**IMPORTANT: Assume all circuit elements are ideal. Unless otherwise specified, all answers must be correct to four decimal places. All answers must be with proper units.**

**Question 1.** (10 points) Evaluate the expressions below. (2 points each). You must answer with the simplest and most proper unit for each expression.

**a)** (5 mA) / (4 V)

**b)** Im[ $(4\angle 30^\circ\ V_{rms})^2 / (3\angle 120^\circ\ \Omega)$ ]

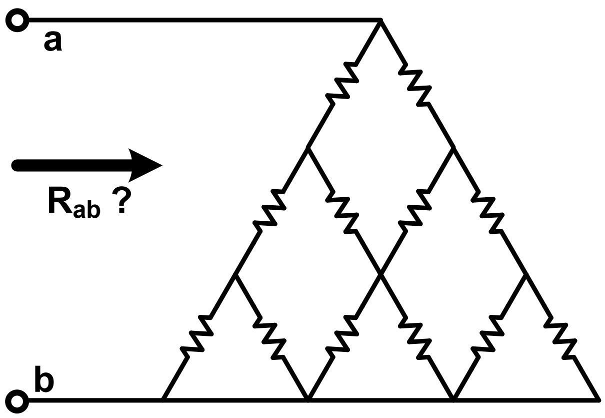
**c)** [ (50 μH) × (20 nF) ]$^{1/2}$

**d)** $(3\ mV)^2$ × (5 mF)

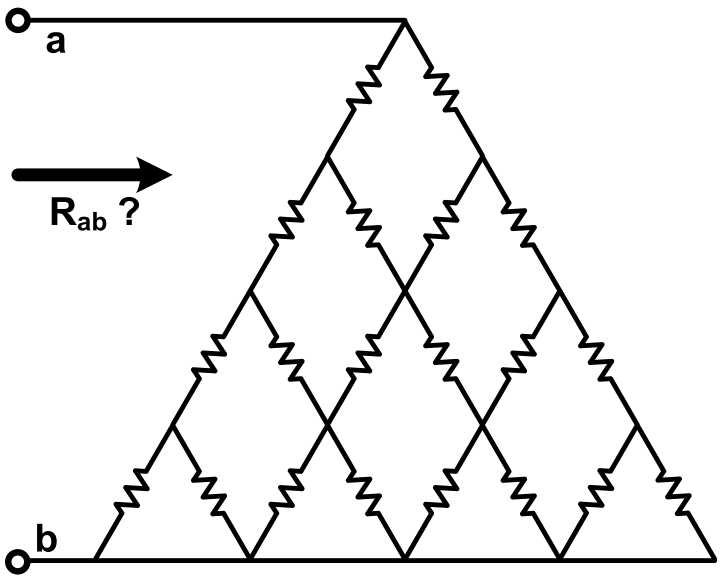
**e)** (10 kΩ) / (5 μH)

**Question 2.** (10 points) Find the equivalent resistance of each circuit. Every resistor in the circuits has a resistance of 1 kΩ.

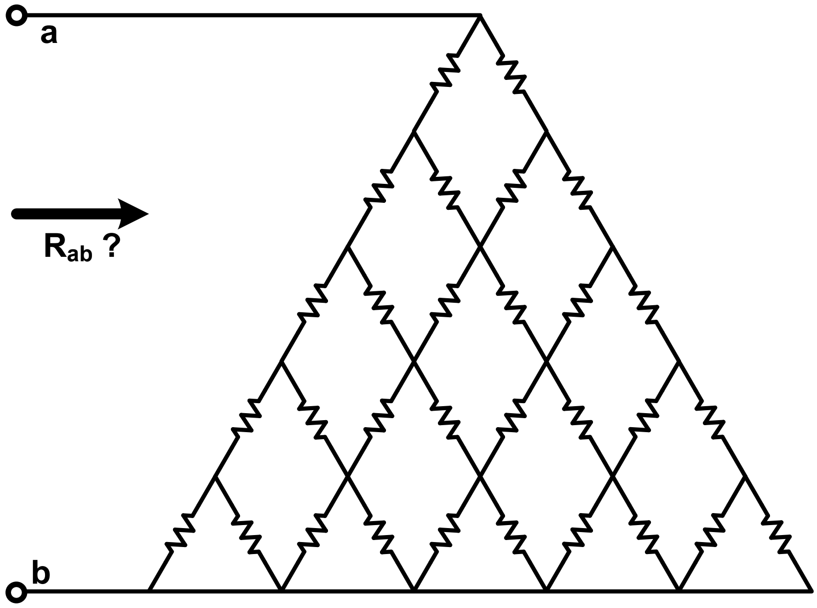
**a)** (2 points)




