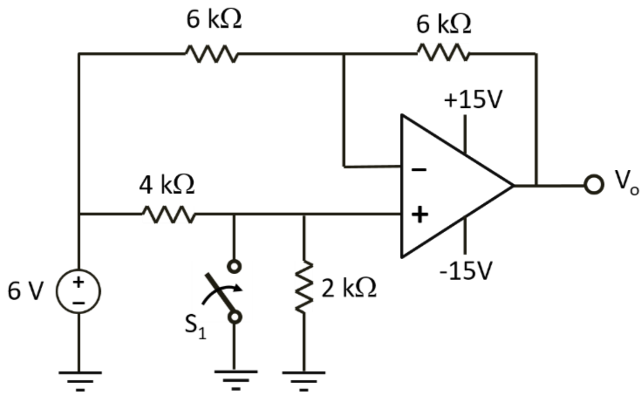
The Hong Kong University of Science and Technology
Department of Electronic and Computer Engineering

ELEC2400 **ELECTRONIC CIRCUITS** FALL 2021-22

HOMEWORK 3 SOLUTION

Q1. Assuming ideal op amp, find the voltage V_o, (a) when the switch, S_1, is open, and (b) when S_1 is closed.



(a) With S_1 open, assume op amp not saturated,

$$V_+ = 6\left(\frac{2\text{k}}{4\text{k} + 2\text{k}}\right) = 2\text{ V} = V_-$$

Apply KCL at V_- ,

$$\frac{V_o - V_-}{6\text{k}} = \frac{V_- - 6}{6\text{k}}$$

$$V_o = 2V_- - 6 = 4 - 6 = -2\text{ V}$$

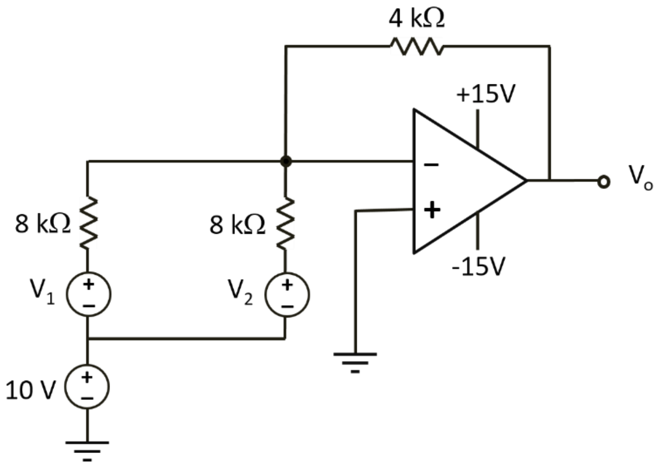
(b) With S_1 closed, assume op amp not saturated,

$$V_+ = 0\text{ V} = V_-$$

This time,

$$V_o = 2V_- - 6 = 0 - 6 = -6\text{ V}$$

Q2. Assuming ideal op amp,
(a) Find the expression for V_o as a function of V_1 and V_2.
(b) Find V_o when $V_1 = 4$ V, $V_2 = 4$ V.
(c) Find V_o when $V_1 = 4$ V, $V_2 = 8$ V.



(a) Assume op amp not saturated,

$$V_- = V_+ = 0\text{ V}$$

Apply KCL at V_- ,

$$\frac{V_o - V_-}{4\text{k}} = \frac{V_- - V_1 - 10}{8\text{k}} + \frac{V_- - V_2 - 10}{8\text{k}}$$

$$2V_o = -(V_1 + V_2 + 20)$$

$$V_o = -\frac{V_1 + V_2}{2} - 10$$

(b)

