1.

Q:- 1

$$V_{Tn} = V_{Tn0} + \gamma\left(\sqrt{|V_{SB}| + |2\phi_F|} - \sqrt{2\phi_F}\right)$$

$$= 0.6 + 0.4\left(\sqrt{0.5+0.8} - \sqrt{0.8}\right)$$

$$= 0.6 + 0.4\,(1.14 - 0.894)$$

$$= 0.698$$

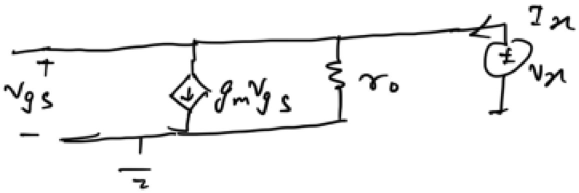
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)\right]^2$$

$$= \frac{1}{2} \times 100 \times 10^{-6} \times 50 \times (0.9 - 0.698)^2$$

$$= 101.77\,\mu A$$

2.

Q:- 2 Small signal model of mosfet



$$R_x = \frac{V_x}{I_x}$$

K.C.L

$$g_m V_{gs} + \frac{V_x}{r_o} = I_x$$

$$V_x - V_{gs} = 0$$

$$V_{gs} = V_x$$

$$g_m V_x + \frac{V_x}{r_o} = I_x$$

$$V_x\left(g_m + \frac{1}{r_o}\right) = I_x$$

$$R_x = \frac{V_x}{I_x} = \frac{1}{\frac{1}{r_o} + g_m}$$

$$= r_o \parallel \frac{1}{g_m}$$

3.

Q:- 3 For 2.73V to 3.73V at input output should be from 0 to 5V.

For 1V input swing output swing is 5V.

Gain of op-amp = $\underline{5}$.

Let's say, for $V_{in} = 3.73V$.

$V_{out} = 5V$

K.C.L at inverting node:-

$$\frac{3.73-5}{R_a} + \frac{3.73}{80k} + \frac{3.73-5}{100k} = 0$$

$$\boxed{R_a = 37k}$$

4.

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{th})^{\alpha}(1+\lambda V_{DS})$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

3 marks

$$\Rightarrow \quad g_m = \frac{\alpha}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{TH})^{\alpha-1}(1+\lambda V_{DS})$$

2 marks

$$r_o = \left(\frac{\partial I_D}{\partial V_{DS}}\right)^{-1}$$

3 marks

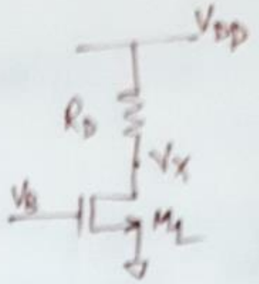
$$\Rightarrow \quad r_o = \frac{1}{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_{th})^{\alpha}\cdot\lambda}$$

2 marks

5.

Q.5. Solution:

For M_1 to be at the edge of the saturation,



$$V_{DS} = V_{GS} - V_{th}$$

$$\Rightarrow V_X = V_B - V_{th}$$ — 2 marks

Now,

$$I_D = \frac{V_{DD} - V_X}{R_D} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

— 2 marks

$$\Rightarrow \frac{1.8 - V_X}{5 \times 10^3} = \frac{1}{2} \cdot 200 \times 10^{-6} \times \frac{20}{0.18} V_X^2 (1 + 0.1 V_X)$$

$$\Rightarrow V_X^3 + 10V_X^2 + 0.18V_X - 0.324 = 0$$

$$\Rightarrow V_X = 0.169\text{ V}$$ — 4 marks

$$\Rightarrow \boxed{V_B = 0.569\text{V}}$$ — 2 marks

Note:

1) Those who have ignored 'λ' (i.e. taken $\lambda = 0$) have been given full marks if they got the answer as $V_B = 0.571$V

2) Those who have taken $\lambda = 0.1$ & left the solution till the cubic equation, have been given full marks if their final cubic equation is correct.

6.

1) Given :– $R_1 = 100\,k\Omega$, $C_f = 0.1\,\mu F$, $V_c(0) = 0 = V_o(0)$

$$\Rightarrow I = \frac{V_i - 0}{R_1} \Rightarrow I = C_f \cdot \frac{d(0 - V_o)}{dt} = -C_f \frac{dV_o}{dt}$$

$$\Rightarrow \frac{V_i}{R_1} = -C_f \frac{dV_o}{dt} \Rightarrow \frac{dV_o}{dt} = -\frac{V_i}{C_f R_1} \Rightarrow V_o = -\underbrace{\int_0^t \frac{V_i\,dt}{R_1 C_f}}_{(i)}$$ ← expression of an integrator