**b)** (3 points)

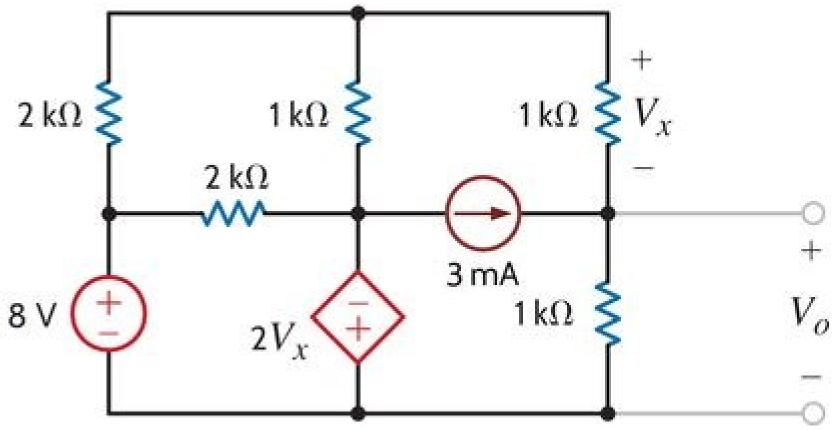


**c)** (5 points)

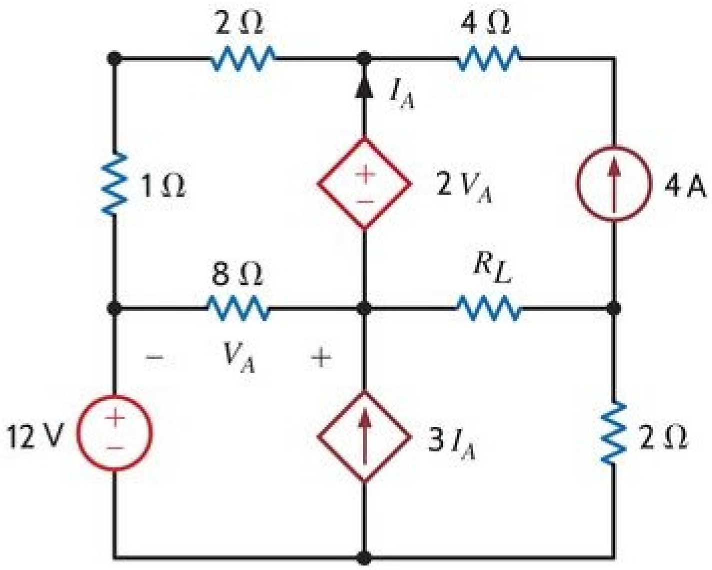



**Question 3.** (10 points) Analyze the circuits below and answer the questions.

**a)** Find $V_O$ in the circuit below.

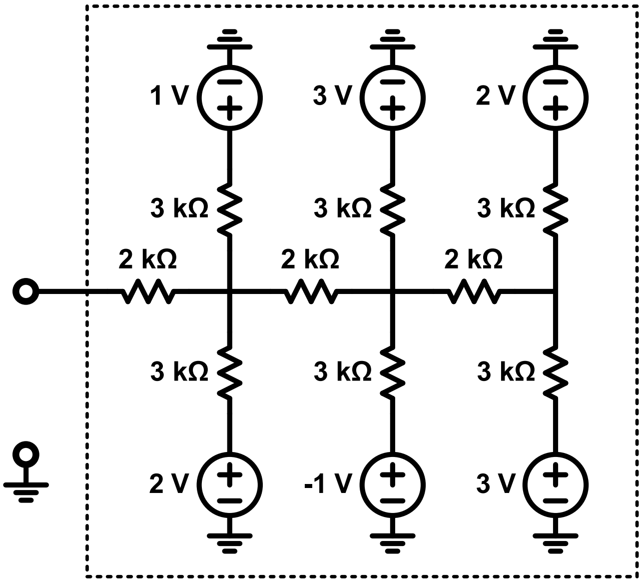



**b)** Find $R_L$ for maximum power transfer and the maximum power dissipated in $R_L$.

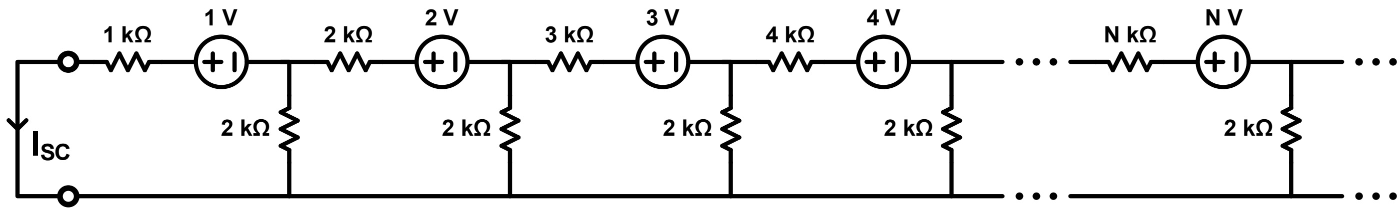


**Question 4.** (10 points)

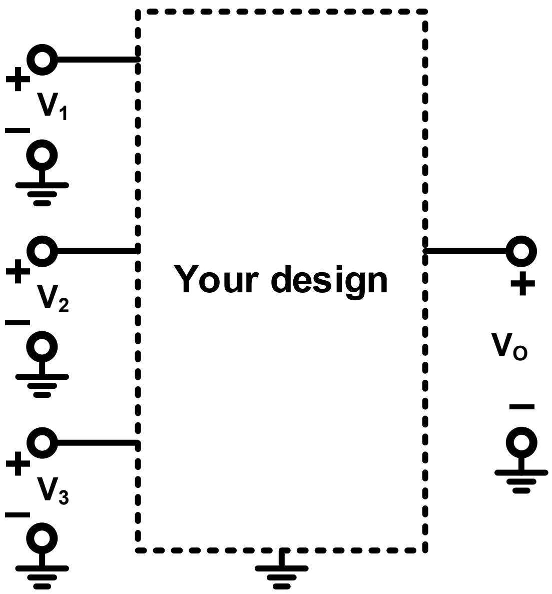
