EECS 16A Designing Information Devices and Systems I
Fall 2019 Midterm 2 - VERSION A

Exam Location: Latimer 120 / VERSION A

PRINT your student ID: ______________________

PRINT AND SIGN your name: ______________, ______________ ______________
(last name) (first name) (signature)

PRINT time of your Monday section and the GSI's name: ______________________

PRINT time of your Wednesday section and the GSI's name: ______________________

Name and SID of the person to your left: ______________________

Name and SID of the person to your right: ______________________

Name and SID of the person in front of you: ______________________

Name and SID of the person behind you: ______________________

1. Tell us about something that makes you happy. (1 Point)

Netflix.

2. What courses are you thinking of taking next semester? (1 Point)

Math 104, Math 185 and a CS class.

Do not turn this page until the proctor tells you to do so. You may work on the questions above.

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3. Power (15 points)

In the circuit shown in Figure 3.1 calculate the total power P_d **delivered** by source I_1 to the rest of the circuit.

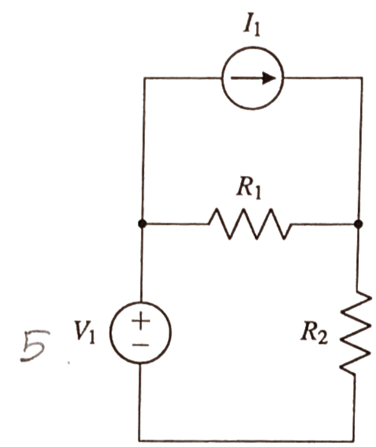

Figure 3.1: Circuit for power calculation

Use the following component values: $R_1 = 2\Omega$, $R_2 = 2\Omega$, $V_1 = 5\text{V}$, $I_1 = -0.5\text{A}$.

$R_1 + R_2 = 2+2 = 4\Omega.$ $V = IR.$

$\therefore I_{Th} = \frac{V}{R} = \frac{5}{4} = 1.25\ A.$

$I_1 = -0.5$

$R_1 = 2.$

$V = I_1R = -1$

$\therefore P_{I_1} = VI = (-0.5)(-1)$

$= 0.5W$

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4. **Equivalent Circuit (15 points)**

Your friend has characterized the circuit shown in Figure 4.1(a) in the lab by first connecting a voltmeter (represented in Figure 4.1(b) by the letter V in a circle) to terminals $A-B$ to measure V_m, then disconnecting the voltmeter and connecting an ammeter (current meter, represented in Figure 4.1(b) by the letter A in a circle) to measure I_m.

Now they ask for your help designing an equivalent circuit model (looking from terminals A and B) consisting only of a current source I_s and resistor R_s.

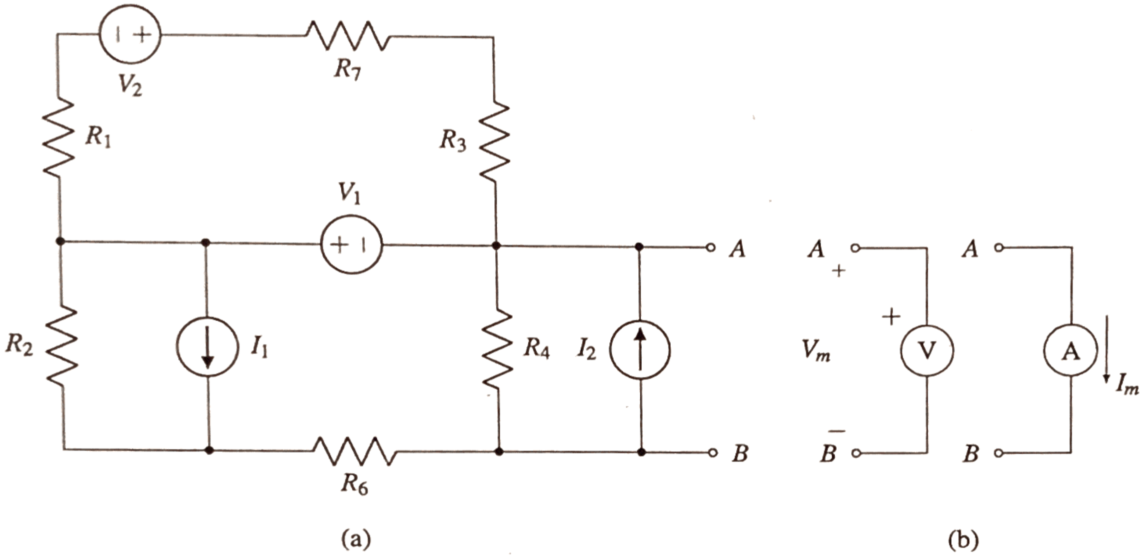
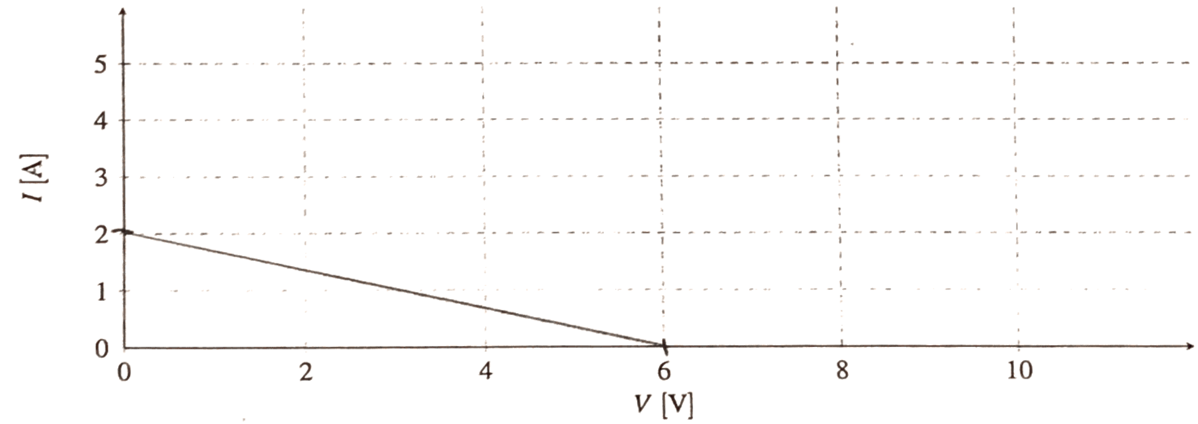


