

MAS.836

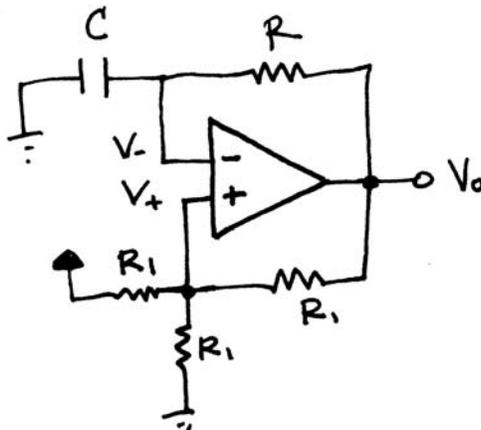
PROBLEM SET / LABORATORY FOUR

Introduction to Capacitive Sensing:

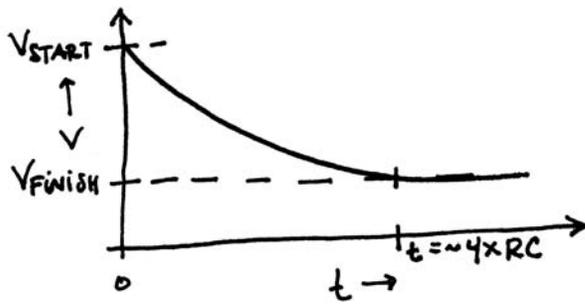
The purpose of this problem set and laboratory exercise is to familiarize yourself with the implementation of capacitive sensors. There are many different ways of implementing position sensing via capacitance change, but we will focus on just one of them. Again, you will construct your circuit from the parts given in the laboratory kit, and any resistors, capacitors, and diodes you may need from the RESENV stock area. You will also need to turn in your functioning kit on your signed protoboard, and turn in a report detailing the design you chose, answering any questions given in the laboratory assignment, and plotting any performance criterion asked for in the laboratory assignment. Both of these things will be collected directly after class on the due date.

Problem One:

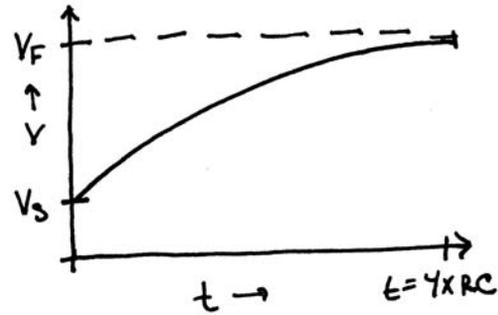
For any capacitive sensing application, there must be an oscillator somewhere in the circuit. This oscillator can either charge and discharge your sense capacitor, or it can create the alternating electric field which is transmitted between electrodes. The simplest form of an oscillator is the relaxation oscillator, and it can be built out of an op-amp or a single inverting logic gate. An example is as follows:



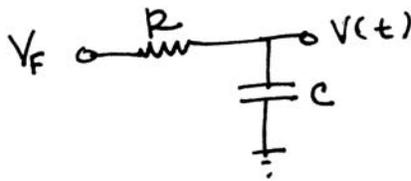
These oscillators use a capacitor which charges and discharges to create an oscillating voltage. Since they use a resistor with a constant voltage source to charge the capacitor, the amount of current flowing into the capacitor changes with time. As more charge flows into the capacitor, the capacitor voltage increases. This decreases the total voltage across the charging resistor, decreasing the current flowing through it, and subsequently decreasing the rate at which the charge accumulates in the capacitor. So, the capacitor continues to charge up, but more and more slowly as time goes on. The equations which describe this behaviour are as follows:



$$V(t) = V_F + (V_S - V_F) e^{-t/RC}$$

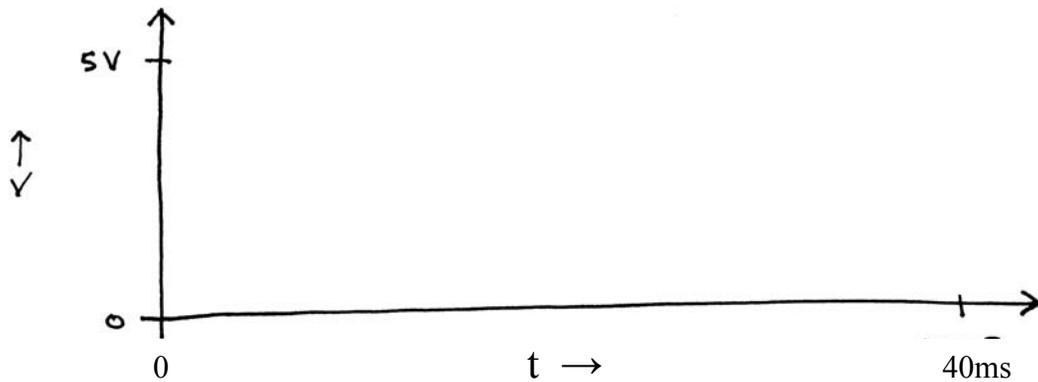


$$V(t) = V_S + (V_F - V_S)(1 - e^{-t/RC})$$



where V_S is the starting voltage on the capacitor, V_F is the voltage on the other end of the charging resistor (the final voltage it will attempt to reach), R is the charging resistor value, C is the capacitor value, and e is the natural log (a constant of value ~ 2.72). Please answer the following questions, using the above circuit as a reference.

1. If the circuit above is run off a single 5V rail, what is the value of V^+ for $V_0 = 5V$?
2. What is the value of V^+ for $V_0 = 0V$?
3. Please plot your results from (1) and (2) as constant values, with respect to time, on the graph below.
4. If the circuit has just started up after being off for a long time, the capacitor will have no charge on it. What are the values of V_0 and V^+ for $V^- = 0V$?
5. Since the output will not change until $V^+ = V^-$, given that $R = 5k\Omega$, $C = 2\mu F$, and we are starting with $0V$ across the capacitor, how long will it take for the output to change state?
6. Please plot, on the graph below, V^+ , V^- , and V_0 as a function of time for this starting condition.
7. What are V^+ , V^- , and V_0 directly after this transition?
8. What is the final voltage (V_f) that the capacitor will attempt to transition to next?
9. How long will it be before V^- once again equals V^+ ?
10. Please plot V^+ , V^- , and V_0 for this transition on the graph below.
11. Repeat steps (7) through (10) until you reach 40ms.
12. What is the frequency of oscillation of this circuit?



Problem Two: Capacitive sensing amplifier construction

The electrode given for this exercise is an aluminum plate approximately two inches by three inches in area. Since there is only one electrode given, the only possible method of capacitive sensing is loading mode. In loading mode, the change of capacitance between the electrode and ground is measured as a person (or other object closely coupled to ground) moves towards the electrode. As shown in Problem Set Three, the capacitance of two parallel plates is given by $C = \epsilon \times A / t$, where ϵ is the permittivity of free space, A is the area of the plates, and t is the spacing between them. So, as the distance between your electrode and the sensed object increases, the capacitance decreases.

All forms of capacitive sensing require an oscillator to drive the electrode. This has the added benefit of creating a drive signal which is higher in frequency than a lot of the ambient electrical noise in the environment (60Hz for example). Good oscillator designs can be found in Horowitz and Hill, but remember that you only have four op-amps for the entire circuit. You will drive the electrode with the oscillator and measure the changing impedance presented by your hand as you move it above the electrode. Your hand will increase the capacitance at the electrode and load down the circuit. There are many ways of measuring this added load, so choose the one which gives you the best sensing range. Finally, you will need to make your LED glow brighter the closer you place your hand to the plate.

Questions:

1. How far away can your hand be from the electrode before the LED starts to come on?
2. How does your answer to (1) compare to the dimensions of the electrode?
3. What is the largest distance you could reasonably sense with your electrode, and what might account for any discrepancies between this and your answer to (2)?

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MAS.836 Sensor Technologies for Interactive Environments
Spring 2011

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