**a)** (4 points) Find the Thevenin equivalent circuit of the circuit below (answer must include open circuit voltage and Thevenin equivalent resistance).



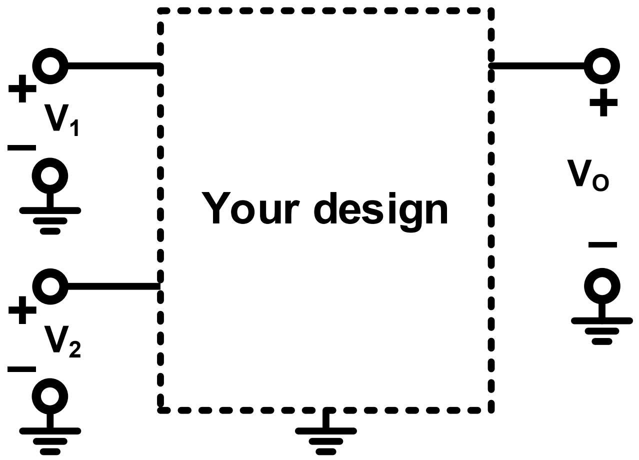

**b)** (6 points) Find the short circuit current ($I_{SC}$) of the circuit below.



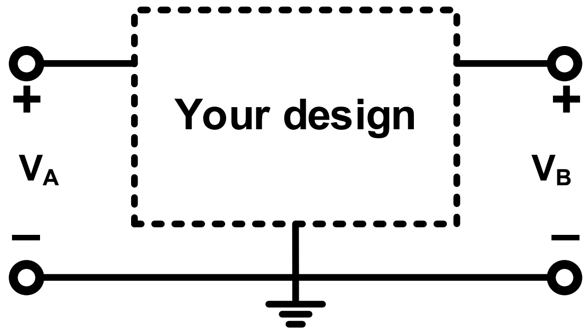

**Question 5.** (10 points) Design an op-amp circuit such that $V_o = V_1 + 2V_2 + 3V_3 - 4\frac{d}{dt}V_1$. Use op-amps, resistors, capacitors, and inductors only. **Do not** use more than 2 op-amps, and only designs with one op-amp can get full points. (You can get max. 5 points with a design with 2 op-amps)



