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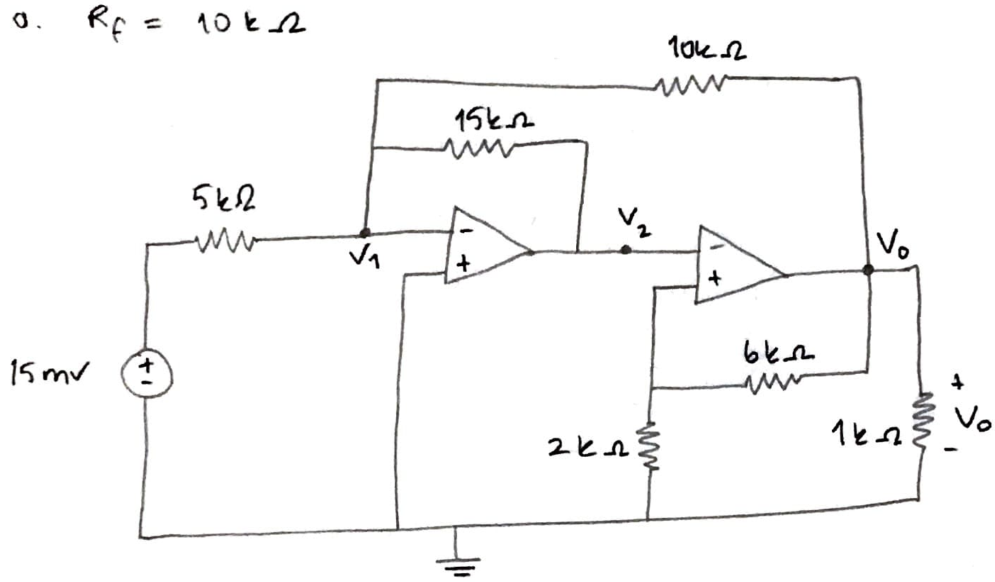
Q1. Calculate V_o in the op amp circuit of Figure 1 for given R_f values assuming all op amps are ideal. Also, obtain and show V_o using PSpice program.

a. $R_f = 10\,k\Omega$



KCL at Node 1:

$$\frac{15\,mV - V_1}{5\,k\Omega} = \frac{V_1 - V_2}{15\,k\Omega} + \frac{V_1 - V_o}{10\,k\Omega}$$

$\boxed{V_1 = V_o}$ (the other terminal of opamp is connected to the ground)

$$\frac{15 \cdot 10^{-3} - 0}{5 \cdot \cancel{10^3}} = \frac{0 - V_2}{15 \cdot \cancel{10^3}} + \frac{0 - V_o}{10 \cdot \cancel{10^3}}$$

$$\boxed{-3 \cdot 10^{-3} = \frac{V_2}{15} + \frac{V_o}{10}}$$

KCL at Node 2:

$$\frac{V_2}{2\,k\Omega} = \frac{V_o - V_2}{6\,k\Omega} \Rightarrow \boxed{4V_2 = V_o}$$

$$-3 \cdot 10^{-3} = \frac{V_2}{15} + \frac{4V_2}{10}$$

$$-90 \cdot 10^{-3} = 2V_2 + 12V_2$$

$$-90 \cdot 10^{-3} = 14V_2$$

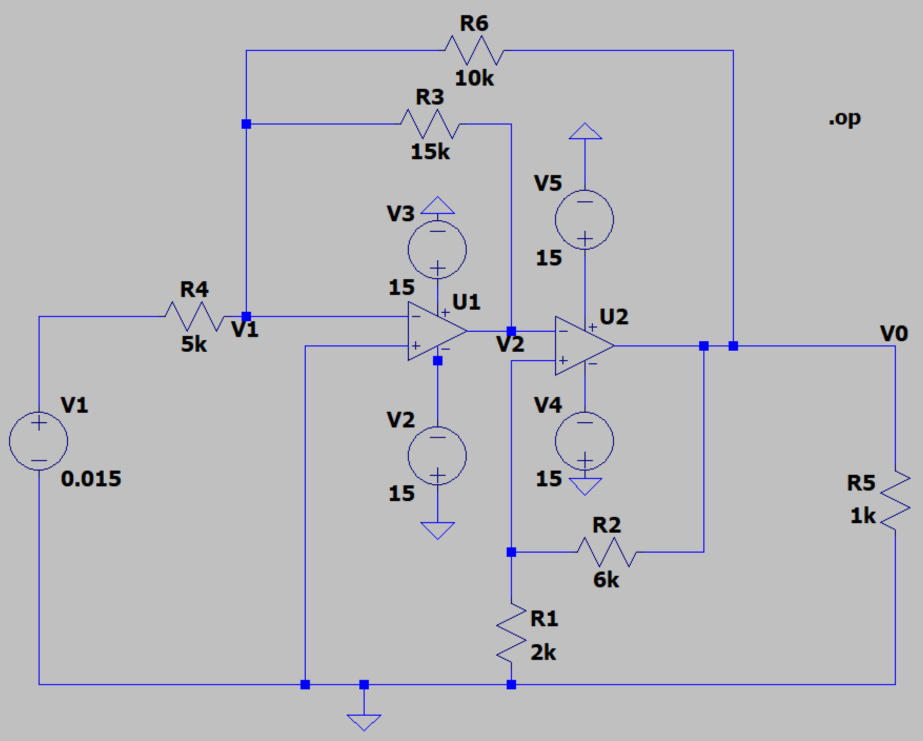
$$V_2 = -6{,}4285 \cdot 10^{-3} \;\checkmark$$

