Solutions to Tutorial Sheet - 5 IEC103

Q1. An amplifier has a voltage gain of 500 without feedback. If a negative feedback is applied, the gain is reduced to 100. Calculate the fraction of output feedback. If, due to ageing of components, the gain without feedback falls by 20%, calculate the percentage fall in gain with feedback.

Sol. $A_v = 500$; $A_{vf} = 100$

$$A_{vf} = \frac{A_v}{1 + A_v\beta}$$

$$100 = \frac{500}{1 + 500\beta}$$

$$\Rightarrow 1 + 500\beta = 5$$

$$\Rightarrow 500\beta = 4 \Rightarrow \beta = 0.008$$

If gain falls by 20% due to ageing, $A_v = 400$

$$A_{vf} = \frac{400}{1 + 400 \times 0.008} = 95.24$$

$$\% \text{ fall in gain} = \frac{100 - 95.24}{100} = 4.76\%$$

Q2 The schmitt trigger has $+V_{sat} = 10V$ and has $-V_{sat} = -10V$, $V_A = 5V$. The schmitt trigger characteristics are shown in Fig. Q2. Using this schmitt trigger, generate a square wave at a frequency of 1KHz. Specify required RC.

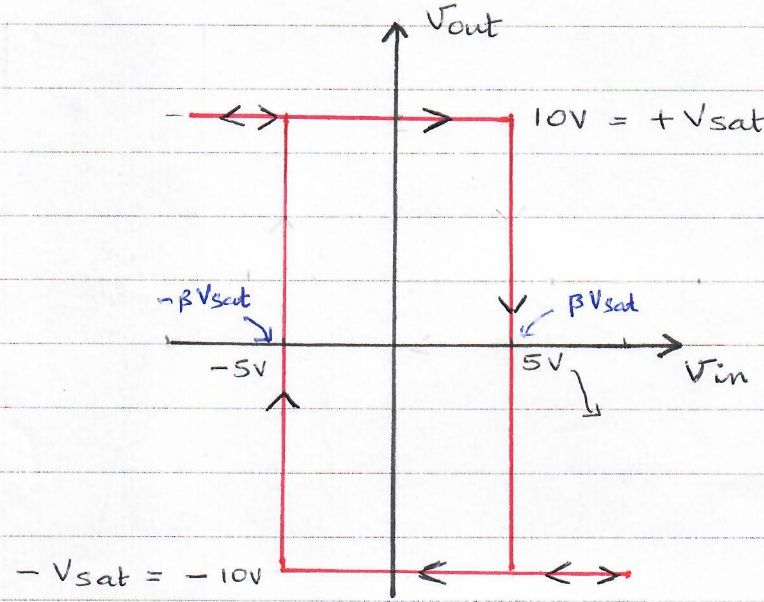


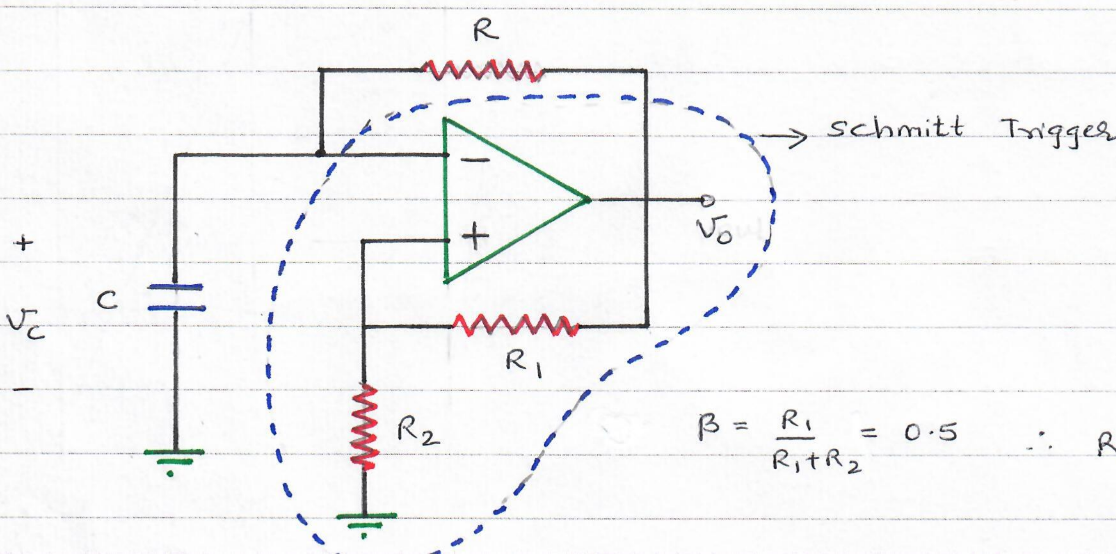
Fig. Q2 (schmitt Trigger characteristic)

