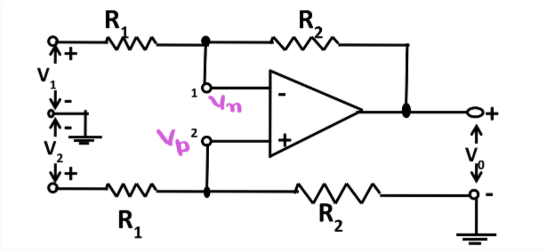
2. The differential input operational amplifier shown consists of a base amplifier of infinite gain. Find the expression of output voltage.



$$V_p = \frac{V_2}{R_1 + R_2} R_2 = V_n$$

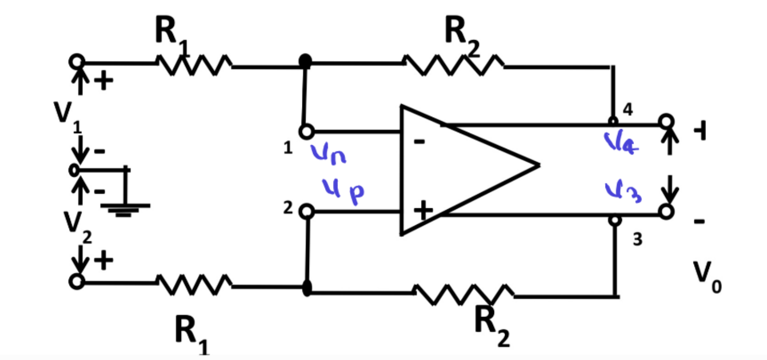
$$\frac{V_1 - V_n}{R_1} = \frac{V_n - V_o}{R_2}$$

$$\frac{V_o}{R_2} = V_n\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_1}{R_1}$$

$$V_o = -\frac{R_2}{R_1} V_1 + \frac{V_2}{R_1 + R_2} R_2 \frac{R_1 + R_2}{R_1}$$

$$V_o = \frac{R_2}{R_1}(V_2 - V_1)$$

3. Repeat the above problem for the amplifier shown.



$$V_p = V_2 - \frac{V_2 - V_3}{R_1 + R_2} R_1$$

$$V_p = V_n$$

$$\frac{V_1 - V_n}{R_1} = \frac{V_n - V_4}{R_2}$$

$$\Rightarrow \frac{V_4}{R_2} = \frac{V_n}{R_2} + \frac{V_n}{R_1} - \frac{V_1}{R_1}$$

$$\Rightarrow V_4 = (R_1 + R_2)\frac{V_n}{R_1} - \frac{R_2}{R_1} V_1$$

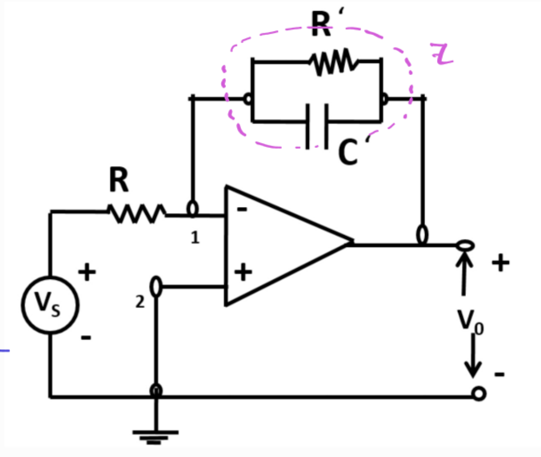
$$V_4 = \frac{R_1 + R_2}{R_1} \cdot \left(V_2 - \frac{V_2 - V_3}{R_1 + R_2} R_1\right) - \frac{R_2}{R_1} V_1$$

$$\Rightarrow V_4 = \left(\frac{R_1 + R_2}{R_1}\right) V_2 - (V_2 - V_3) - \frac{R_2}{R_1} V_1$$

$$\Rightarrow V_4 - V_3 = \left(1 + \frac{R_2}{R_1}\right) V_2 - V_2 - \frac{R_2}{R_1} V_1$$

$$\Rightarrow V_o = \frac{R_2}{R_1}(V_2 - V_1)$$

4. The circuit shown represents a low-pass de-coupled amplifier. Assuming an ideal operational amplifier determine the low- frequency gain $A_V = V_0 / V_S$.

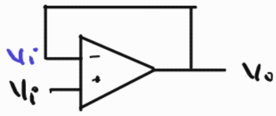


$$Z = \frac{R' \cdot \frac{1}{j\omega C}}{R' + \frac{1}{j\omega C}} = \frac{R'}{1 + j\omega C R'}$$

$$\frac{V_s}{R} = -\frac{V_o}{Z} \Rightarrow \frac{V_o}{V_s} = -\frac{Z}{R} = \frac{\frac{R'}{1 + j\omega C R'}}{R}$$

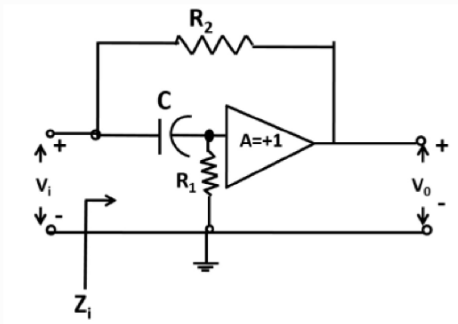
$$|A_v| = \left|\frac{V_o}{V_s}\right| = \frac{R'}{R} \cdot \frac{1}{1 + (\omega C R')^2}$$

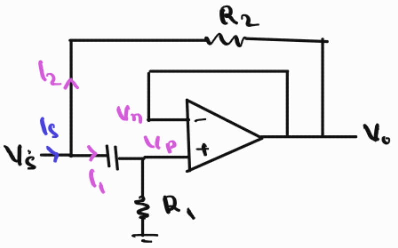
5) a) Show that if the inverting terminal of an OPAMP is shorted to output, then it acts as unit gain buffer (unit gain amplifier with high input impedance)



$$V_o = V_i \Rightarrow A_v = \frac{V_o}{V_i} = 1$$

b) show that the circuit of the accompanying figure can simulate a grounded inductor if $R_1 > R_2$. In other words, show that the reactive part of the input impedance of the circuit is positive if $R_1 > R_2$. In the circuit the OPAMP is a unit gain buffer.





