_0+60\ ms) = 0.1\ V$.

5

Hints:

Use the following general formula for the voltage stepping response of the first order system

$V_o(t) = V_{inf} + (V(0) - V_{inf})*exp(-t/\tau)$, ($\tau$ is the time constant)

Where: V_{inf} -- steady state, asymptotic voltage,

$V(0)$ -- initial out voltage

$V(0) - V_{inf}$ -- transient part, dies out after "sufficient" time (practically sufficient time means ~ *3* to *5* τ)

In this case (see Figure 7) $V_{inf} = 0$, and the equation above reduces to

$V_o(t) = V(0)*exp(-t/\tau)$

Finally, after substituting conditions 4) into the last equation and recognizing that $V(0) = 2*V_i$ (convince yourself that this holds true), it follows

$3.5 = 2*V_i*exp(-10\ msec/\tau)$ and $0.1 = 2*V_i*exp(-60\ msec/\tau)$

The last two equations can now be solved for V_i and τ.

(11) Sketch the circuit and record the calculations and results, including plots of Vin vs. Vout with the relevant values indicated by the cursors.

(12) Using *L= 330 mH,* design and sketch an *RL* circuit with the same specifications indicated above.   *Remember τ=L/R for an RL circuit*

Discussion/Conclusion

Discuss and thoroughly explain each of numbered the concepts below, listed by exercise. When applicable, consider the following items when formulating your responses:

- ➤ A comparison of theoretical and experimental results.
- ➤ An identification and description of the likely sources of error.
- ➤ A description of the purpose and function of each circuit and possible applications.
- ➤ A comparison of similar circuits in the lab and the respective functions.
- ➤ A discussion of relevant observations, results, and deductions.

Exercise 1
1. Compare the experimental values with the calculated values and indicate any discrepancies.
2. Why is 37% of the original value chosen to determine the time constant?
3. Will the oscilloscope's internal resistance always have a significant effect on measurements of this type? Explain.

Exercise 2
4. Compare the values to theoretical value and indicate discrepancies and possible sources of error.
5. Explain what happens to the shape of the waveform displayed on the oscilloscope at high frequencies.

Exercise 3
6. Explain the relationship between $V_i(t_0)$ and $V_0(t_0)$. Compare and explain actual and theoretical results.
7. Why was $T \sim 250\ ms$ selected?
8. Explain the effects of the oscilloscope on the RC circuit.