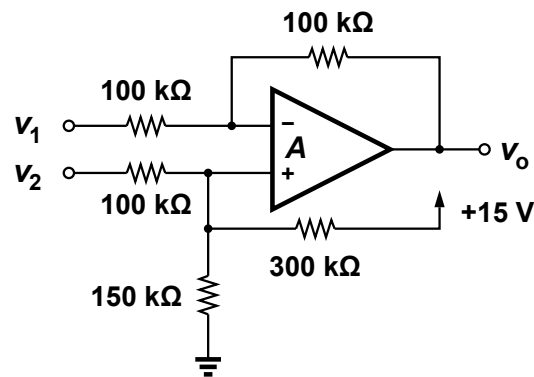


Question 1

Assume the op amp is ideal and operates in its linear region. For the circuit shown below, express the output voltage v_o in terms of the input voltages v_1 and v_2 . Include the contribution of the +15 V DC source.



Circuit for Question 1

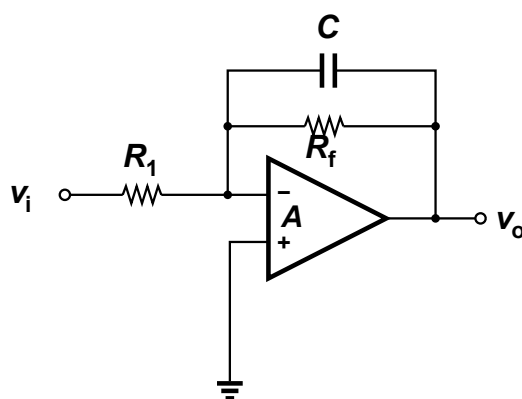
Final answer

$$v_o = v_2 - v_1 + 5 \text{ V}$$

Question 2

Assume the op amp is ideal and operates in its linear region, R_1 , R_f , and C are positive, and the capacitor is initially uncharged. For the circuit shown below:

- Derive the transfer function $H(s) = V_o(s)/V_i(s)$.
- Determine the DC voltage gain and the -3 dB cutoff frequency f_c in hertz, relative to the DC gain magnitude.
- Identify the filter type and describe the gain magnitude at frequencies well below and well above f_c .



Circuit for Question 2

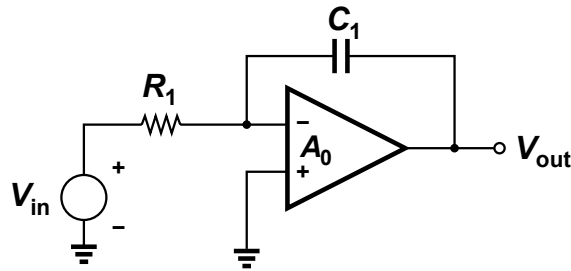
Final answer

$$H(s) = -\frac{R_f/R_1}{1 + sR_fC}, \quad H(0) = -\frac{R_f}{R_1}, \quad f_c = \frac{1}{2\pi R_fC}$$

$$\text{Low-pass: } |H| \rightarrow R_f/R_1 \ (f \ll f_c), \quad |H| \rightarrow 0 \ (f \rightarrow \infty)$$

Question 3

The integrator shown below must have a pole frequency no higher than 1 Hz. If R_1 and C_1 cannot exceed $10\text{ k}\Omega$ and 1 nF , respectively, determine the minimum required open-loop gain A_0 of the op amp. Model the op amp with a finite, frequency-independent gain A_0 , infinite input resistance, and zero output resistance.



