ESC201A Assignment 7

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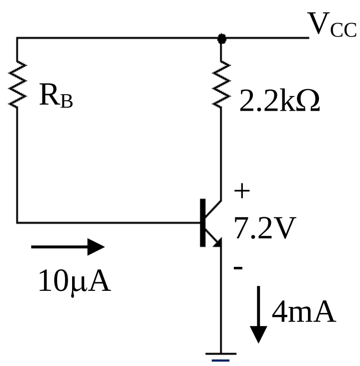
2023-2024 Semester I

Topics

BJTs, OPAMPs

Questions

1. Determine V_{CC} and R_B in the following circuit.



Applying KVL,

$$V_{CC} - (4\times10^{-3})(2.2\times10^{3}) - 7.2 = 0$$

$$\Rightarrow V_{CC} = 8.8 + 7.2 \text{ V}$$

$$\Rightarrow V_{CC} = 16\text{V}$$

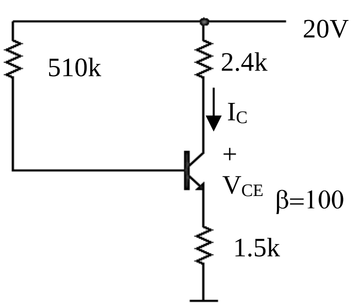
Applying KVL,

$$V_{CC} - (10\times10^{-6})(R_B) - V_{BE} = 0$$

$$\Rightarrow V_{CC} = (10\times10^{-6})(R_B) + V_{BE}$$

$$\text{or } R_B = \frac{16-0.7}{10}\ M\Omega = 1.53M\Omega$$

2. Determine I_C and V_{CE} in the following circuit.



Applying KVL,

$$20 - (510\times10^{3})(I_B) - V_{BE} - (1.5\times10^{3})(I_E) = 0$$

$$\Rightarrow 20 - (510\times10^{3})\left(\frac{I_C}{\beta}\right) - V_{BE} - (1.5\times10^{3})\left(\frac{I_C}{\frac{\beta}{(\beta+1)}}\right) = 0$$

$$\Rightarrow 20 - (510\times10^{3})\left(\frac{I_C}{100}\right) - 0.7 - (1.5\times10^{3})\left(\frac{I_C}{\beta}\right)(\beta+1) = 0$$

$$\Rightarrow 20 - 5100 I_C - 0.7 - \left(\frac{1.5\times10^{3}}{100}\times101\right) I_C = 0$$

$$\Rightarrow 19.3 = 5100 I_C + 1515 I_C$$

$$\text{or } 6615 I_C = 19.3$$

$$\Rightarrow I_C = \frac{19.3}{6615}\text{ A} = 2.917\text{ mA} \approx 2.92\text{ mA}$$

Applying KVL,

$$20 - (2.92\times10^{-3})(2.4\times10^{3}) - V_{CE} - (1.5\times10^{3})(I_E) = 0$$

$$\Rightarrow 20 - 7.008 - V_{CE} - (1.5\times10^{3})\left(\frac{2.92\times10^{-3}}{100}\right)(101) = 0$$

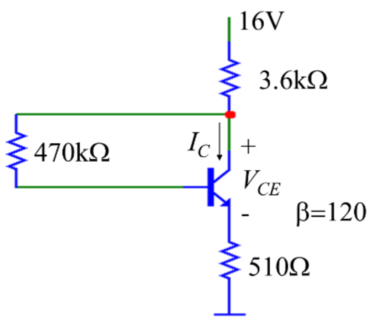
$$\Rightarrow 12.992 - V_{CE} - 4.4238 = 0$$

or $V_{CE} = 12.992 - 4.4238\ V$

$$\Rightarrow V_{CE} = 8.5682V \approx 8.57V$$

Since $V_{CE} > 0.2V$, our assumption is correct.