Figure 4.1: (a) Circuit tested in the lab, (b) Circuit used to measure V_m and I_m

Use the following values: $V_m = 6\text{V}$, $I_m = 2\text{A}$.

(a) Draw the I-V characteristic between nodes A, B of the circuit in Figure 4.1(a).



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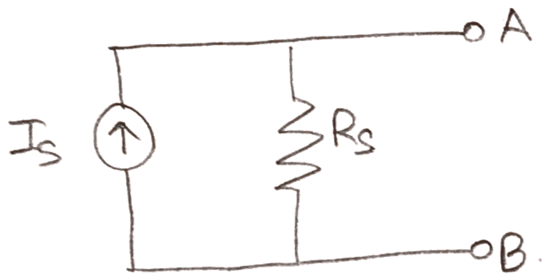
(b) Draw the circuit diagram of the equivalent model as seen from nodes A, B. Clearly mark nodes A and B, current I_s (including direction), and resistor R_s.



$I_s = I_m$

$R_s = \frac{V_m}{I_m}$.

(c) Calculate the numerical values of I_s and R_s. Mark your calculated component values in the circuit diagram drawn in part (b). Clearly mark the direction of the current.

$I_s = I_m = \underline{\underline{2A}}$.

$R_s = \frac{V_m}{I_m} = \frac{6}{2} = \underline{\underline{3\,\Omega}}$

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5. **Next-Phone (15 points)**

You have been hired by "Next-Phone", a promising startup that has developed a 3D printer to produce individually customized smartphones.

Only one problem remains: designing accurate position sensing for the printhead. "No problem," you tell your new boss, "I'll take care of that!"

Figure 5.1 shows your design. The printhead is supported by two rollers that move the head in the x direction. Each roller runs on two conductive tracks with resistivities ρ_1 and ρ_2, respectively, length L, and cross-sectional area A. The rollers are made of metal electrically connecting the strips. The printhead is an insulator (i.e. nonconductive material) so it can be modeled as an open-circuit. You connect two voltage sources of voltage V_s as shown in Figure 5.1. You then measure voltage $V_{AB} = V_A - V_B$ to sense position x.