Sol. $V_{sat} = 10V$; $-V_{sat} = -10V$

$\beta V_{sat} = 5$ $\qquad$ $-\beta V_{sat} = -5$

$\Rightarrow \beta = \frac{5}{10} = 0.5$ $\qquad$ $\Rightarrow \beta = \frac{-5}{-10} = 0.5$

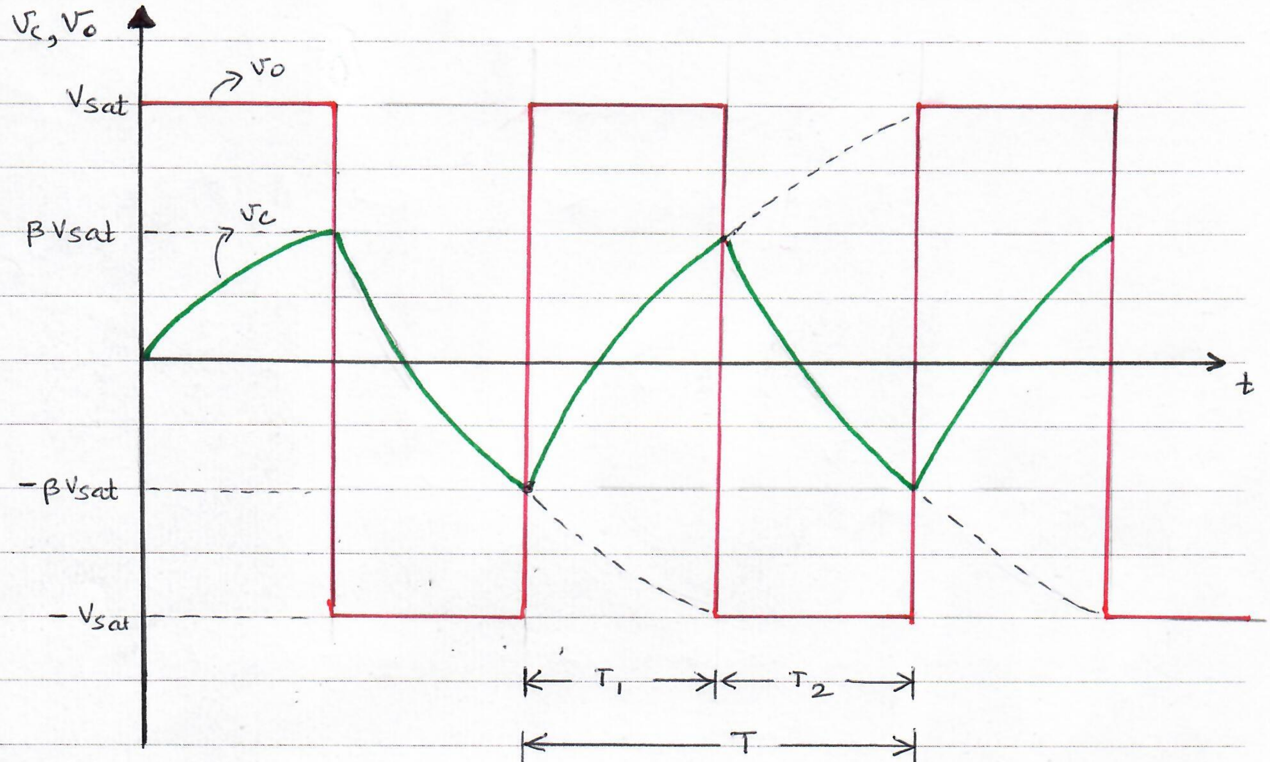
Square wave generator with above schmitt Trigger is as shown below.



