

MAE140 – Linear Circuits – Fall – 2018
Final, December 11th

Instructions

1. This exam is open book. You may use whatever written materials you choose, including your class notes and textbook. You may use a handheld calculator with no communication capabilities.
2. You have 170 minutes.
3. Do not forget to write your name and student number.
4. This exam has 6 questions, for a total of 60 points and 2 bonus points.

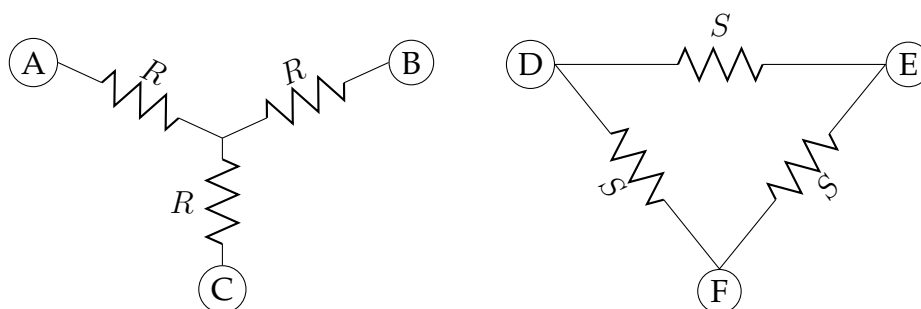


Figure 1: Circuits for Question 1

1. Circuit Equivalence

Consider the circuits in Fig. 1 and answer the following questions:

- (a) (3 points) Calculate the equivalent resistance as seen from (A) and (B), (A) and (C), and (B) and (C).
- (b) (3 points) Calculate the equivalent resistance as seen from (D) and (E), (D) and (F), and (E) and (F).
- (c) (3 points) Calculate a formula for S as a function of R so that both circuits are completely equivalent.
- (d) (1 point) Explain what would change in the formula you obtained in part (c) if the resistances R and S were replaced by impedances in the s -domain.

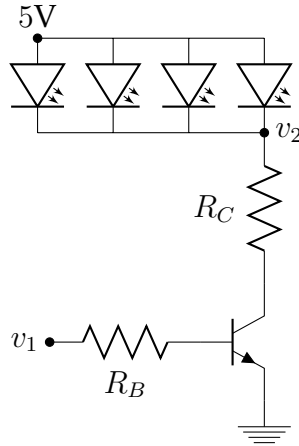


Figure 2: Circuit for Question 2

2. LED Driver

A student needs to drive four LEDs using the digital output of a microcontroller. Each LED is rated at 1.2 V and 30 mA. Because the microcontroller output pin can output a maximum of 20mA, the student needs to construct the circuit in Fig. 2 to drive the required 4×30 mA. Answer the following questions to help him or her select appropriate values for the resistors R_B and R_C .

- (4 points) Assume that the BJT transistor is saturated and calculate the value of R_C so that each LED has a voltage drop of 1.2 V with a current of 30 mA. Calculate the corresponding value of v_2 and the power absorbed by the resistor R_C .
- (4 points) Let $v_\gamma = 0.6$ V, a transistor current gain $\beta = 100$, and calculate the value of R_B so that when $v_1 = 5$ V and each LED is operating at their rated voltage and current the transistor is saturated. Calculate the current through R_B and the power it absorbs.
- (2 points) Explain how the circuit you helped design works as v_1 takes the values $v_1 = 0$ V and $v_1 = 5$ V. Does it keep the microcontroller output pin current below 20 mA?

3. OpAmp Design

In this question you will design an opAmp circuit to realize the transfer-function:

$$T(s) = \frac{10(s + 1,000)}{s^2 + 10,010s + 100,000}$$

- (3 points) Calculate positive real numbers α and β so that

$$T(s) = \frac{\alpha}{s + 10} + \frac{\beta}{s + 10,000}$$

- (7 points) Design a circuit using opAmps that implements $T(s)$ as the sum of the two transfer-functions from part (a).