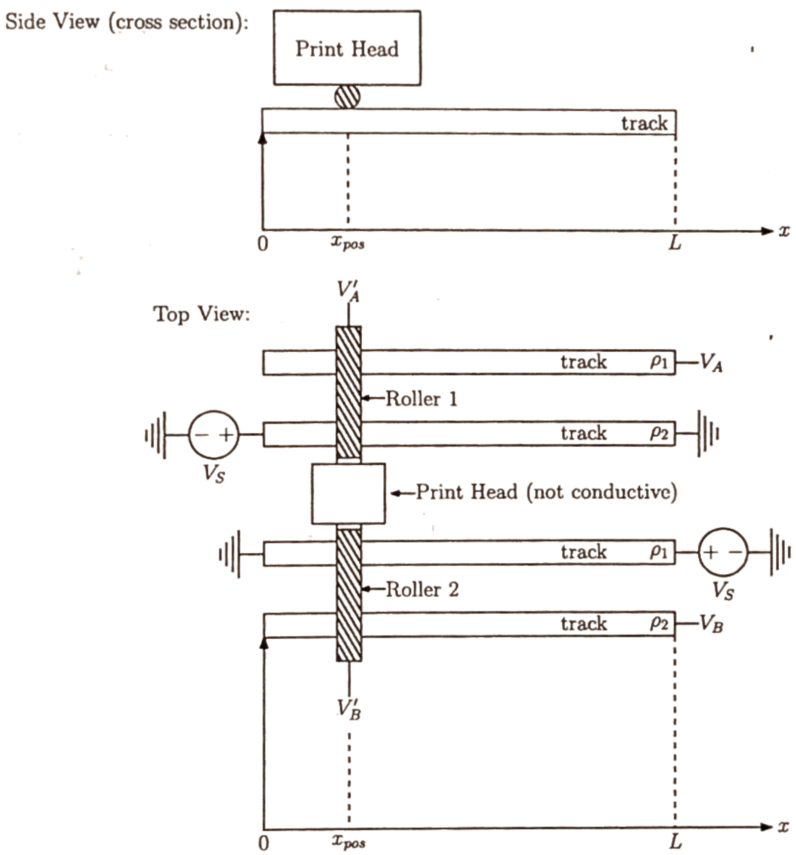

Figure 5.1: 3D printhead position sensor (top and side views)

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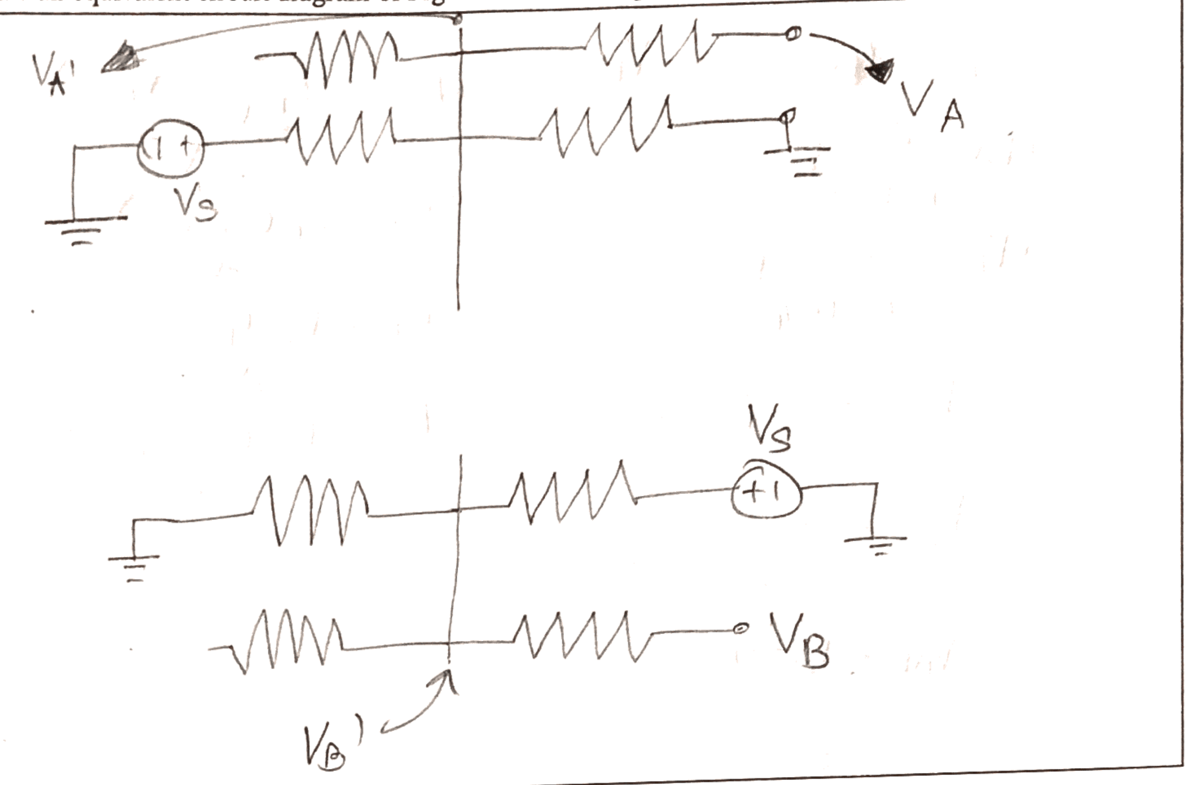
(a) Draw an equivalent circuit diagram of Figure 5.1 consisting of sources, resistors, etc.