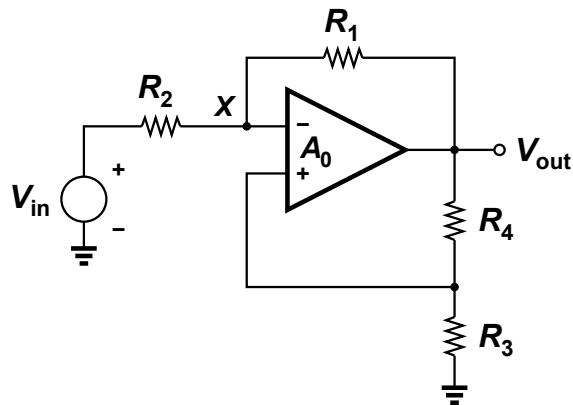
Circuit for Question 3

Final answer

$$f_p = \frac{1}{2\pi(A_0 + 1)R_1C_1}, \quad A_{0,\min} = \frac{1}{2\pi(1)(10^4)(10^{-9})} - 1 \approx 1.59145 \times 10^4$$

Question 4

Assuming $A_0 = \infty$, determine the closed-loop voltage gain v_{out}/v_{in} of the circuit shown below in terms of R_1 , R_2 , R_3 , and R_4 .



Circuit for Question 4

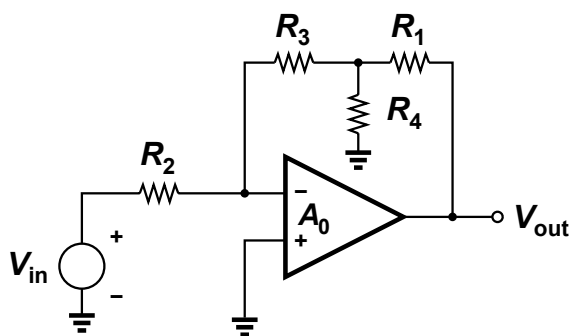
Final answer

$$\frac{V_{out}}{V_{in}} = \frac{R_1(R_3 + R_4)}{R_1R_3 - R_2R_4}$$

$$R_1R_3 < R_2R_4 \quad (\text{net negative feedback})$$

Question 5

Assuming $A_0 = \infty$, compute the closed-loop voltage gain $V_{\text{out}}/V_{\text{in}}$ of the inverting amplifier shown below in terms of R_1 , R_2 , R_3 , and R_4 . Verify that your result reduces to the expected gain in each of the limiting cases $R_1 \rightarrow 0$ and $R_3 \rightarrow 0$.



Circuit for Question 5

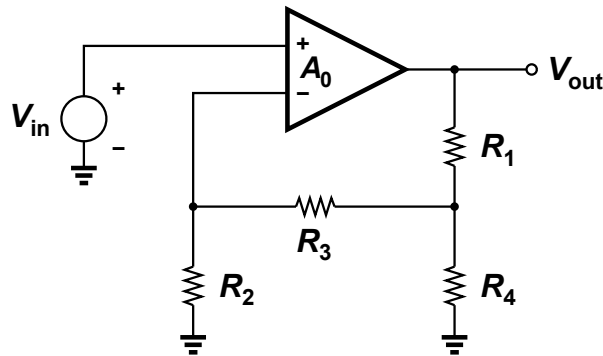
Final answer

$$G = -\frac{R_1 + R_3 + R_1 R_3 / R_4}{R_2}$$

$$R_1 \rightarrow 0 : G \rightarrow -\frac{R_3}{R_2}, \quad R_3 \rightarrow 0 : G \rightarrow -\frac{R_1}{R_2}$$

Question 6

Assuming $A_0 = \infty$, calculate the closed-loop voltage gain $V_{\text{out}}/V_{\text{in}}$ of the non-inverting amplifier shown below in terms of R_1 , R_2 , R_3 , and R_4 . Verify that your result reduces to the expected gain in each of the limiting cases $R_1 \rightarrow 0$ and $R_3 \rightarrow 0$.



Circuit for Question 6

Final answer

$$G = \left(1 + \frac{R_3}{R_2}\right) \left(1 + \frac{R_1}{R_4}\right) + \frac{R_1}{R_2}$$

$$R_1 \rightarrow 0 : G \rightarrow 1 + \frac{R_3}{R_2}, \quad R_3 \rightarrow 0 : G \rightarrow 1 + \frac{R_1}{R_2} + \frac{R_1}{R_4}$$