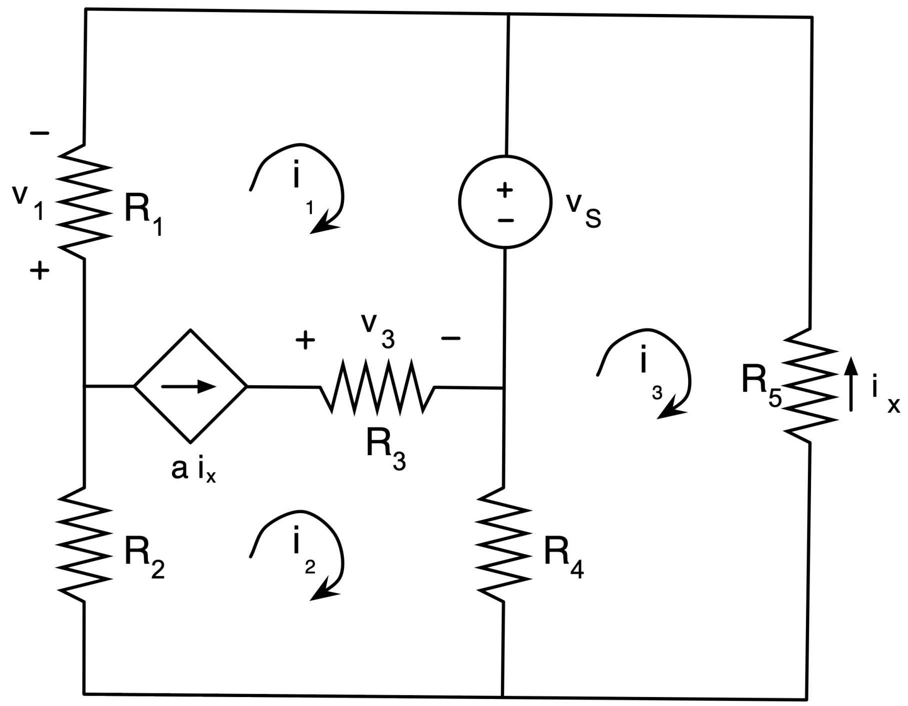
1._ Part I



Looking at the circuit, we observe the presence of 1 current source, which is a problem we need to deal with to use mesh current analysis.

Since the current source belongs to two meshes (and we cannot modify the circuit), we have to use a supermesh. We set [+1 point]

$$i_2 - i_1 = a i_x$$ [+1 point]

Next, we write KVL for the supermesh,

$$V_S + R_4(i_2 - i_3) + R_2 i_2 + R_1 i_1 = 0$$

[+1 point]

The other KVL we need to write is the one for the mesh on the right,

$$R_5(i_3) + R_4(i_3 - i_2) - V_S = 0 \qquad [+1 \text{ point}]$$

Finally, we need to account for the presence of the dependent source. Looking at the circuit, we see that

$$i_x = -i_3 \qquad [+1 \text{ point}]$$

This gives a total of 4 eqs in 4 unknowns. Substituting the last equation into the first, we get

$$-i_1 + i_2 + a i_3 = 0$$

In matrix form,

$$\begin{pmatrix} -1 & 1 & a \\ R_1 & R_2+R_4 & -R_4 \\ 0 & -R_4 & R_4+R_5 \end{pmatrix} \begin{pmatrix} i_1 \\ i_2 \\ i_3 \end{pmatrix} = \begin{pmatrix} 0 \\ -V_S \\ V_S \end{pmatrix}$$

[+1 point]