for $0 \le t < 1 \rightarrow V_i = 50\,mV$

$1 \le t < 2 \rightarrow V_i = -50\,mV$

By incorporating the charge developed on the capacitor :–

$$\Rightarrow V_o(t) - V_o(t_i) = -\frac{1}{R_1 C_f} \int_0^t V_i\,dt$$

<u>For $0 \le t < 1$</u> :– $V_o(0) = 0$

$$\Rightarrow V_o(t) - V_o(0) = -\frac{1}{R_1 C_f} \int_0^t V_i\,dt = -\frac{1}{100 \times 10^3 \times 0.1 \times 10^{-6}} \int_0^t 50 \times 10^{-3}\,dt$$

$$\Rightarrow V_o(t) - 0 = -\frac{50 \times 10^{-3}}{10^5 \times 10^{-7}} \times t \Rightarrow \underline{V_o(t) = -5t}$$ for $0 \le t < 1$

When $t = 1s$, $V_o(1) = -5V$ ⇐ charge developed on the capacitor at $t = 1s$

<u>For $1 \le t < 2$</u> :– $\Rightarrow V_o(t) - V_o(t_1) = -\frac{1}{R_1 C_f} \int_1^t V_i\,dt$

$$\Rightarrow V_o(t) + 5 = -\frac{1}{100 \times 10^3 \times 0.1 \times 10^{-6}} \int_1^t (-50 \times 10^{-3})\,dt$$

$$\Rightarrow V_o(t) + 5 = 5\,[t]_1^t - 5 \Rightarrow V_o(t) = 5(t-1) - 5$$

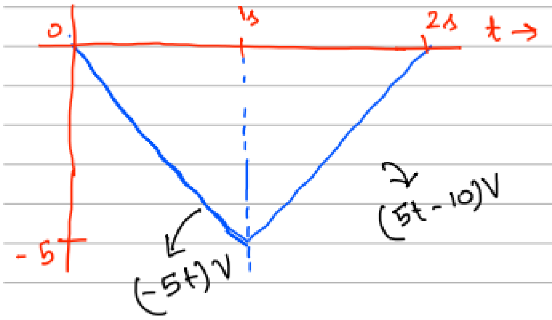
$\Rightarrow V_o(t) = 5t - 10 \Leftarrow$ for $1 \le t < 2$

When $\underline{t = 2s}$ $\Rightarrow V_o(2) = 0V$.

$$\boxed{\begin{aligned} V_o(0) &= 0V \\ V_o(1) &= -5V \\ V_o(2) &= 0V. \end{aligned}}$$

for $0 \le t < 1 \rightarrow V_o = (-5t)V$

$1 \le t < 2 \rightarrow V_o = (5t - 10)V$



7.

2) $\Rightarrow I_c = C \cdot \frac{d}{dt}\left(\frac{V_i - 0}{1}\right) = \frac{C dV_i}{dt}$

$\Rightarrow I_c = \frac{0 - V_o}{R_f} = -\frac{V_o}{R_f} \Rightarrow \frac{C dV_i}{dt} = -\frac{V_o}{R_f} \Rightarrow V_o = -C \cdot R_f \frac{dV_i}{dt}$

$\Rightarrow V_o = -2 \times 10^{-6} \times 10 \times 10^3 \times \frac{d}{dt}(30t) = \left(-2 \times 10^{-2} \times 30\right)V = -0.6V$

8.

2) $V_o = 2V_1 - 3V_2 + 4V_3 - 5V_4$

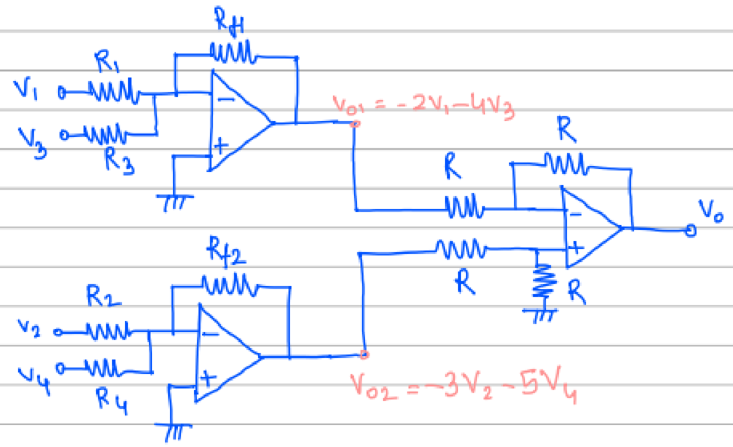
The +ve and -ve terms can be added separately using 2 adders and then subtractor can be used.