$\beta = \frac{R_1}{R_1 + R_2} = 0.5$ $\quad \therefore \quad R_1 = R_2$

Let us assume that the output voltage of the square wave generator be $+V_{sat}$ at $t=0$.

The output wave form will be as shown below.



$$V_c(t) = V_c(\infty) + (V_c(0) - V_c(\infty))e^{-t/RC}$$

$$\& \quad V_c(t) = V_c(0)e^{-t/RC} + V_c(\infty)(1-e^{-t/RC})$$

During charging

$V_c(\infty) = V_{sat}$

$V_c(0) = -\beta V_{sat}$

$$V_c(t) = -\beta V_{sat} e^{-t/RC} + V_{sat}(1-e^{-t/RC})$$

$$\therefore \quad V_c(T_1) = \beta V_{sat} = -\beta V_{sat} e^{-T_1/RC} + V_{sat}(1-e^{-T_1/RC})$$

$$\Rightarrow \beta V_{sat} = V_{sat} + (-\beta V_{sat} - V_{sat})e^{-T_1/RC}$$

$$\Rightarrow \beta V_{sat} = V_{sat} - (1+\beta)V_{sat}e^{-T_1/RC}$$

$$\Rightarrow (\beta-1)V_{sat} = -(1+\beta)V_{sat}e^{-T_1/RC}$$

$$\Rightarrow (\beta-1) = -(1+\beta)e^{-t/RC}$$

$$\Rightarrow (1+\beta)e^{-T_1/RC} = (1-\beta)$$

$$\Rightarrow e^{-T_1/RC} = \frac{(1-\beta)}{(1+\beta)}$$

$$\Rightarrow -\frac{T_1}{RC} = \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow -T_1 = RC\ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow T_1 = RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

During discharging of capacitor $\nearrow$ $v_c(\infty) = -V_{sat}\,;\ v_c(0) = \beta V_{sat}$

$$v_c(t) = \beta V_{sat} e^{-t/RC} - V_{sat}\left(1 - e^{-t/RC}\right)$$

$$v_c(T_2) = -\beta V_{sat} = \beta V_{sat} e^{-T_2/RC} - V_{sat}\left(1 - e^{-T_2/RC}\right)$$

$$\Rightarrow -\beta V_{sat} = \beta V_{sat}\, e^{-T_2/RC} - V_{sat} + V_{sat}\, e^{-T_2/RC}$$

$$\Rightarrow -\beta = \beta e^{-T_2/RC} - 1 + e^{-T_2/RC}$$

$$\Rightarrow (1-\beta) = (1+\beta)e^{-T_2/RC}$$

$$\Rightarrow e^{-T_2/RC} = \frac{(1-\beta)}{(1+\beta)}$$

$$\Rightarrow -\frac{T_2}{RC} = \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow -T_2 = RC\ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$\Rightarrow T_2 = RC\ln\left(\frac{1+\beta}{1-\beta}\right) = T_1$$

$$T = T_1 + T_2 = 2RC\ln\left(\frac{1+\beta}{1-\beta}\right)$$

In the above circuit $\beta = 0.5$

$$T = 2RC\ln\left(\frac{1.5}{0.5}\right) = 2RC\ln(3)$$
$$\simeq 2.2RC$$

Specified frequency $= f = 1\,KHz$

$$\Rightarrow T = \frac{1}{f} = 10^{-3}\ sec$$

$$\therefore\ 10^{-3} = 2.2RC$$

$$\Rightarrow RC = \frac{10^{-3}}{2.2} = 4.55\times 10^{-4}$$

If we choose $C = 1\,\mu F$

$$\therefore\ R = \frac{4.55\times 10^{-4}}{10^{-6}} = 4.55\times 10^{2} = 455\,\Omega$$

(Q3.) An opamp is , having the saturation levels $+V_{sat}(V_H)$ and V_L $(-V_{sat})$. The opamp is connected as a schmitt trigger as shown in Fig. Q3. Sketch the transfer function v_{out} versus v_{in}.