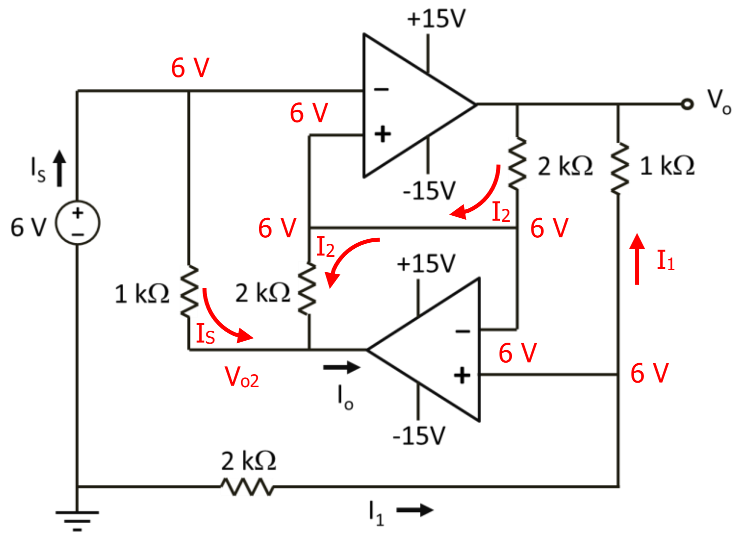
$$V_o = -\frac{4+4}{2} - 10 = -14\text{ V}$$

(c)

$$V_o = -\frac{4+8}{2} - 10 = -16\text{ V}$$

However, this is lower than the –15-V power supply. In reality, the op amp will be saturated around –15 V.

Q3. Find I_1, I_S, I_o and V_o assuming ideal op amps.



Assume op amps not saturated, their inputs are all at 6 V. Furthermore, the op amps take no input currents. We start by marking all the known voltages and main current flows in the circuit diagram above.

Notice that I_1 can be computed by the voltage across the bottom 2-kΩ resistor as follows

$$I_1 = -\frac{6}{2\text{k}} = -3 \text{ mA}$$

Next,

$$V_o = -I_1(2\text{k} + 1\text{k}) = 9 \text{ V}$$

From which

$$I_2 = \frac{V_o - 6}{2\text{k}} = 1.5 \text{ mA}$$

Hence,

$$V_{o2} = 6 - I_2 \times 2\text{k} = 3 \text{ V}$$

Therefore,

$$I_S = \frac{6 - V_{o2}}{1\text{k}} = 3 \text{ mA}$$

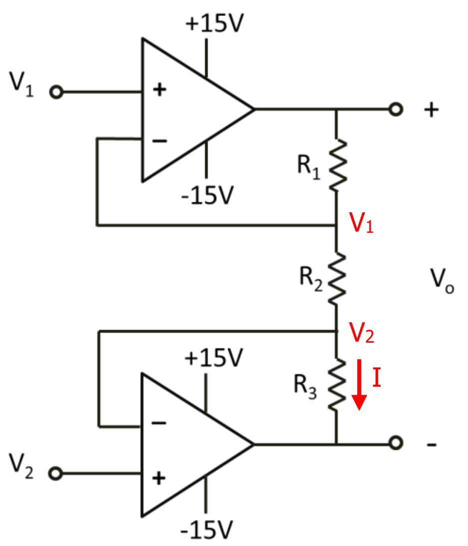
Finally,

$$I_o = I_S + I_2 = 4.5 \text{ mA}$$

Q4. Assuming ideal op amps,

(a) Find the expression for V_o as a function of V_1 and V_2.

(b) Find V_o when $V_1 = 3$ V, $V_2 = 4$ V, $R_1 = R_2 = R_3 = 1$ kΩ.



(a) We start by marking all the known voltages and the main current flow in the circuit diagram above. Assume op amps not saturated.