$$\boxed{V_2 = -6{,}4285\ mV}$$

$$V_o = 4V_2$$

$$\boxed{V_o = -25{,}714\ mV}$$

Q1-a simulation:



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--- Operating Point ---

V(n002):	0.015	voltage
V(v2):	-0.00642853	voltage
V(n001):	15	voltage
V(n004):	-15	voltage
V(v1):	6.44218e-009	voltage
V(v0):	-0.0257143	voltage
V(n003):	15	voltage
V(n006):	-15	voltage
V(n005):	-0.00642855	voltage
I(R6):	2.57143e-006	device_current
I(R5):	2.57143e-005	device_current
I(R4):	-3e-006	device_current
I(R3):	-4.28569e-007	device_current
I(R2):	-3.21429e-006	device_current
I(R1):	-3.21428e-006	device_current
I(V5):	-0.00148264	device_current
I(V4):	-0.00151414	device_current
I(V3):	-0.00149809	device_current
I(V2):	-0.00149852	device_current
I(V1):	-3e-006	device_current
Ix(u1:1):	0	subckt_current
Ix(u1:2):	1.28844e-017	subckt_current
Ix(u1:3):	0.00149809	subckt_current
Ix(u1:4):	-0.00149852	subckt_current
Ix(u1:5):	4.28582e-007	subckt_current
Ix(u2:1):	-1.28571e-011	subckt_current
Ix(u2:2):	-1.28571e-011	subckt_current
Ix(u2:3):	0.00148264	subckt_current
Ix(u2:4):	-0.00151414	subckt_current
Ix(u2:5):	3.15e-005	subckt_current

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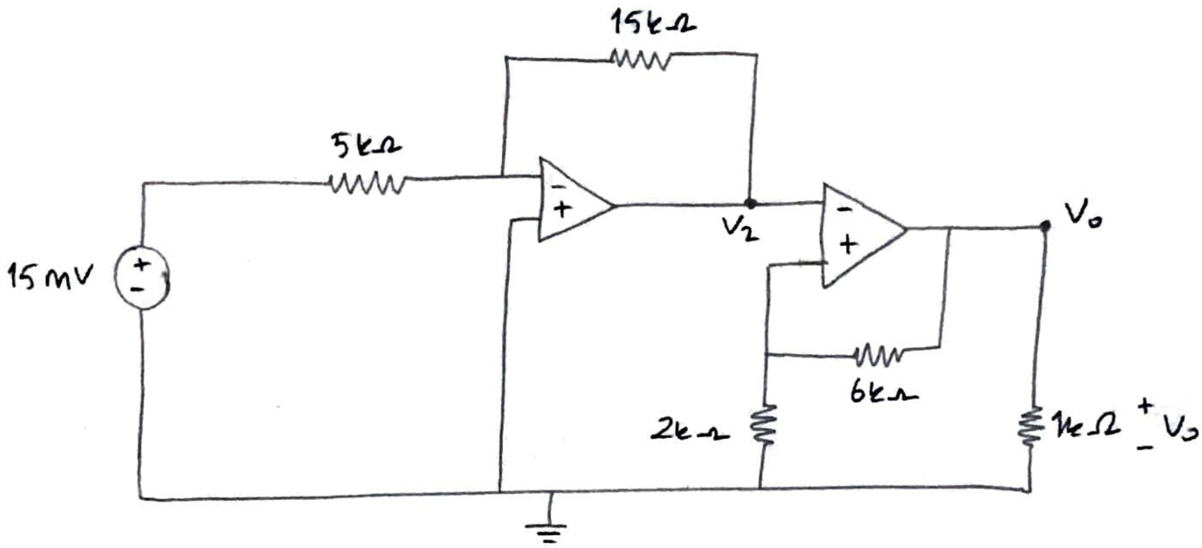
Q1.