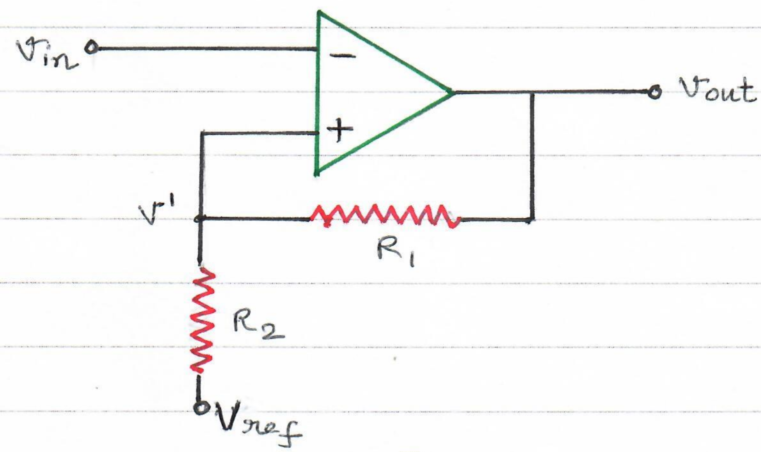


Fig. Q3

Sol.

If $v_O = V_H = +V_{sat}$

$$v' = V_B = \frac{V_H \times R_2}{R_1+R_2} + V_{ref} \times \frac{R_1}{R_1+R_2}$$

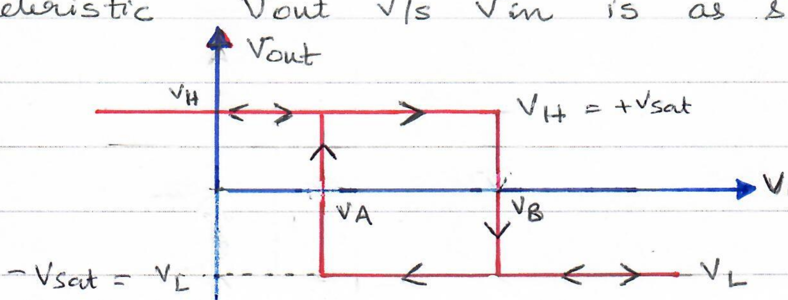
As we go on increasing $v_{in}(\uparrow)$ when $v_{in} > V_B$, the output v_{out} drops to V_L

If $v_{out} = V_L = -V_{sat}$

$$v' = V_A = \frac{V_L \times R_2}{R_1+R_2} + V_{ref} \times \frac{R_1}{R_1+R_2}$$

As we go on decreasing $v_{in}(\downarrow)$ and when $v_{in} < V_A$, the output v_{out} jumps to V_H.

Transfer characteristic v_{out} v/s v_{in} is as shown below.



(Q4) The stable state of the monostable given in Fig. Q4 is output V_o at $+V_{sat} = 10V$. When a negative trigger at the non inverting terminal is applied the mono changes state and the output voltage V_o instantaneously changes to $-V_{sat} = -10V$.