(b) Derive algebraic expressions for $V_{AA'} = V_A - V_{A'}$ and $V_{BB'} = V_B - V_{B'}$ as a function of x_{pos}.

No current flows to R connected to VA since not connected to anything. Same for VA'. This is an open circuit

$\therefore V_{AA'} = V_A - V_{A'} = 0$

$V_{BB'} = V_B - V_{B'} = 0$

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(c) Find the value of voltage $V_{AB}(x_{pos}) = V_A - V_B$ for $V_s = 10\text{V}$, $\rho_1 = 1\,\Omega\text{m}$, $\rho_2 = 2\,\Omega\text{m}$, $L = 200\text{mm}$, $A = 1\text{cm}^2$, and $x_{pos} = 50\text{mm}$.

$V_{AB}(x_{pos}) = V_A - V_B$

- $V_A = \frac{R_1}{R_1+R_2} V_s$
- $V_B = \frac{R_3}{R_3+R_4} V_s$

- $R_3 = \frac{\rho_1 (L - x_{pos})}{A}$
- $R_4 = \frac{\rho_1 (x_{pos})}{A}$
- $R_1 = \frac{\rho_2 x_{pos}}{A}$
- $R_2 = \frac{\rho_2 (L - x_{pos})}{A}$

$\therefore V_A = \frac{L - x_{pos}}{L} V_s$

$\therefore V_B = \frac{x_{pos}}{L} V_s$

$$\therefore V_{AB} = V_A - V_B$$
$$= \frac{L - 2x_{pos}}{L} V_s$$
$$= \frac{(200\times10^{-3}) - 2(50\times10^{-3})}{(1\times10^{-2})} = \boxed{5V}$$

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6. **Current Sensor (19 points)**

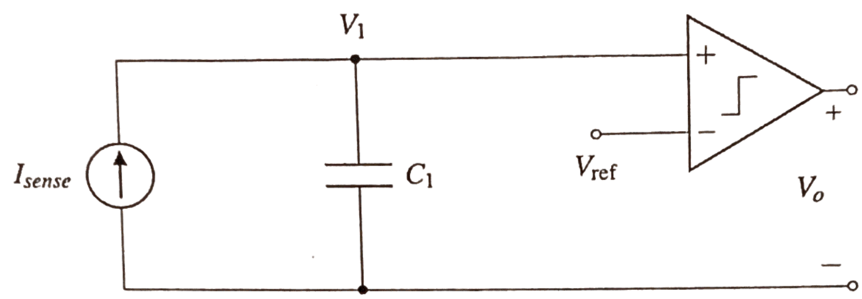

Figure 6.1: First version of the current sensor circuit

(a) You've built a light sensor that outputs a current I_{sense} that is proportional to light intensity. Now, you need a circuit that measures this current. Figure 6.1 shows the design of the first version of the current sensor circuit. At time $t = 0$ capacitor C_1 is discharged and a timer (stop watch) is started. When voltage V_1 reaches V_{ref} the comparator "trips" and stops the timer at T_1.

In the grids below, plot V_1 and V_o as a function of time t, from $t = 0$ to $t = 2T_1$.

Use $I_{sense} = 0.2\text{A}$, $C_1 = 1\text{F}$, and $V_{ref} = 0.2\text{V}$.

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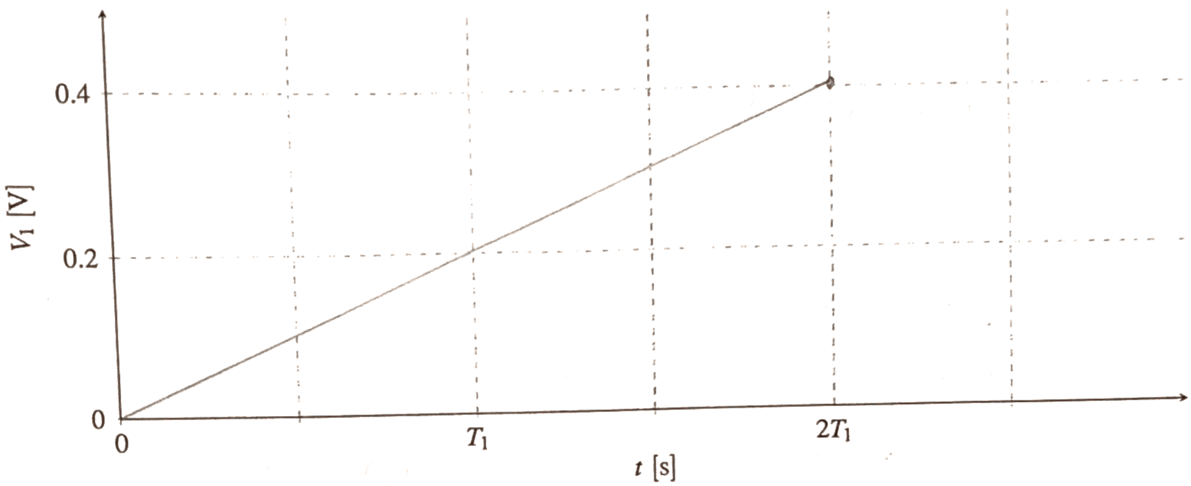