3. Determine I_C and V_{CE} in the following circuit.



Assuming that the transistor is in forward active mode.

$$I_C + I_B = (\beta + 1)I_B = 121I_B$$

Applying KVL

$$-16 + (121I_B)3.6k + I_B 470k + 0.7 + (121I_B)510 = 0$$

$$I_B = \frac{16 - 0.7}{121 \times 3.6k + 470k + 121 \times 510} = 0.0158mA$$

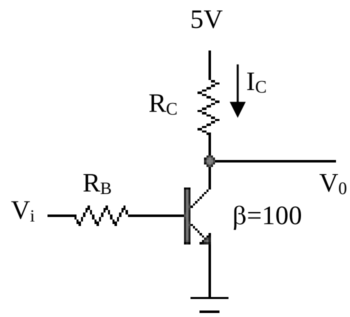
$$I_C = \beta I_B = 120 \times 0.0158mA = 1.9mA$$

Applying KVL

$$I_B 470k + 0.7 - V_{CE} = 0$$

$$V_{CE} = 0.0158 \times 470 + 0.7 = 8.13V$$

4. Determine R_B and R_C such that the transistor is in saturation with $I_C = 2mA$ and $\beta_{forced} = 20$ when $V_i = 5V$. Draw the voltage transfer characteristics (a plot of V_0 vs V_i) with these resistances.



For saturation, $V_{CE} = 0.2V$

$$\therefore R_C = \frac{5-0.2}{2 \times 10^{-3}} \, \Omega = 2.4 k\Omega$$

$$\beta = 20$$

$$\therefore I_B = \frac{2mA}{20} = 0.1mA$$

$$\therefore R_B = \frac{5-0.7}{0.1 \times 10^{-3}} \, \Omega = 43k\Omega$$

$$V_0 = V_{CC} - I_C R_C$$

$$\Rightarrow V_0 = V_{CC} - \beta I_B R_C$$

$$\Rightarrow V_0 = V_{CC} - \beta\left(\frac{V_i - 0.7}{R_B}\right) R_C \quad \text{———— (1)}$$

for $V_i < 0.7V$, the transistor is in cut-off mode

$\therefore$ For $V_i < 0.7V$, $V_0 = 5V$

When V_i increases beyond 0.7V, the transistor enters the forward active mode and continue to remain ~~till~~ in forward active mode till a value of V_i where $V_0 = 0.2V$ and the transistor goes in saturation. To find the (a value of V_i where $V_0 = 0.2V$, from equation(1),

$$\therefore 0.2 = 5 - 100\left(\frac{V_i - 0.7}{43 \times 10^3}\right)(2.4 \times 10^3)$$