Note that

$$I = \frac{V_1 - V_2}{R_2}$$

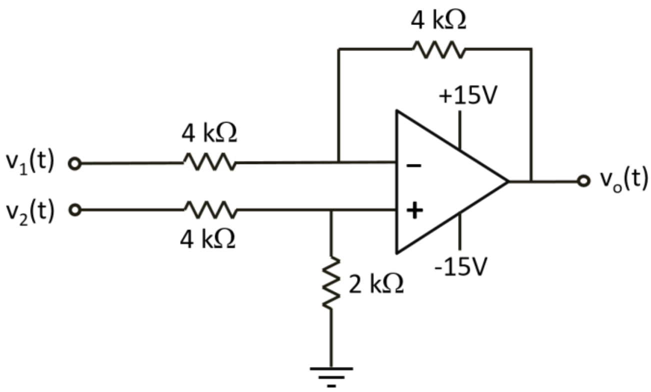
Therefore,

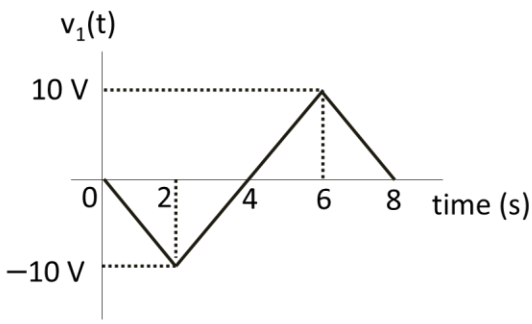
$$V_o = I(R_1 + R_2 + R_3) = \left(\frac{R_1 + R_2 + R_3}{R_2}\right)(V_1 - V_2)$$

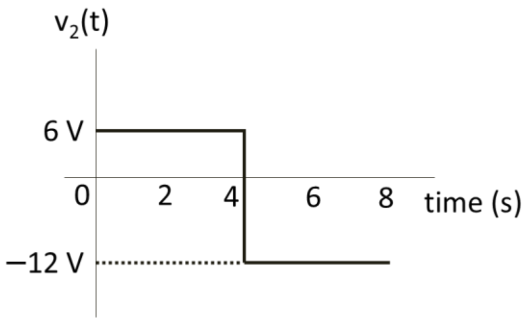
(b) When $V_1 = 3$ V, $V_2 = 4$ V, $R_1 = R_2 = R_3 = 1$ kΩ,

$$V_o = \left(\frac{1\text{k} + 1\text{k} + 1\text{k}}{1\text{k}}\right)(3 - 4) = -3 \text{ V}$$

Q5. Plot the waveform of $v_o(t)$ assuming ideal op amp.







Assume op amp not saturated,

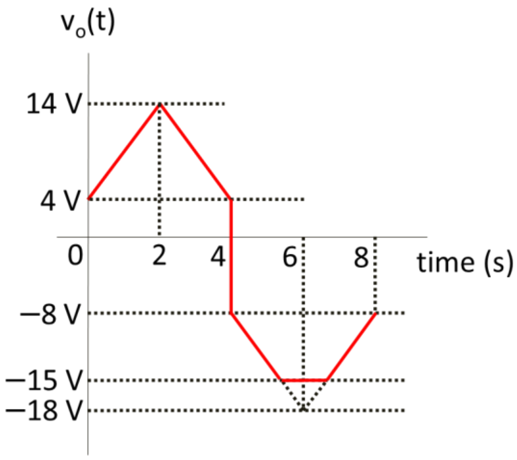
$$v_+ = \left(\frac{2\text{k}}{4\text{k} + 2\text{k}}\right)v_2 = \frac{v_2}{3} = v_-$$

Apply KCL to node v_-,

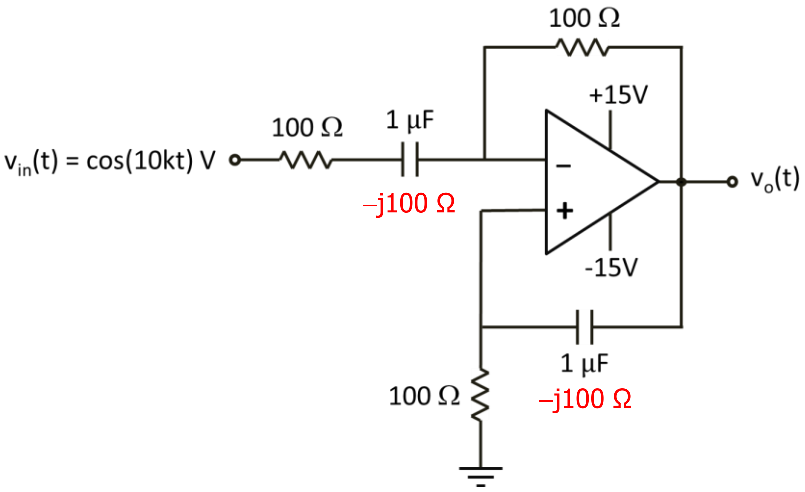
$$\frac{v_o - v_-}{4\text{k}} = \frac{v_- - v_1}{4\text{k}}$$

$$v_o = 2v_- - v_1 = \frac{2v_2}{3} - v_1$$

The $v_o(t)$ waveform is plotted below. Notice that the op amp reaches saturation and $v_o(t)$ is railed at around –15 V during part of the second phase.