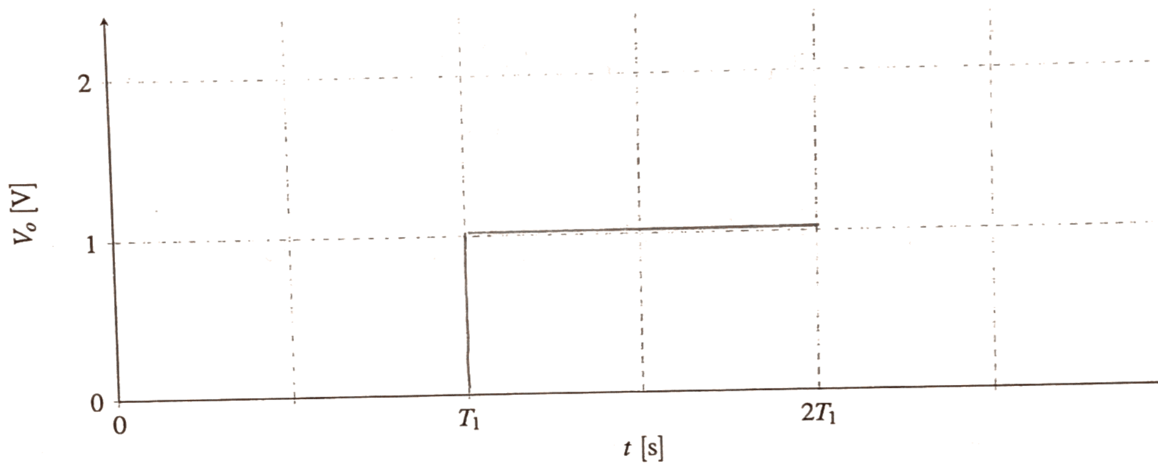

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(b) Derive an expression for the time T_1 measured by the timer as a function of I_{sense}, C_1, and V_{ref}. Then, calculate its numerical value using the same component values as given in part (a).

time: $(0, T_1)$

$$I_{sense} = \frac{c\, dV_c}{dt}$$

$$\int \frac{I_{sense}}{c} \cdot dt = \int_0^{V_c(t_1)} dV_c.$$

$$\frac{I_{sense} \cdot T_1}{c} = V_c(T_1) - 0$$

$$T_1 = \frac{V_c(T_1) \cdot c}{I_{sense}}$$

$$\therefore \; T_1 = \frac{V_{ref} \cdot c}{I_{sense}} = \boxed{1}$$

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(c) Figure 6.2 shows an improved current sensor that does not depend on the value of capacitor C_1.