$$\Rightarrow (V_i - 0.7)\, 5.58 = 4.8$$

$$\Rightarrow V_i = 1.56 V$$

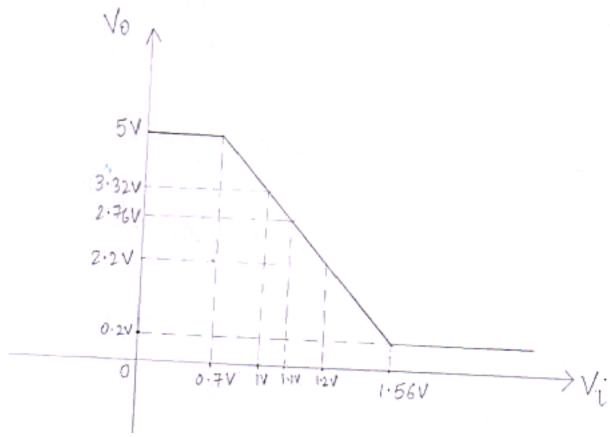
e.g. From equation (1),

for $V_i = 1V$, $V_0 = 3.32V$

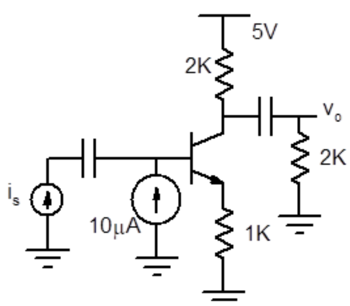
for $V_i = 1.1V$, $V_0 = 2.76V$

for $V_i = 1.2V$, $V_0 = 2.2V$

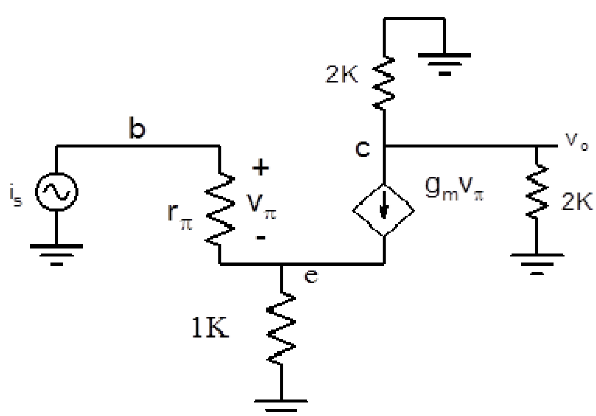
For $V_i > 1.56V$, $V_0 = 0.2V$



5. For the circuit shown below, carry out ac analysis to determine the ratio $\frac{v_0}{i_s}$, where $\mathbf{v_o}$ is ac output voltage and $\mathbf{i_s}$ is ac sinusoidal current . Assume that transistor is biased in forward active mode and current gain $\beta_F = 100$.



Small signal equivalent circuit:



$$r_\pi = \frac{V_T}{I_C}\beta$$

$$g_m = \frac{I_C}{V_T}$$

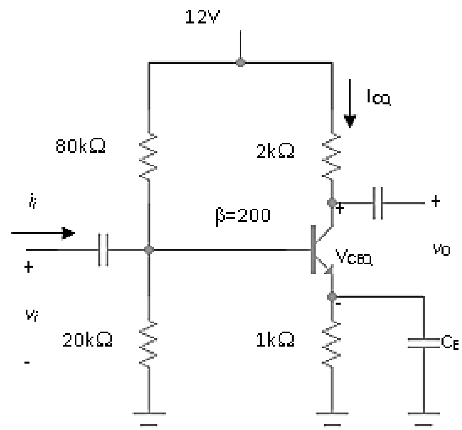
$$v_0 = -g_m v_\pi (2K||2K)$$

$$v_\pi = i_s r_\pi$$

$$v_0 = -\frac{I_C}{V_T} i_s \frac{V_T}{I_C}\beta(2K||2K)$$

$$\frac{v_0}{i_s} = -\beta(1K)$$
$$\frac{v_0}{i_s} = -10^5\Omega$$

6. For the following circuit, calculate V_{CEQ} and I_{CQ}. Also, calculate the small signal voltage gain $A_v = \frac{v_o}{v_i}$ and the input impedance $\left(Z_i = \frac{v_i}{i_i}\right)$.



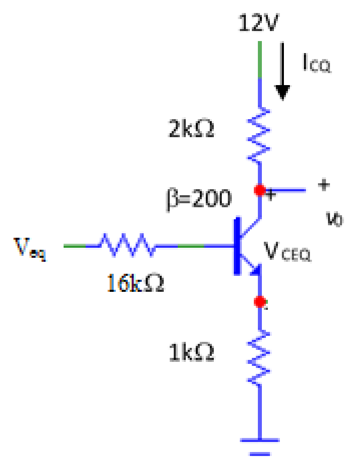
Solution

DC Analysis

$$V_{eq} = \frac{20 \times 12V}{100} = 2.4V$$

Also,

$$80k||20k = 16k$$



Assume transistor in forward-active mode.

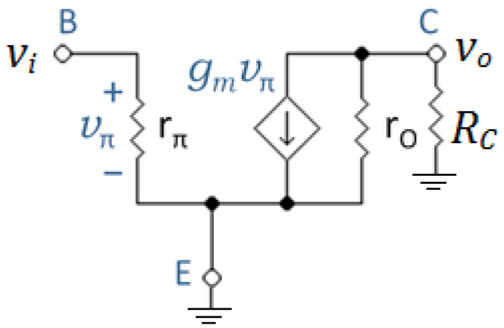
Applying KVL:

$$2.4 - (16 \times 10^3)I_B - 0.7 - 10^3 I_E = 0$$
$$\Rightarrow 2.4 - (16 \times 10^3)\frac{I_{CQ}}{\beta} - 0.7 - 10^3\frac{I_{CQ}}{\beta}(\beta + 1) = 0$$
$$\Rightarrow I_{CQ} = 1.57mA$$

Applying KVL:

$$12 - (2 \times 10^3)(1.57 \times 10^{-3}) - V_{CEQ} - 10^3\frac{1.57 \times 10^{-3}}{200}201 = 0$$
$$\Rightarrow V_{CEQ} = 7.28V > 0.2V$$

So assumption correct.