Part II

From looking at the circuit, we obtain

$$V_1 = R_1 i_1 \qquad [+1 \text{ point}]$$

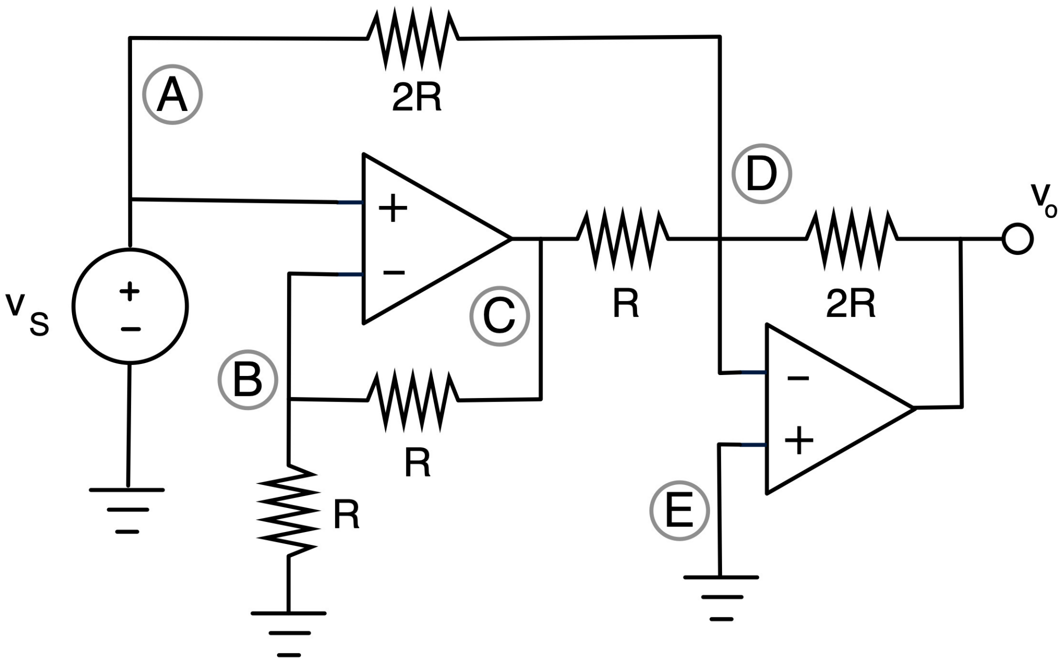
$$V_3 = R_3(i_2 - i_1)$$ [+1 point]

Part III

Changing the value of resistor R_3 will not change/affect the mesh currents. This is because R_3 is in series with a current source, and we know from circuit equivalence that a current source in series w/ a resistor is equivalent to just the current source. This can also be seen in the equations obtained in Part I, where R_3 does not show up, indicating that its value does not affect i_1, i_2, i_3.

[+2 points]

2.



Part I

As instructed, we use nodal analysis to figure out the output voltage.

We know $V_A = V_S$. [+1 point]

KCL at node B gives us (with $i_n = 0$)

$$\frac{1}{R}(V_B - 0) + \frac{1}{R}(V_B - V_C) = 0$$

[+1 point]

KCL at node D (with $i_n = 0$),

$$\frac{1}{R}(V_D - V_C) + \frac{1}{2R}(V_D - V_A) + \frac{1}{2R}(V_D - V_o) = 0$$ [+1 point]

Ideal conditions mean that

$$V_A = V_B \quad \& \quad V_D = V_E = 0$$ [+2 points]

From KCL @ B, we get

$$\frac{1}{R} V_C = \frac{2}{R} V_B \Rightarrow \quad V_C = 2V_B = 2V_A = 2V_S$$

From KCL @ D, we get

$$\frac{1}{2R} V_0 = -\frac{1}{R} V_C - \frac{1}{2R} V_A \Rightarrow$$

$$V_0 = -2\cdot(2V_S) - V_S = -5V_S$$

Therefore, $\boxed{V_0 = -5V_S}$ [+1 point]

Part II

[+1 point]