b. $R_f = \infty\ k\Omega$ (open circuit)



KCL at Node 1:

$$\frac{15\ mV - 0}{5k\Omega} = \frac{0 - V_2}{15k\Omega}$$

$$45\ mV = -V_2$$

$$\boxed{V_2 = -45\ mV}$$

KCL at Node 2:

$$\frac{V_2 - 0}{2k\Omega} = \frac{V_o - V_2}{6k\Omega}$$

$$V_2 = \frac{V_o - V_2}{3}$$

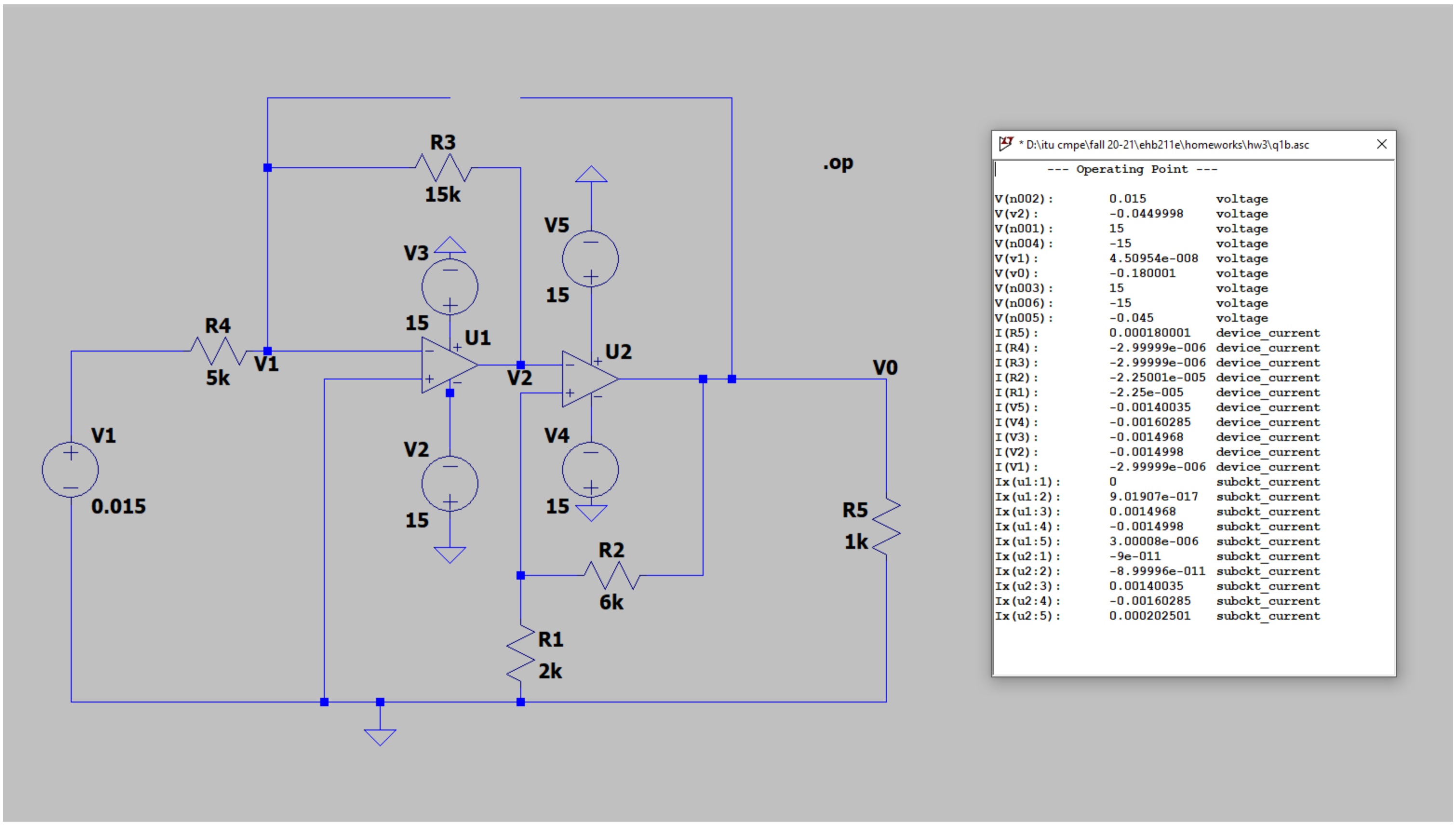
$$3V_2 = V_o - V_2$$

$$\boxed{4V_2 = V_o}$$

$$4 \cdot (-45)\ mV = V_o = -180\ mV$$

$$\boxed{V_o = -0{,}18\ V}$$

Q1-b simulation:



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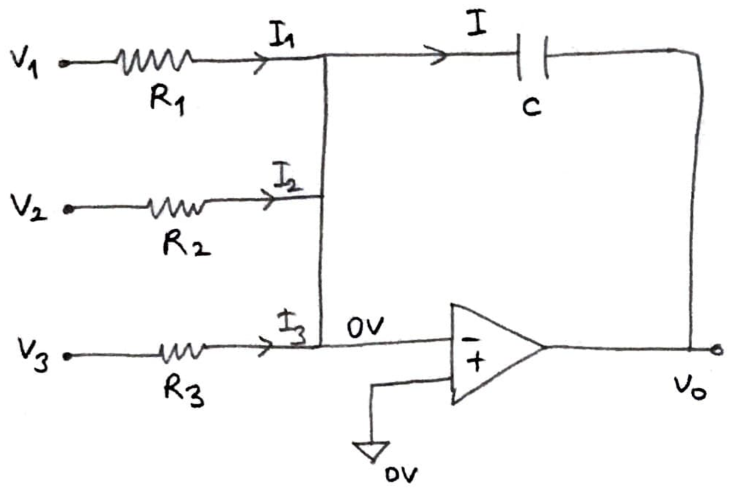
Q2. Design a single op amp circuit with $C = 2\mu F$ to generate the given function below by identifying other component values.

$$V_o = \int_0^t (V_1 + 4V_2 + 10V_3)\,dt$$



$$I_1 = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2}{R_2}$$

$$I_3 = \frac{V_3}{R_3}$$

$$I = I_1 + I_2 + I_3$$

$$V_o = -\frac{1}{C}\int_{-\infty}^{t} I\,dt$$

$$V_o = -\left[V_o(0^-) + \frac{1}{C}\int_0^t I\,dt\right] \quad , \quad V_o(0^-) = 0$$

$$V_o = -\int_0^t \left(\frac{V_1}{CR_1} + \frac{V_2}{CR_2} + \frac{V_3}{CR_3}\right)dt$$

$$\frac{1}{CR_1} = 1 \qquad R_1 = \frac{1}{1 \cdot C} = \frac{1}{2 \cdot 10^{-6}} = 50k\Omega$$

$$\frac{1}{CR_2} = 4 \qquad R_2 = \frac{1}{4 \cdot C} = \frac{1}{8 \cdot 10^{-6}} = 12{,}5\,k\Omega$$

$$\frac{1}{CR_3} = 10 \qquad R_3 = \frac{1}{10C} = \frac{1}{2 \cdot 10^{-5}} = 5k\Omega$$

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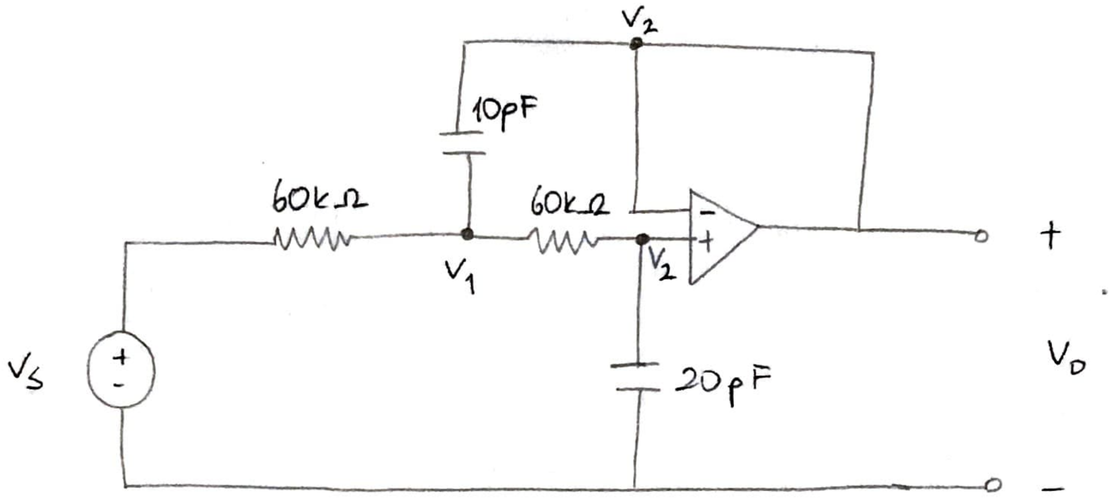
Q3. For the op amp circuit in the figure, obtain the differantial equations for $V_o(t)$.