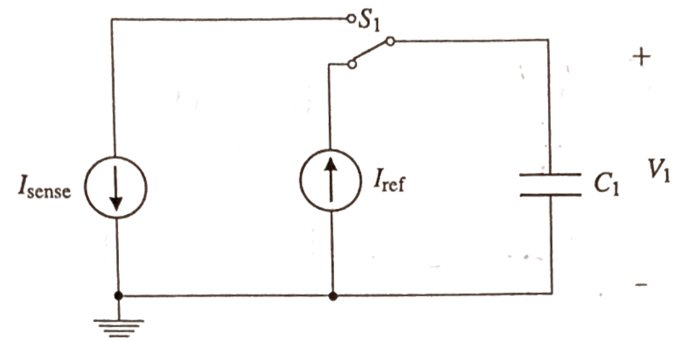
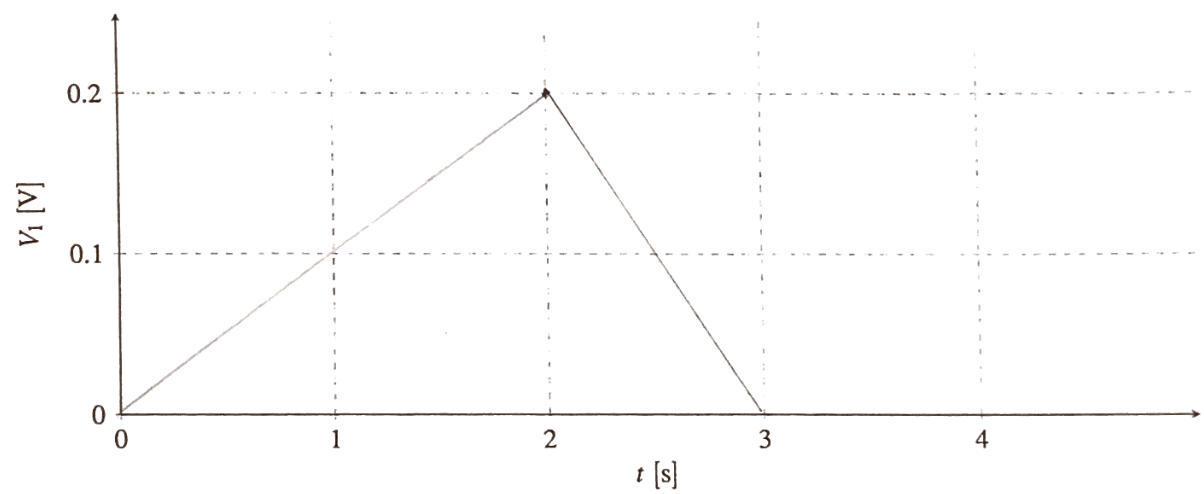


Figure 6.2: Improved Current Sensor

Capacitor C_1 is discharged at time $t = 0$ and switch S_1 is connected to I_{ref}. When V_1 reaches V_{ref} at time T_1, switch S_1 is disconnected from I_{ref} and connected to I_{sense} instead. T_2 is defined as the time from connecting S_1 to I_{sense} to the moment V_1 reaches 0V.

Plot V_1 versus time from $t = 0$ to $t = T_1 + T_2$.

Use $I_{sense} = 0.2\text{A}$, $C_1 = 1\text{F}$, $V_{ref} = 0.2\text{V}$ and $I_{ref} = 0.1\text{A}$.



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(d) Derive an expression for the ratio $\frac{T_1}{T_2}$ (the times calculated in part (c)) as a function of I_{sense}, C_1, and V_{ref}. Then, calculate its numerical value using the same component values as given in part (c).

$$T_1 = \frac{C_1 V_{ref}}{I_{ref}} \leftarrow \text{charging}$$

$$T_2 = \frac{C_1 V_{ref}}{I_{sense}} \leftarrow \text{Discharging}$$

$$\frac{T_1}{T_2} = \boxed{\frac{I_{sense}}{I_{ref}}}$$

$$= \boxed{2}$$

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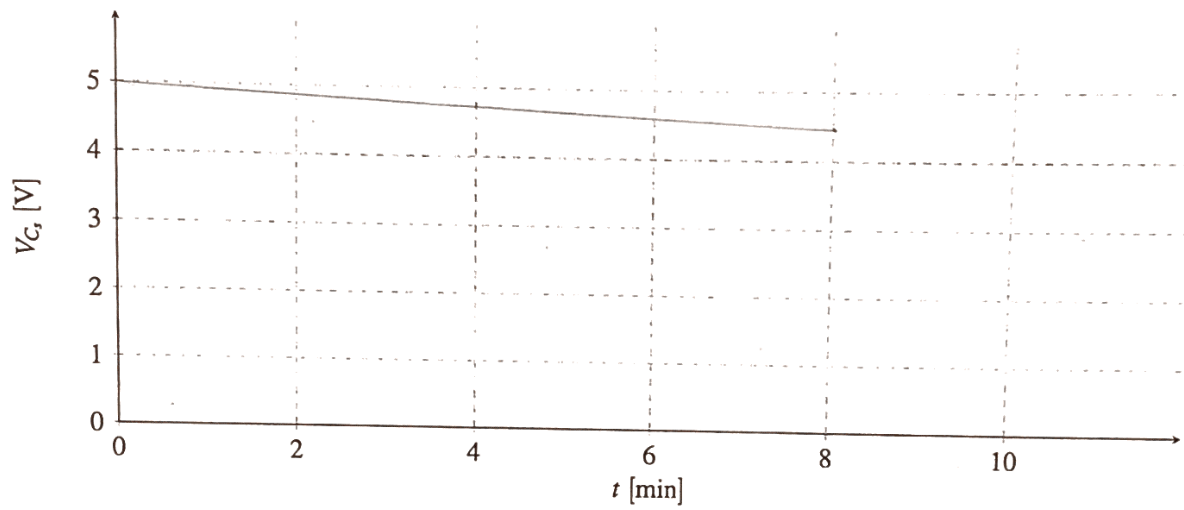
7. Capacitor Powered Quadcopter (15 points)

You've made a fun little quadcopter that juggles 10 colorful balls - all while flying in circles above the heads of its stunned audience that cannot get enough of the spectacle.