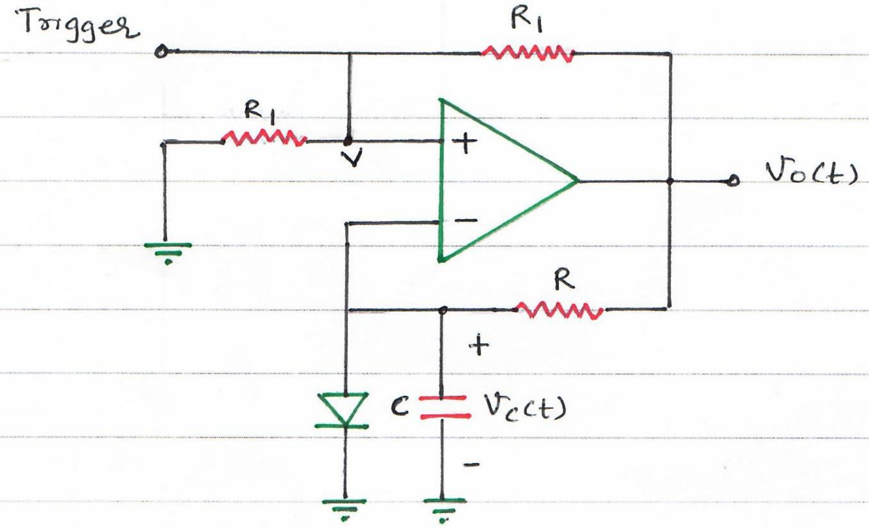


Fig. Q4

i) Sketch the waveforms of voltage across the capacitor $v_c(t)$ and output voltage $v_o(t)$ starting from the instant of application of negative trigger. Label the amplitudes and transition times legibly.

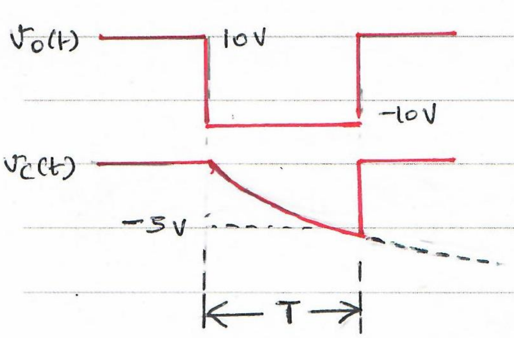
ii) Show that the mono puts out a pulse at the output of width $T = RC \ln 2$ and amplitude $\pm 10V$. [4+4]

Sol. $v_c(0) = 0$ as $v_o = +10V$ and diode is conducting, $V = 5V$.

When trigger occurs $v_o = -10V$, $V = -5V$, Diode off, capacitor starts charging towards $-10V$. $v_c(t) = 0 + (-10-0)(1-e^{-t/RC})$

$$-5 = -10\,(1 - e^{-T/RC})$$

$$\Rightarrow e^{-T/RC} = \frac{1}{2} \quad \Rightarrow \quad \boxed{T = RC \ln 2}$$



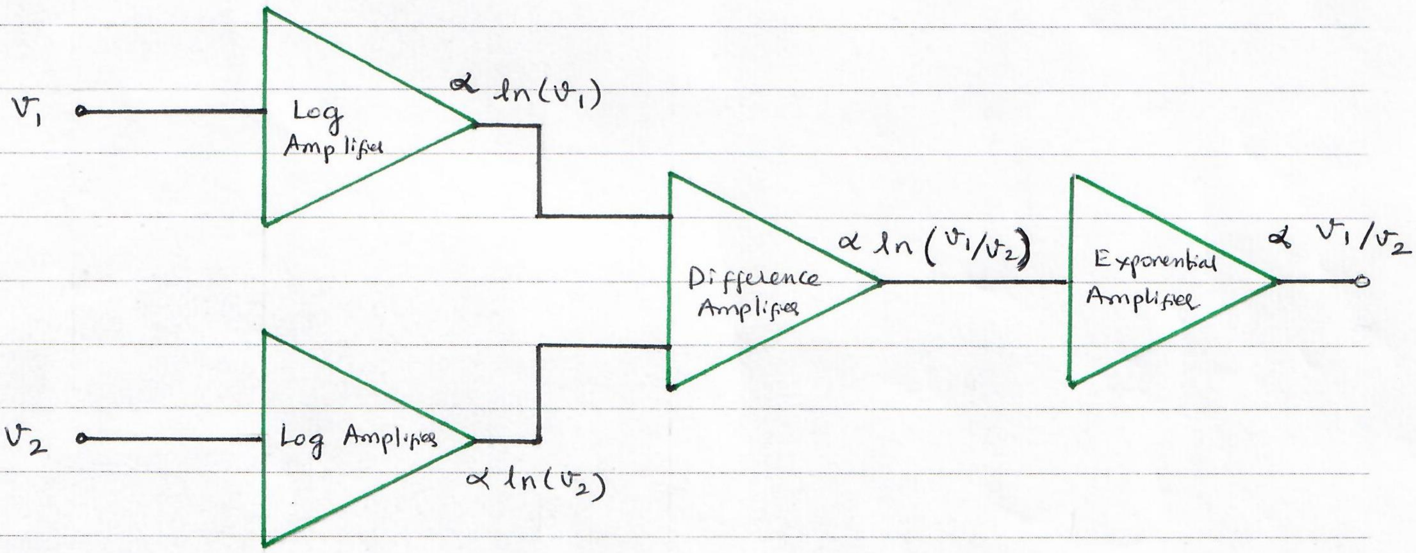
(Q5) Design an op-amp circuit to give an output voltage proportional to produce quotient of two voltages (v_1/v_2).