Q6. Assuming ideal op amp, find $v_o(t)$.



At $\omega = 10\text{k rad/s}$, the impedance of the capacitors $= \frac{1}{j10\text{k}\times 1\mu} = -j100\ \Omega$.

The bottom resistor and capacitor form a voltage divider. Assume op amp not saturated,

$$V_+ = \left(\frac{100}{100 - j100}\right) V_o = \left(\frac{1}{1-j}\right) V_o = \left(\frac{1+j}{2}\right) V_o = V_- \qquad (1)$$

Apply KCL to node V_-,

$$\frac{V_{in} - V_-}{100 - j100} = \frac{V_- - V_o}{100}$$

$$V_{in} = (1-j)(V_- - V_o) + V_- = (2-j)V_- - (1-j)V_o$$

Substituting (1),

$$V_{in} = \frac{(2-j)(1+j)}{2} V_o - (1-j)V_o = \left(\frac{2+1-j+j2-2+j2}{2}\right) V_o = \left(\frac{1+j3}{2}\right) V_o$$

$$= (0.5 + j1.5)V_o = 1.581\angle 71.57° \times V_o$$

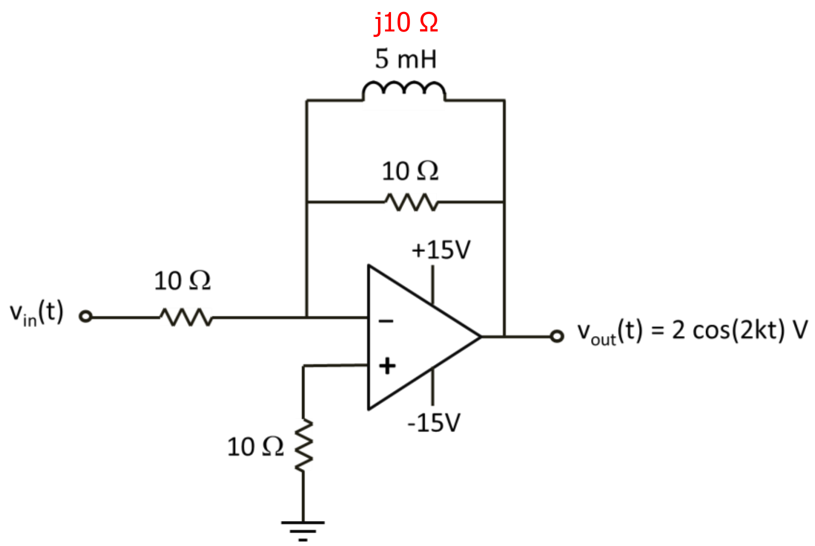
Hence,

$$V_o = \frac{V_{in}}{1.581\angle 71.57°} = 0.632\angle(-71.6°) \times 1\angle 0° = 0.632\angle(-71.6°)$$

Finally,

$$v_o(t) = 0.632\cos(10\text{k}t - 71.6°)\text{ V}$$

Q7. Assuming ideal op amp, find $v_{in}(t)$.



At $\omega = 2\text{k}$ rad/s, the impedance of the inductor $= j2\text{k} \times 5\text{m} = j10\ \Omega$.

V_+ is at 0 V ground. The presence of the 10-Ω resistor doesn't matter because there is no current going through it for an ideal op amp. (For a non-ideal op amp, the resistor could be used to balance out the tiny input bias currents.) Assume op amp not saturated,

$$V_- = V_+ = 0\text{ V}$$

Apply KCL to node V_-,

$$\frac{V_{in} - V_-}{10} = \frac{V_- - V_{out}}{10||j10}$$

$$\frac{V_{in} - 0}{10} = \frac{0 - V_{out}}{\dfrac{j100}{10 + j10}} = -\left(\frac{1+j}{j10}\right)V_{out}$$

$$V_{in} = j(1+j)V_{out} = \angle 90°(\sqrt{2}\angle 45°)V_{out} = 1.414\angle 135° \times 2\angle 0°$$

Hence,

$$v_{in}(t) = 2.82\cos(2\text{k}t + 135°)\text{ V}$$