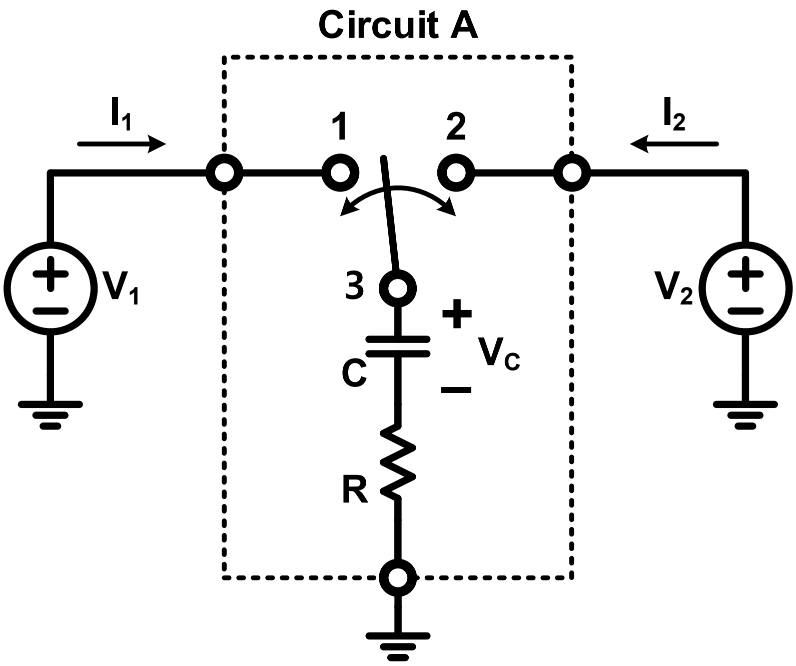
**Question 6.** (7 points) Prove or disprove: Can we design an op-amp circuit such that $V_o = V_1 \times V_2$, using op-amps, resistors, capacitors, and inductors only? Assume all elements are ideal.




**Question 7.** (5 points) By using resistors, capacitors, and inductors only, design a circuit that acts as a low-pass filter if $V_A$ is input and $V_B$ is output, and acts as a band-pass filter if $V_B$ is input and $V_A$ is output.




**Question 8.** (15 points) The switch in the circuit below switches between the terminal 1 and 2 by a time period T. At t = 0, the switch changes the connection to connect terminals 1 and 3, and at t = T/2, the switch changes the connection to connect terminals 2 and 3.



Suppose $V_1$ and $V_2$ are DC voltage sources for **a)** – **c)**. Assume the circuit is in a periodic steady-state (all voltages and currents in the circuit are periodic with period T).

**a)** (3 points) Find the expression of $V_C$ (voltage across $C_1$) for $0 \le t \le T$, and its rms value.

**b)** (3 points) Find the expression of $I_1$ and $I_2$ for $0 \le t \le T$, and their rms values.

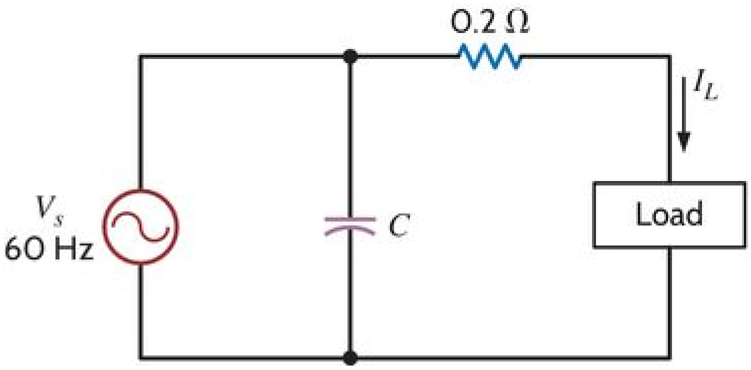
**c)** (3 points) Find the expression of the average value of $I_1$, and describe how this expression can be approximated in two extreme cases, one where $T \ll RC$ and the other where $T \gg RC$.

Suppose $V_1$ and $V_2$ are AC voltage sources with angular frequency $\omega$ for **d)** and **e)**.