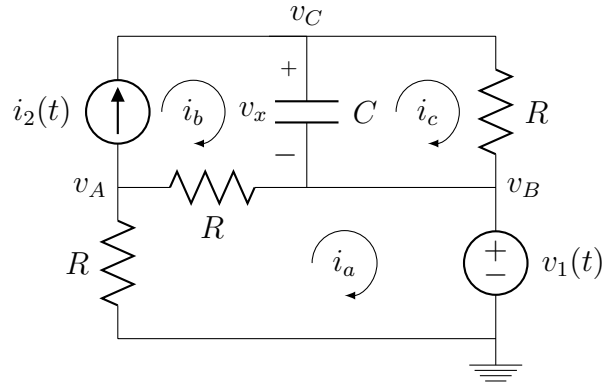


Figure 3: Circuit for Question 4

4. Circuit Analysis

Let $v_x(0) = 1$ V and answer the following questions:

- (4 points) Convert the circuit in Fig. 3 to the s -domain and formulate its node-voltage equations. Use the node-voltage and labels provided in the figure and clearly indicate the final equations and circuit variable unknowns. Make sure your final equations only involve node-voltages.
- (4 points) Convert the circuit in Fig. 3 to the s -domain and formulate its mesh-current equations. Use the mesh-currents and labels provided in the figure and clearly indicate the final equations and circuit variable unknowns. Make sure your final equations only involve mesh-currents.
- (2 points) Write s -domain expressions for the current through the voltage source v_1 and the voltage across the current source i_2 in terms of the node voltages and mesh currents from parts (a) and (b).

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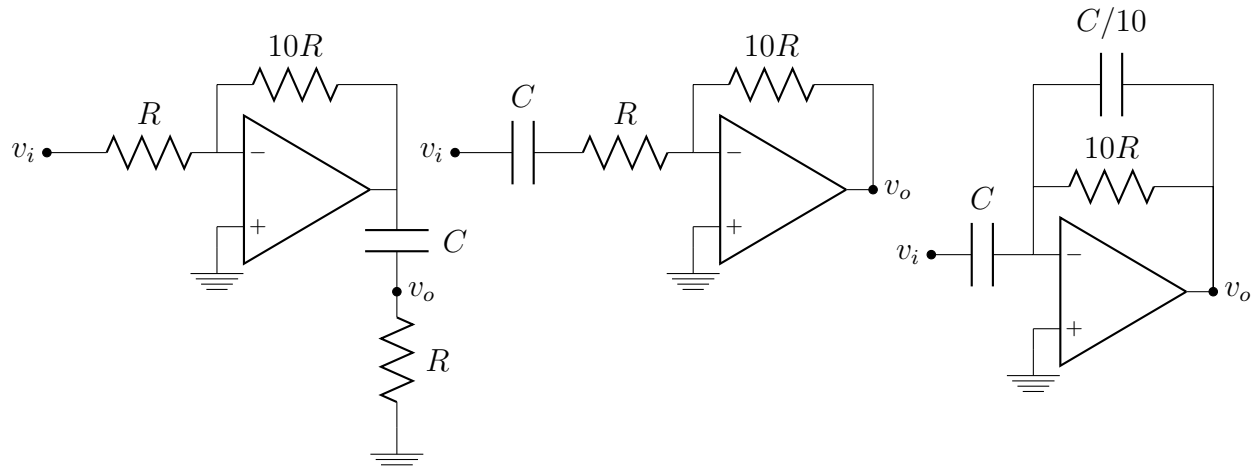


Figure 4: Circuits for Questions (5) and (6)

5. OpAmp Circuit Analysis

Assume zero initial-conditions for the circuits in Fig. 4 and answer the questions:

- (a) (7 points) Convert the three circuits into the s -domain and show that they have identical transfer-functions

$$\frac{V_o(s)}{V_i(s)} = \frac{-10s}{s + \frac{1}{RC}}.$$

- (b) (3 points) Let $v_i(t) = V_s u(t)$ and calculate the response $v_o(t)$.

6. Frequency Response

Consider the circuits in Fig. 4 and answer the following questions:

- (a) (3 points) Calculate the magnitude and phase of the circuits' frequency response at $\omega = 0$, $\omega = (RC)^{-1}$, and $\omega \rightarrow \infty$.
- (b) (4 points) Sketch the magnitude and phase of the circuits' frequency response. What kind of filter is the circuit?
- (c) (3 points) Calculate the steady-state response $v_o^{ss}(t)$ produced in response to an input voltage $v_i(t) = 1 + \cos((RC)^{-1}t)$.
- (d) (2 points (bonus)) Which of the circuits has a problem with saturation? Explain.

Have a great Winter break!