KCL at Node 1:

$$\frac{V_s - V_1}{60k} = \frac{V_1 - V_2}{60k} + 10pF \frac{d}{dt}(V_1 - V_o) \quad , \quad \boxed{V_2 = V_o}$$

$$V_s = 2V_1 - V_o + 6 \cdot 10^{-7} \cdot \frac{d(V_1 - V_o)}{dt}$$

KCL at Node 2:

$$\frac{V_1 - V_2}{60k} = 20pF \frac{d(V_2 - 0)}{dt} \quad , \quad V_2 = V_o$$

$$V_1 = V_o + 1{,}2 \cdot 10^{-6} \frac{dV_o}{dt}$$

Applying (2) into (1):

$$V_s = 2\left(V_o + 1{,}2 \cdot 10^{-6} \frac{dV_o}{dt}\right) - V_o + 6 \cdot 10^{-7}\left(1{,}2 \cdot 10^{-6} \frac{d^2V_o}{dt^2}\right)$$

$$\Rightarrow \boxed{V_s = V_o + 2{,}4 \cdot 10^{-6}\left(\frac{dV_o}{dt}\right) + 7.2 \cdot 10^{-13}\left(\frac{d^2V_o}{dt^2}\right)}$$

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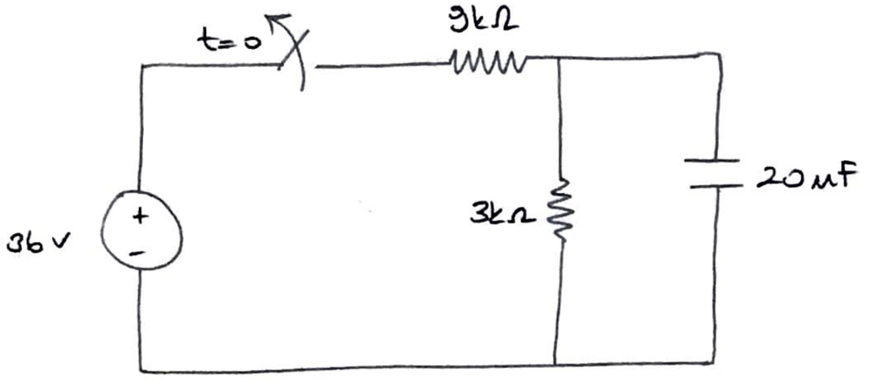
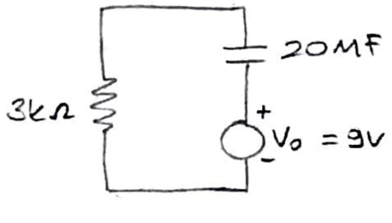
Qu. For the circuit in the figure find $V_o(t)$ for $t>0$, determine the time necessary for the capacitor voltage to decay to one - third of its value at $t=0$.



for $-\infty$ to 0^- the switch is closed. Capacitor fully charged and acts like open circuit. Voltage across the capacitor is equal to 3kΩ resistor.

$$V_o(0) = 36 \cdot \frac{3k}{3k+9k} = 9V$$

for $t>0$, switch is open



$V_o = 0$

$V(\infty) = 0$

$$V_o(t) = V_o(\infty) + [V_o(0^-) - V_o(\infty)] \cdot e^{-t/RC}$$

$$= 0 + (9V - 0) e^{-t/RC}$$

$$= 9 e^{-t/R \cdot C}$$, $R \cdot C = \frac{9}{4} \cdot 20MF = 45 \cdot 10^{-3}$

$$V_o(t) = 9 \cdot e^{-t/45 \cdot 10^{-3}}$$

$$\frac{1}{3} = 9 e^{-t/45 \cdot 10^{-3}} \Rightarrow \boxed{t = -45 \cdot 10^{-3} \cdot \ln(1/3)}$$