Unfortunately it takes quite a bit of time to recharge the battery after each demonstration. To shorten the time you decide to replace the battery with a capacitor C_s which can be charged virtually instantaneously.

The drone consumes a constant current $I_d = 0.5\text{A}$. The nominal supply voltage of the drone is $V_{nom} = 5\text{V}$, but it works with voltages as low as $V_{min} = 4\text{V}$ (i.e. when the capacitor voltage drops below 4V the drone crashes).

(a) Plot the voltage across the capacitor V_{C_s} as a function of time from 0 to 10 minutes in the graph space provided to you below. Use $C_s = 600\text{F}$.



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(b) Calculate the minimum value of the capacitor C_s required to support 10 minutes of flying time.

$$I_d = C_s \frac{dV_o}{dt} = C_s \frac{\Delta V}{\Delta t}$$

$$\therefore \Delta t = C_s \frac{\Delta V}{I_d}$$

$$= \frac{C_s (V_{nom} - V_{min})}{I_d}$$

$$\therefore 600 = \frac{(C_s)(5-4)}{0.5}$$

$$\therefore C_s = \underline{300F}$$

(c) Regardless of your answer in (b), assume $C_s = 5$F. Calculate the ratio of the energy E_2 remaining in the capacitor at the end of the flight divided by the energy E_1 initially stored in the capacitor C_s when it is fully charged.

$$E = \frac{1}{2} CV^2$$

$$\frac{E_1}{E_2} = \frac{\frac{1}{2} C_s V_{min}^2}{\frac{1}{2} C_s V_{nom}^2} = \frac{16}{25} = \underline{0.64}$$

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8. Fun with charge sharing (19 points)

(a) In Figure 8.1, capacitors C_1 and C_2 are charged to V_1 and V_2 and switch S_1 is open for time $t < 0$. At time $t = 0$, switch S_1 is closed. Calculate V_1 at time $t > 0$.

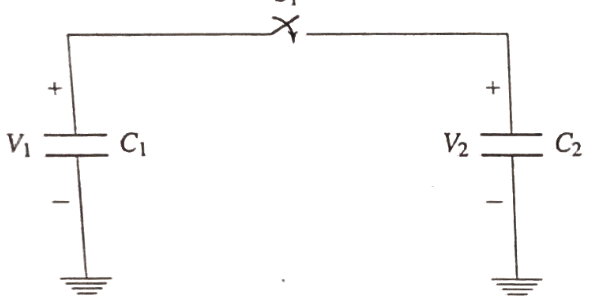

Figure 8.1: Capacitor Charge Sharing

Use the following values: $C_1 = 1\text{F}$, $C_2 = 4\text{F}$, $V_1 = 6\text{V}$, $V_2 = 1\text{V}$.

Phase Initial $\rightarrow$ $Q_{1i} = C_1V_1$

$Q_{2i} = C_2V_2$

Phase final $\rightarrow$ $Q_{\text{Total, final}} = Q_{1f} + Q_{2f}$.

$\therefore Q_{1f} + Q_{2f} = C_1V_1 + C_2V_2$.

$C_1V_{1f} + C_2V_{2f} = C_1V_1 + C_2V_2$

$V_1f = V_2f$

$\therefore C_1V_1f + C_2V_2f = C_1V_1 + C_2V_2$.

$\therefore V_1f = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2} = \dfrac{6+4}{5} = \underline{\underline{2\text{V}}}$.

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(b) The circuit shown in Figure 8.2 operates in two phases. During phase 1, switches labeled S_1 are closed and switches S_2 are open. During phase 2, switches S_1 are open and switches S_2 are closed, as illustrated in the timing diagram shown in Figure 8.3.