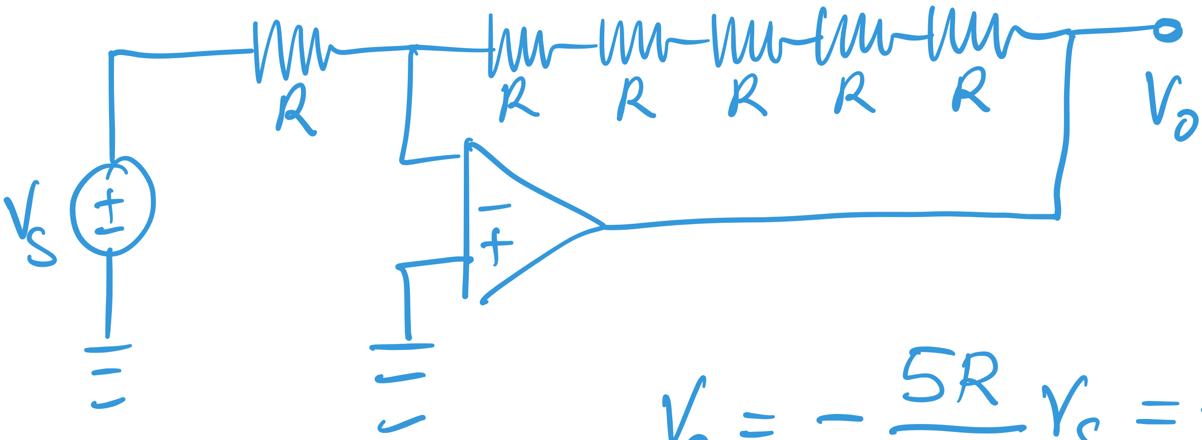
With $V_{CC} = \pm 12V$, when we input $V_S = 3V$, the 2^{nd} op-amp gets saturated (since $-5\cdot 3 = -15 < -12$) and hence $V_0 = -12V$. This is the voltage drop that the load resistor sees, and hence

$$P_L = \frac{1}{R_L} V_0^2 = \frac{1}{10}\cdot 12^2 = 14.4\,W$$ [+1 point]

which explains what the engineer found.

Part III

Since we want to generate $V_o = -5V_S$, we use an inverting op-amp.

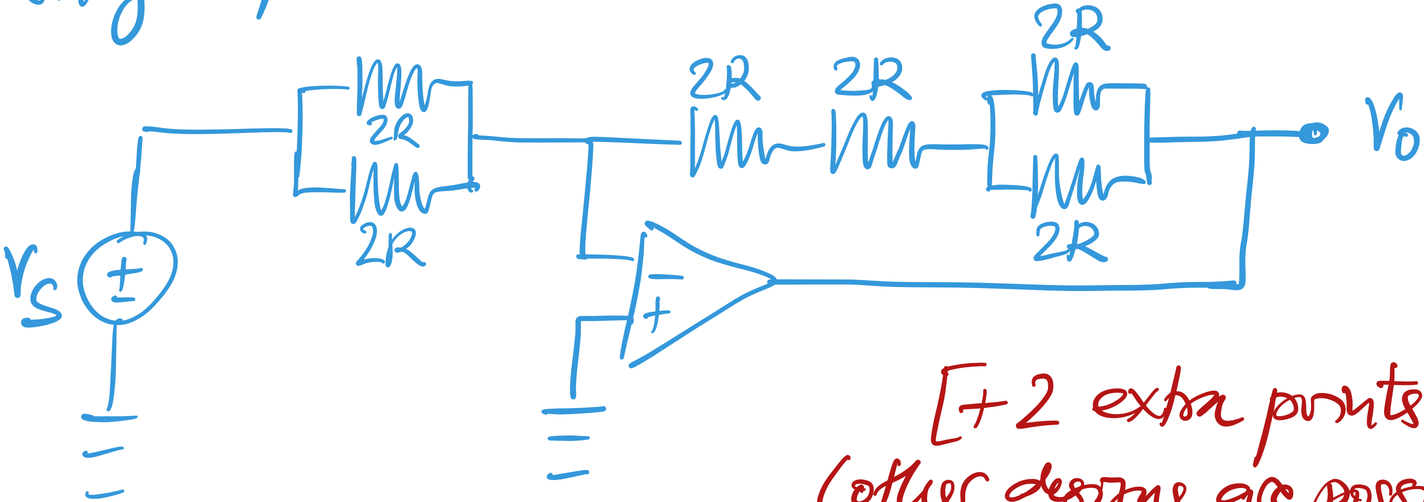


$$V_o = -\frac{5R}{R} V_S = -5V_S$$

[+1 point for using inverting op-amp, +1 point for correct design] (other designs are possible)

Part IV

We also use an inverting op-amp, but now only w/ 2R resistors.



[+2 extra points]
(other designs are possible)