Sol.

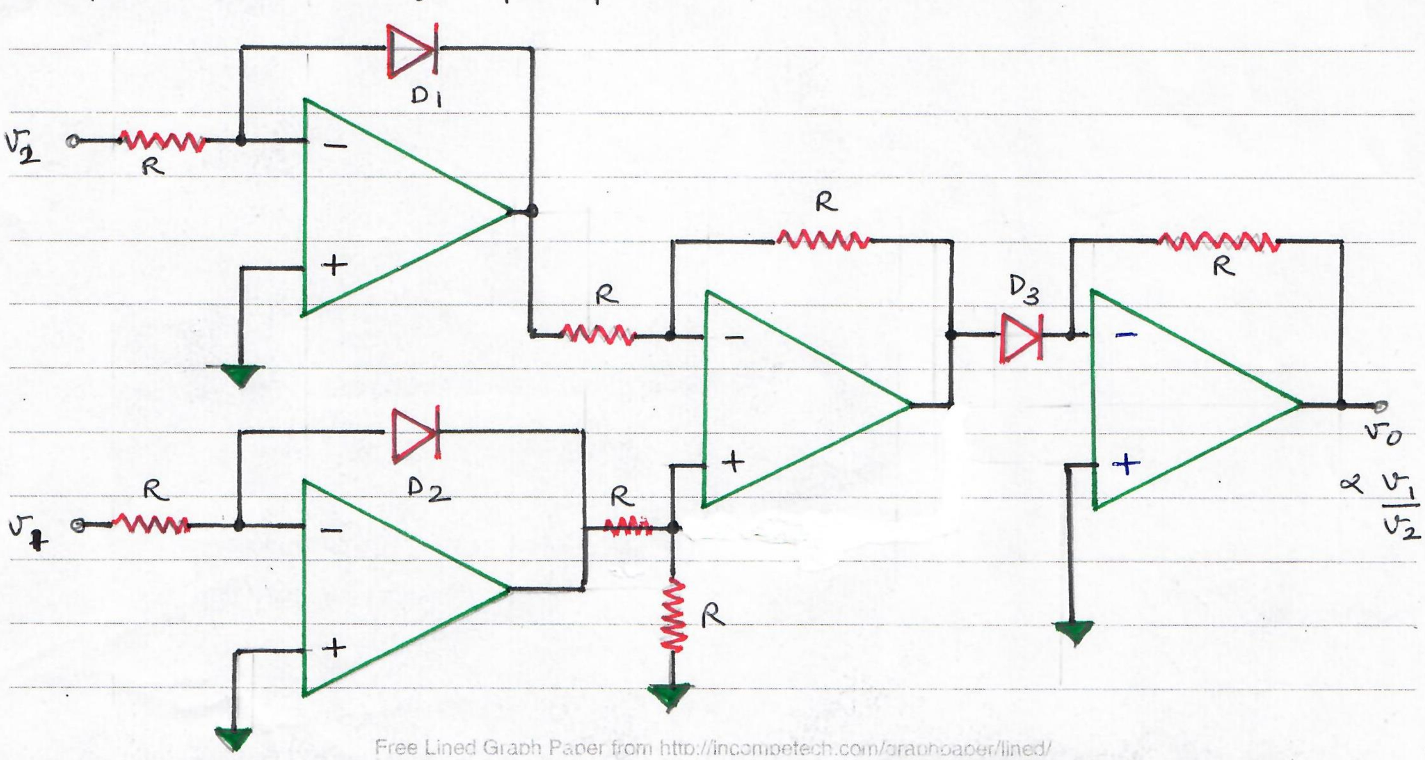
$$e^{[\ln(v_1) - \ln(v_2)]}$$

$$= e^{\ln(v_1/v_2)} = \frac{v_1}{v_2}$$

The circuit can be implemented using logarithmic, exponential and difference amplifier.



Implementation using op-amps



Q6 The circuit of Fig. Q6 is, in essence, a non inverting amplifier with a feedback impedance Z_N and is known as a negative-impedance converter (NIC). Find the Thevenin or driving-point impedance to the right of the input terminals, and explain why such a name is appropriate. Assume that op-amp is ideal

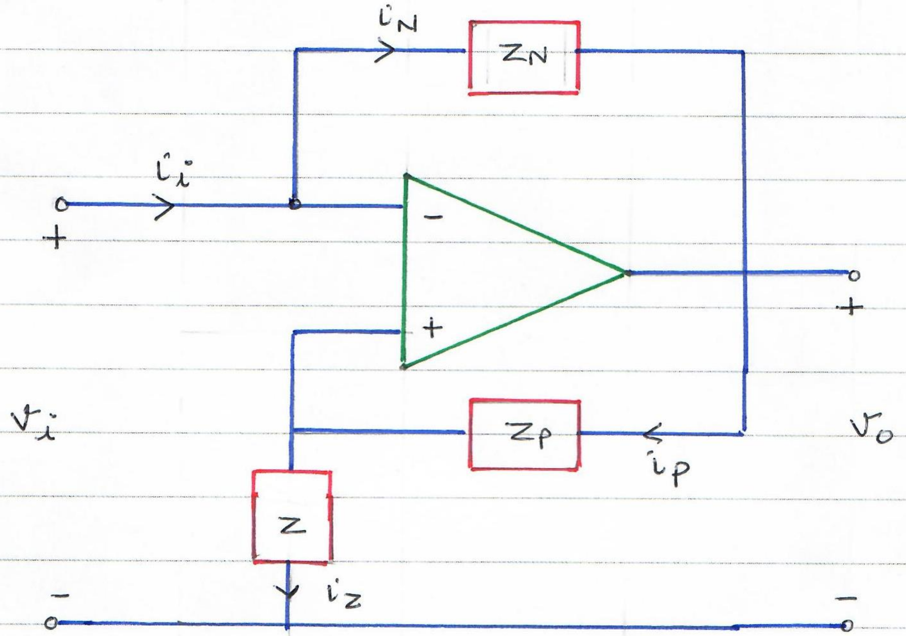


Fig. Q6

Sol. At inverting node, the phasor input current is given by

$$I_i = I_N = \frac{V_i - V_o}{Z_N}$$

$$\therefore \quad V_o = V_i - I_i Z_N \quad \cdots \quad (A)$$

Since $V_d \approx 0$

$$I_p = \frac{V_o - V_i}{Z_p} = I_Z = \frac{V_i}{Z}$$

$$V_o = I_p Z_p + I_Z Z$$

$$= I_p (Z_p + Z) = (Z_p + Z)\frac{V_i}{Z}$$

$$V_o = \frac{Z_p}{Z} V_i + V_i \quad \cdots \quad (B)$$

Equating eq ① & ② : $V_i - I_i Z_N = \left(\frac{Z_p}{Z} + 1\right) V_i$

$$\Rightarrow \quad V_i \left(1 - \frac{Z_p}{Z} - 1\right) = I_i Z_N$$

$$\Rightarrow \quad \frac{V_i}{I_i} = -\frac{Z_N}{Z_p} Z$$

If $Z_p = Z_N$, then impedance Z appears as −ve of its value, hence the name.