$$A_v = -g_m R_c = -\frac{\alpha I_E}{V_T} R_c = -\frac{I_{CQ}}{V_T} R_C = -\frac{1.57 \times 10^{-3}}{26 \times 10^{-3}} \times 2 \times 10^3 = -120.07$$

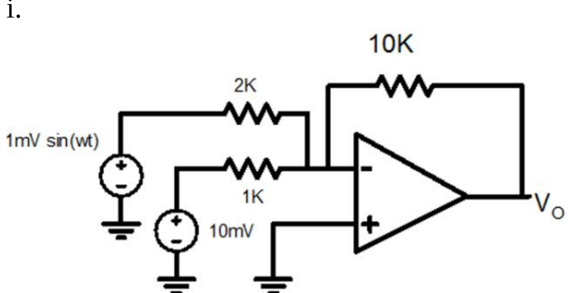
$$Z_i = 80k||20k||r_\pi$$

$$r_\pi = \frac{\beta}{g_m} = \frac{200}{1.57} \times 26\Omega = 3.3k\Omega$$

$$Z_i = 80k||20k||3.3k = 2.735k\Omega$$

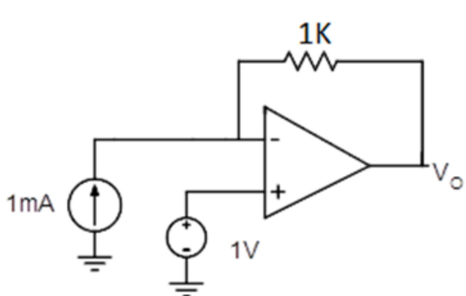
7. Determine the output of the ideal op-amp circuits shown below.

i.



$$v_o = -\{\frac{10K}{1K} \times 10mV + \frac{10K}{2K} \times 1mV \sin(\omega t)\}$$
$$= -\{0.1 + 5 \times 10^{-3} \sin(\omega t)\}$$

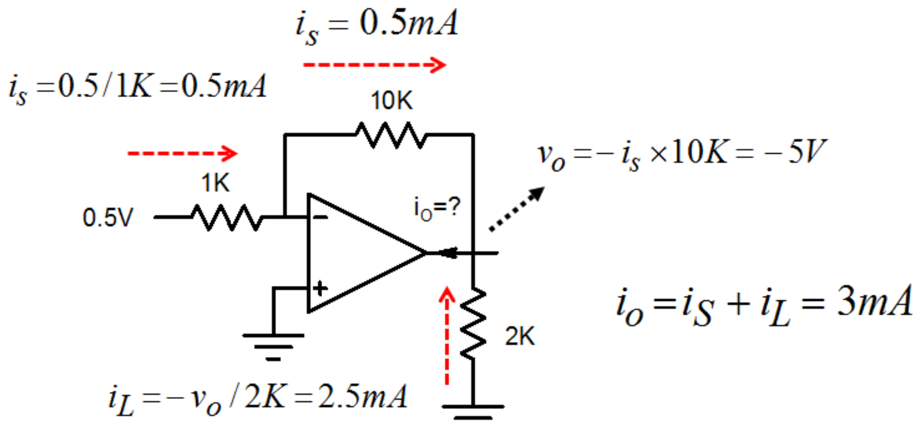
ii.