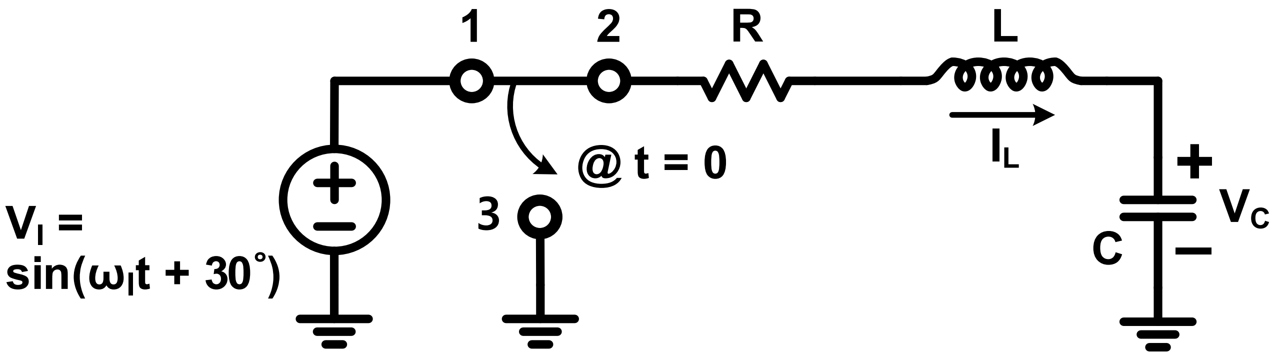
**d)** (3 points) As $T \to 0$, the behavior of Circuit A converges to the behavior of a circuit without a switch. Find this circuit and justify your answer. (Hint: analyze DC and low-frequency responses assuming $T \ll RC$ and $\omega T \ll 1$.)

**e)** (3 points) Suppose R = 10 kΩ, C = 10 nF, and $V_2$ = 0. Using the switch-less circuit found in **d)**, find the transfer function $\boldsymbol{G}(\omega) = \boldsymbol{V_C}/\boldsymbol{V_1}$ and draw the Bode plot of it. Mark the position of all poles and zeros in the plot.

**Question 9.** The load in the circuit below draws 12kVA at pf = 0.75 lagging. If $|I_L|$ = 60 $A_{rms}$, what must be the value of C to cause the source to operate at pf = 0.95 lagging?




**Question 10.** (10 points) Suppose the circuit below has been in a periodic steady-state before the switch changes connection at t = 0. Use $\omega_I$ = 1Mrad/s, R = 2 Ω, L = 10 μH, C = 25 nF)

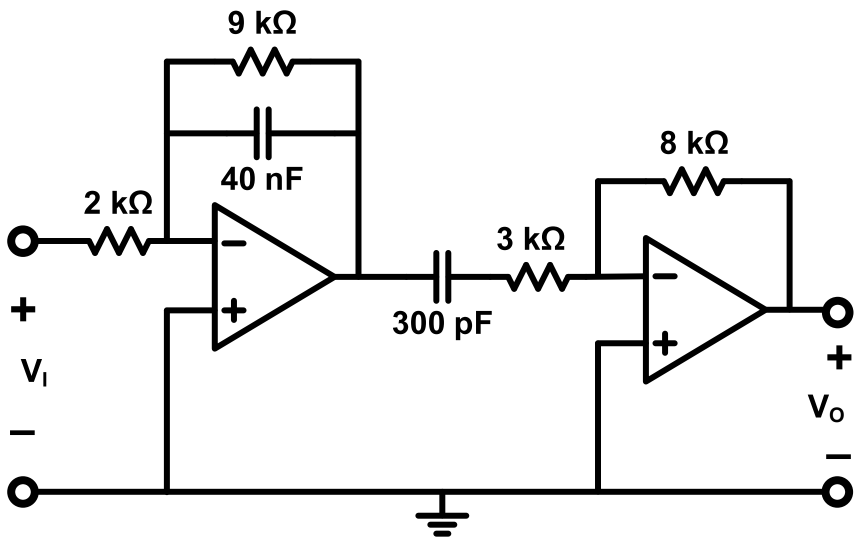



**a)** (3 points) Find the expressions of $I_L(t)$ and $V_C(t)$ for t < 0.

**b)** (4 points) Find the expressions of $I_L(t)$ and $V_C(t)$ for t > 0.

**c)** (3 points) Find the total energy stored in the capacitor and inductor at t = 0 and t = π μs.

**Question 11.** (8 points) For the circuit below,




**a)** (4 points) Find the transfer function $\boldsymbol{G}(\omega) = \boldsymbol{V_o}/\boldsymbol{V_I}$ and draw the Bode plot of it.

**b)** (4 points) Find the values of $\omega$ and $\boldsymbol{G}(\omega)$ where the magnitude of $\boldsymbol{G}(\omega)$ is maximized.