$(R_1 > R_2)$

$$Z = \frac{V_s}{I_s}$$

$$I_s = I_1 + I_2 = \frac{V_s}{R_1 + \frac{1}{j\omega C}} + \frac{V_s - V_o}{R_2}$$

$$V_o = \frac{V_s(j\omega C)}{1 + j\omega C R_1} R_1$$

$$I_s = \frac{V_s(j\omega C)}{1 + R_1(j\omega C)} + \frac{V_s - \frac{V_s(j\omega C)}{1 + (j\omega C R_1)} R_1}{R_2}$$

$$= \frac{V_s(j\omega C)}{1 + R_1(j\omega C)} + \frac{V_s(1 + j\omega C R_1 - j\omega C R_1)}{(1 + j\omega C R_1) R_2}$$

$$= \frac{V_s(j\omega C) R_2 + V_s}{(1 + R_1(j\omega C)) R_2}$$

$$Z = \frac{V_s}{I_s} = \frac{R_2(1 + j\omega C R_1)}{1 + j\omega C R_2} \times \frac{1 - j\omega C R_2}{1 - j\omega C R_2}$$

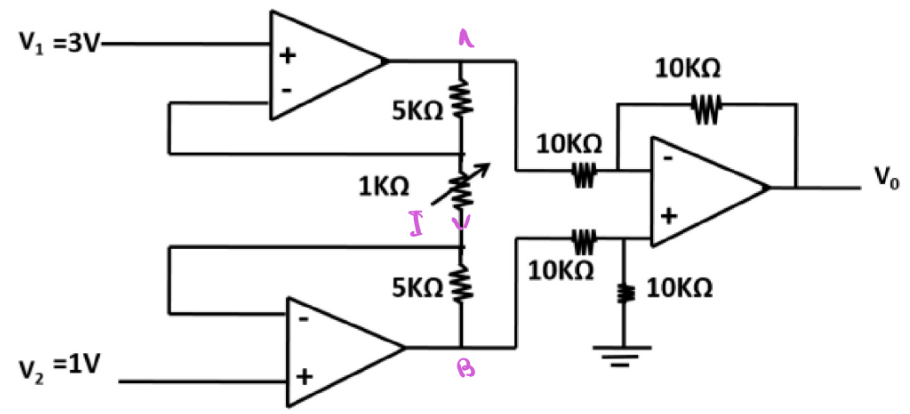
$$= \frac{R_2}{1 + (\omega C R_2)^2} \cdot \frac{1 + (\omega C)^2 R_1 R_2 + j\omega C(-R_2 + R_1)}{}$$

Analysing complex part

$$Img(Z) = \frac{R_2 \omega C (R_1 - R_2)}{1 + (\omega C R_2)^2}$$

$R_1 > R_2 \quad Img(Z) > 0 \Rightarrow$ inductor behaviour

6) Calculate V_0 in the circuit.



$I = 2\,mA$

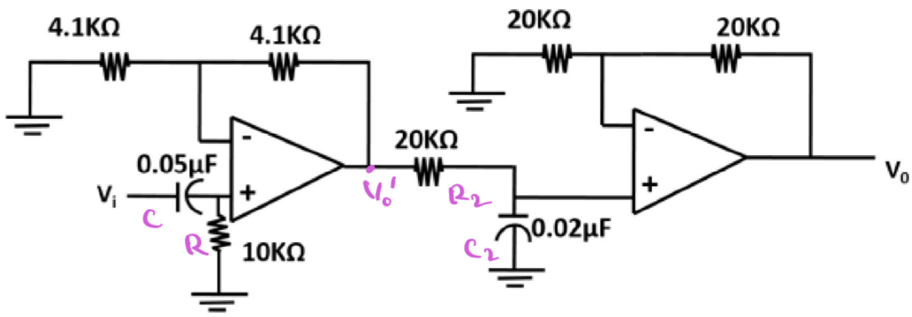
$V_A = 13\ V$

$V_B = -9\ V$

$V_o = V_B - V_A$

$= -22\ V$

7) Calculate the lower and upper cutoff frequency in the band pass filter circuit.



$$V_p = \frac{V_i}{R + \frac{1}{j\omega C}} R$$

$$-\frac{V_p}{\cancel{R_1}} = \frac{-V_o' + V_p}{\cancel{R_1}}$$

$$V_o' = 2V_p$$

$$V_p' = \frac{2V_p}{R_2 + \frac{1}{j\omega C_2}} \cdot \frac{1}{j\omega C_2}$$

$$= \frac{2V_p}{1 + jR_2\omega C_2}$$

$$-\frac{V_p'}{R_3} = \frac{V_p' - V_o}{R_3}$$

$$\Rightarrow V_o = 2V_p'$$

$$V_o = \frac{4V_p}{1 + j\omega R_2 C_2}$$

$$V_o = \frac{4}{1 + j\omega C_2 R_2} \cdot \frac{V_i (j\omega C)}{1 + R(j\omega C)} R$$

$$f_H = \frac{10^6}{2\pi(0.02)(20)\times 10^3}$$

$$f_L = \frac{10^6}{2\pi(0.05)\,10\times 10^3}$$