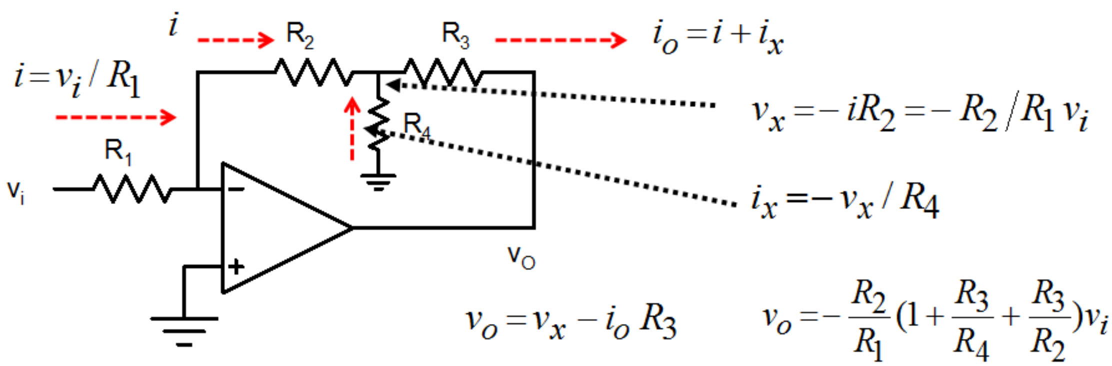
$$v_+ = v_- = 1V$$

$$\frac{1 - v_o}{1K} = 1mA \qquad v_o = 0V$$

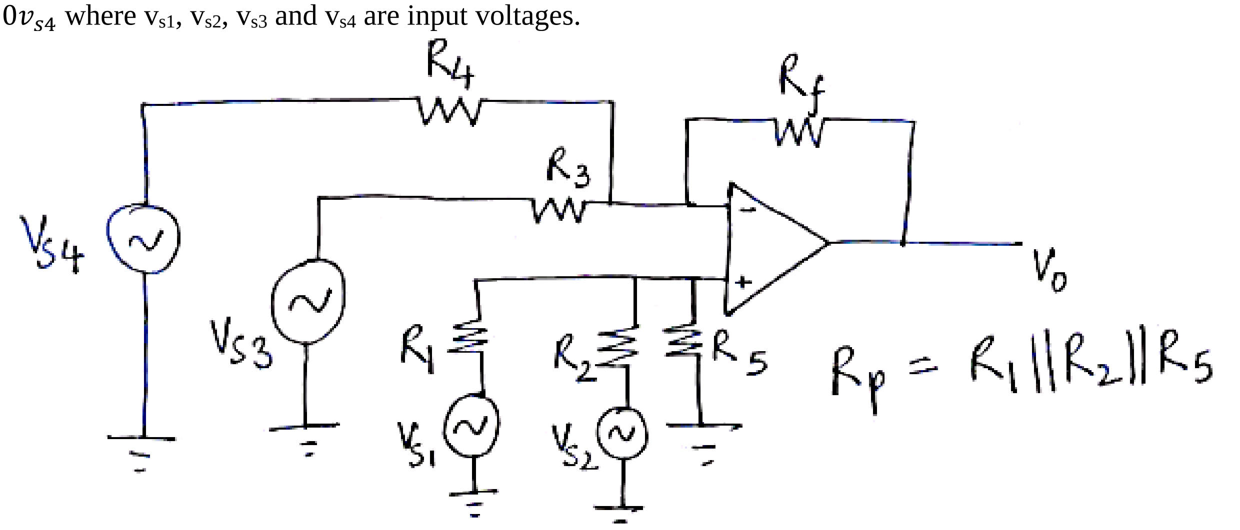
iii.



iv.



8. Design an op-amp circuit that would generate the following output voltage $V_O = 2v_{s1} + 4v_{s2} - 8v_{s3} - 10v_{s4}$ where v_{s1}, v_{s2}, v_{s3} and v_{s4} are input voltages.



$$v_o = -\left(\frac{R_f}{R_3}\right)v_{S3} - \left(\frac{R_f}{R_4}\right)v_{S4} + \left(1+\frac{R_f}{R_3 \| R_4}\right)\times\frac{R_p}{R_1}v_{S1}$$

$$+\left(1+\frac{R_f}{R_3 \| R_4}\right)\times\frac{R_p}{R_2}v_{S2}$$

$$V_0 = 2v_{S1} + 4v_{S2} - 8v_{S3} - 10v_{S4}$$

Let $R_f = 10K$

$$\therefore \frac{R_f}{R_3} = 8$$

$$\frac{10K}{R_3} = 8 \Rightarrow R_3 = 1.25k\Omega$$

$$\frac{R_f}{R_4} = 10$$

$$\therefore \frac{10K}{R_4} = 10 \Rightarrow R_4 = 1k\Omega$$

$$\frac{R_f}{R_3 \| R_4} \times \frac{R_p}{R_1} = 2 \Rightarrow \frac{10K}{(1.25k \| 1k)} \times \frac{R_p}{R_1} = 2$$

$$\Rightarrow \frac{R_p}{R_1} = 0.105$$

$$\frac{R_f}{R_3 \| R_4} \times \frac{R_p}{R_2} = 4 \Rightarrow \frac{10K}{(1.25k \| 1k)} \times \frac{R_p}{R_2} = 4$$