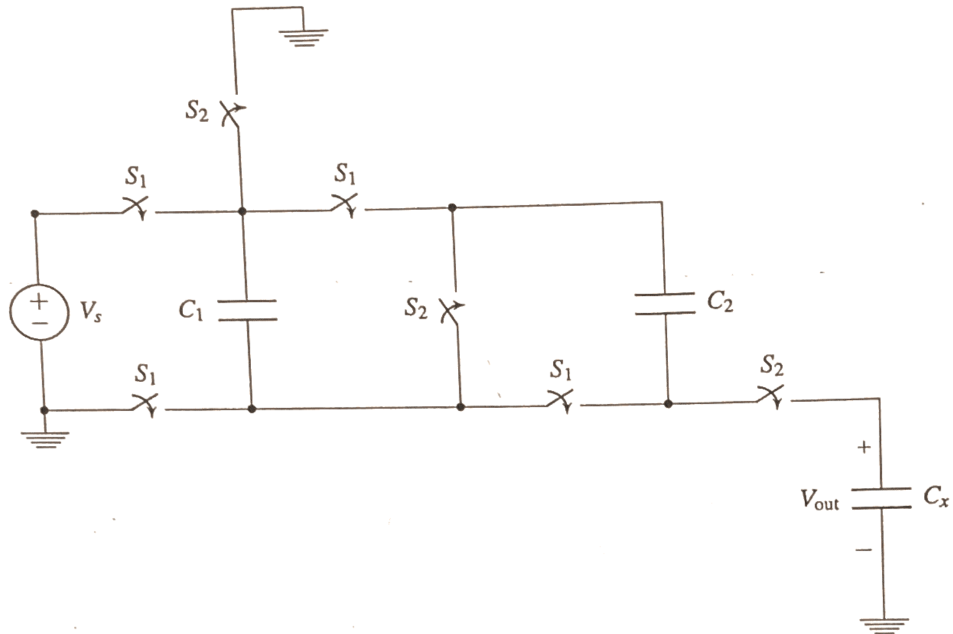

Figure 8.2: Capacitor Charge Sharing

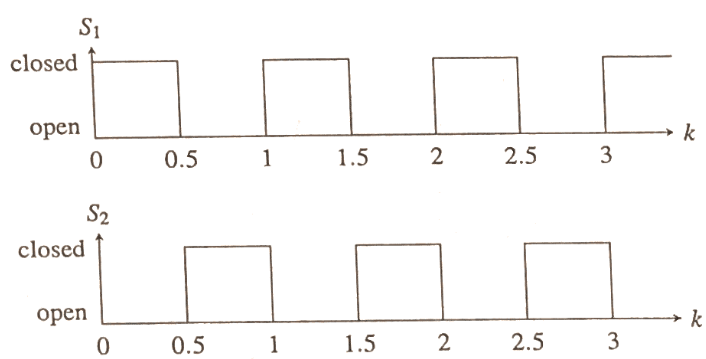

Figure 8.3: Timing diagram for switches

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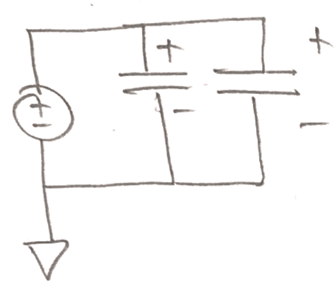
i. Redraw the circuit during phase 1. Replace closed switches with "wires" and open switches with "open circuits" (i.e. just omit them from the diagram). Use $C_1 = C_2 = C_0$.

Phase 1



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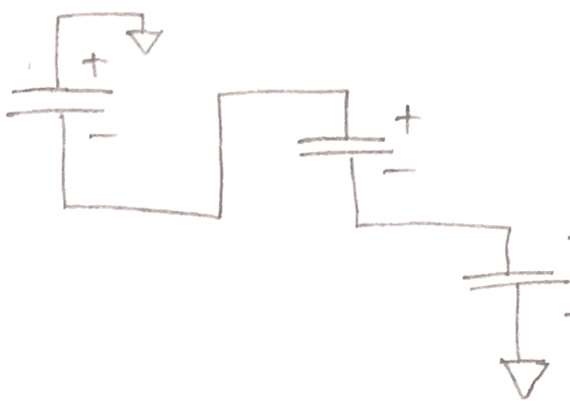
ii. Redraw the circuit during phase 2. Replace closed switches with "wires" and open switches with "open circuits" (i.e. just omit them from the diagram). Use $C_1 = C_2 = C_0$.

Phase 2



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iii. Calculate the value of the voltage V_{out} during phase 2 as a function of C_0, C_x, and V_s.

$Q_{c_1 i} = C_1 V_1$

$Q_{c_2 i} = C_2 V_s.$

$Q_{total 1} = C_2 V_s - C_1 V_s$

$Q_{total 2} = -C_2 V_s$

$\therefore V_{out} = \dfrac{-2C_1C_2V_s}{C_1C_x + C_1C_2 + C_2C_x} = \dfrac{-2V_s}{1 + \frac{2C_x}{C_o}}.$

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