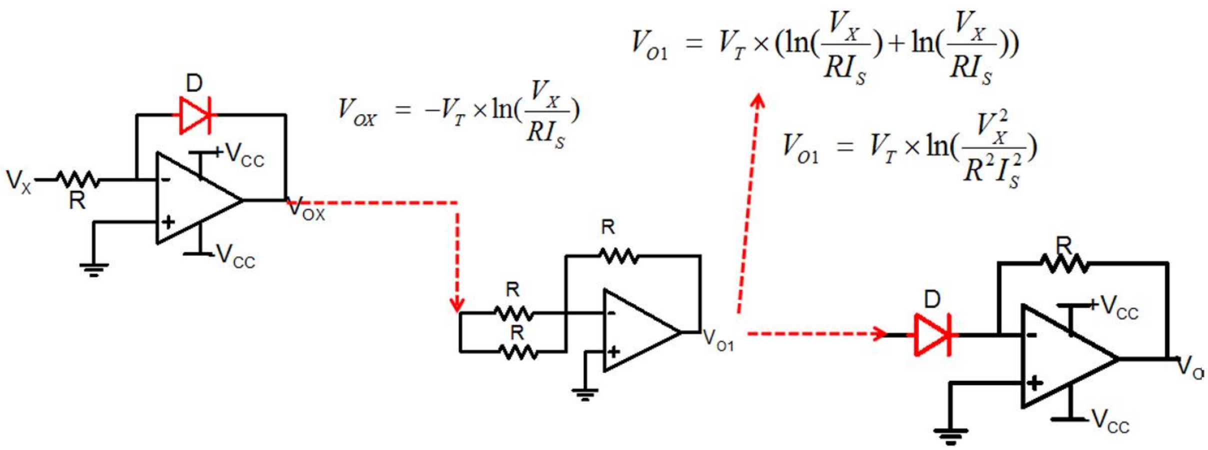
$$\Rightarrow \frac{R_p}{R_2} = 0.211$$

$$\frac{R_1}{R_p} \times \frac{R_p}{R_2} = \frac{1}{0.105} \times 0.211 \Rightarrow \frac{R_1}{R_2} = 2$$

Let $R_2 = 1k\Omega \Rightarrow R_1 = 2k\Omega \Rightarrow R_p = 0.211k\Omega$

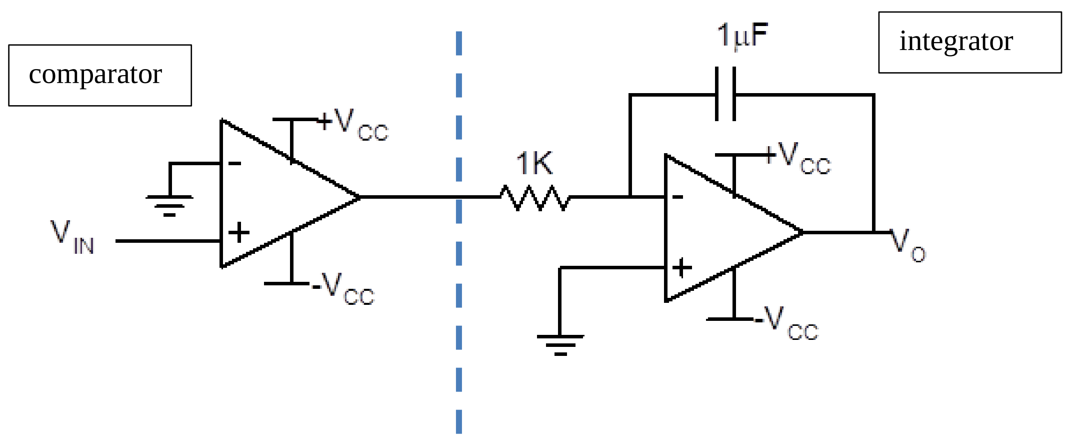
$$\therefore R_5 = 0.308k\Omega$$

9. Design an op-amp circuit that can produce $V_O = K \times V_{IN}^2$ where V_{in} is the input voltage.



$$V_O \cong -RI_S \times e^{\frac{V_{O1}}{V_T}} = -\frac{V_X^2}{RI_S}$$

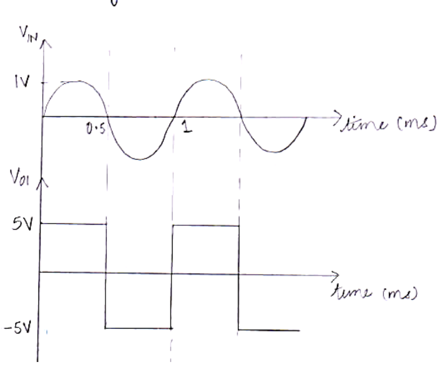
10. Sketch the output voltage of the circuit shown below for $V_{in} = 1V sin(2\pi f t); f = 1KHz$ and supply voltages of $\pm 5V$



for the comparator,

$V_{01} = +5V$ if $V_{IN} > 0$

$= -5V$ if $V_{IN} < 0$

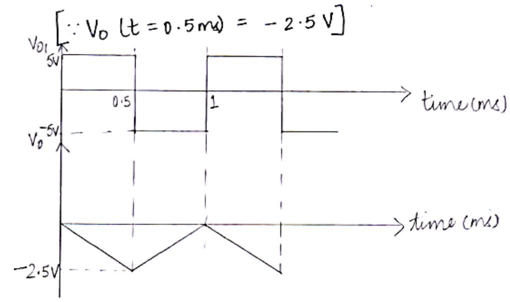


For the integrator, $V_O(t) = \frac{-1}{RC}\int V_{01}\,dt = -10^3 \int V_{01}\,dt$

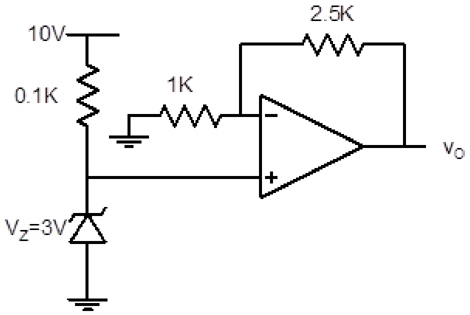
for $V_{IN} > 0$, $V_0 = -5 \times 10^3 \times t$

for $V_{IN} < 0$, $V_0 = -2.5 + 5 \times 10^3 (t - 0.5ms)$

$[\because V_0(t = 0.5ms) = -2.5V]$



11 Determine the output for the ideal op-amp circuit shown below.



This is a non-inverting amplifier with V_Z as input.

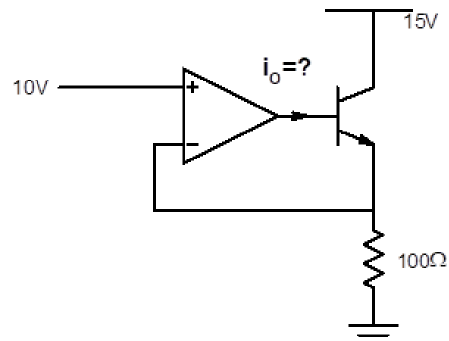
$$v_0 = V_Z\left(1 + \frac{R_2}{R_1}\right)$$

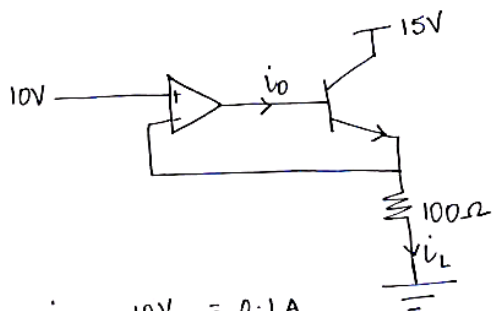
$$\therefore v_0 = 3\left(1 + \frac{2.5}{1}\right) V$$

$$\Rightarrow v_0 = 3(3.5) V$$

$$\Rightarrow v_0 = 10.5 V$$

12. Determine the output for the ideal op-amp circuits shown below. For the transistor assume a current gain of 100. What is the usefulness of each of the circuits?





$$i_L = \frac{10V}{100\Omega} = 0.1 A$$

$$I_0 = i_0 = I_B = \frac{I_E}{\beta+1} = \frac{i_L}{\beta+1} = \frac{0.1 A}{101} = 0.99mA.$$

The circuit can supply load current that is much larger than op-amp output current.