$\Rightarrow V_{o1} = -\left(\frac{R_{f1}}{R_1} V_1 + \frac{R_{f1}}{R_3} V_3\right) \quad \Rightarrow \frac{R_{f1}}{R_1} = 2 \quad \Rightarrow \frac{R_{f1}}{R_3} = 4$

Let $R_{f1} = 100k\Omega$, then $R_1 = 50k\Omega$, $R_3 = 25k\Omega$

$\Rightarrow V_{o2} = -\left(\frac{R_{f2}}{R_2} V_1 + \frac{R_{f2}}{R_4} V_3\right) \quad \Rightarrow \frac{R_{f2}}{R_2} = 3 \quad \Rightarrow \frac{R_{f2}}{R_4} = 5$

Let $R_{f2} = 150k\Omega \quad \Rightarrow R_2 = 50k\Omega \quad \Rightarrow R_4 = 30k\Omega$



9.

3) For an ideal integrator:- $V_o = -\frac{1}{R_1 C_f}\int_0^t V_{in}\, dt$

$R_1 = 100k\Omega$, $C_f = 1\mu F$, $V_m = 6mV$, $\omega = 2\pi f = 4\pi \times 10^3$ rad/s

$\Rightarrow V_o = -\frac{1}{100\times10^3 \times 1\times10^{-6}}\int_0^t 6\times10^{-3}\sin(4\pi\times10^3 t)\, dt$

$\Rightarrow V_o = -0.06\left[\frac{-\cos(4\pi\times10^3 t)}{4\pi\times10^3}\right]_0^t = 4.77\times10^{-6}\left[\cos(4000\pi t) - 1\right] V$

(Ans)

10.

a) By symmetry,

$$I_{D_1} = I_{D_2} = I/2 = 0.2\,mA \;,\; V_{D_1} = V_{D_2} = 3 - 2.5 \times 0.2 = 2.5V$$

For $V_{cm} = 2.5$

Assuming the transistors are in saturation, — 2 marks

$$I_{D_1} = \frac{1}{2} \cdot \mu_n C_{ox} \frac{W}{L} (V_{cm} - V_S - V_{th})^2$$

$$200 \times 10^{-6} = \frac{1}{2} \cdot 200 \times 10^{-6} \times 10 \, (V_{GS} - 0.4)^2$$

$$\Rightarrow V_{GS} = 847m$$ — 2 marks

b) $V_S = V_{CM} - V_{GS} = 1.653\,V$ — 2 marks

c) For saturation $V_{D_1} > V_{cm} - V_{th}$

$\therefore \boxed{V_{cm} < 2.9V}$ — 2 marks

d) For conduction,

$$V_{GS} > V_{th}$$

$$\therefore V_{cm} - V_S > V_{th}$$

$\therefore \boxed{V_{cm} \geq 0.7V}$ — 2 marks

Note: Some students have used $V_{GS} = 847m$ in part 'd'. They have been given full marks.

11.

Q:- (1)

$$g_{m_1} = \sqrt{2 I_{D_1} \mu_n C_{ox} \left(\frac{W}{L}\right)_1}$$

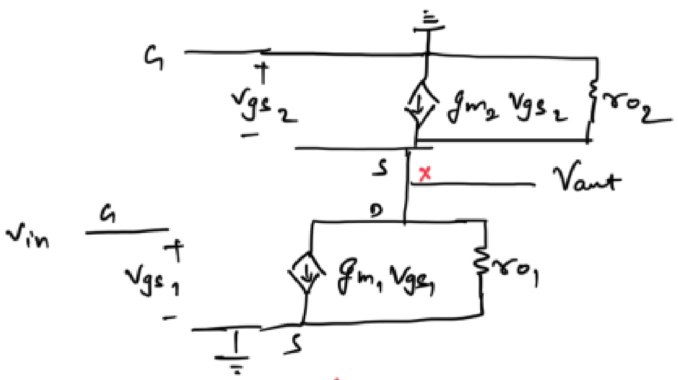
$$= \sqrt{2 \times 150 \times 10^{-6} \times 60 \times 10^{-6} \times 5}$$

$$= 300 \mu A/V$$

$$g_{m_2} = \sqrt{2 I_{D_2} \mu_n C_{ox} \left(\frac{W}{L}\right)_2}$$

$$= \sqrt{2 \times 150 \times 10^{-6} \times 60 \times 10^{-6} \times 20}$$

$$= 600 \mu A/V$$



K.C.L at node x

$$g_{m_1} V_{gs_1} + \frac{V_{out}}{r_{o_1}} + \frac{V_{out}}{r_{o_2}} - g_{m_2} V_{gs_2} = 0 \quad \text{— (iii)}$$

$$V_{in} - V_{gs_1} = 0$$

$$V_{in} = V_{gs_1} \quad \text{— (i)}$$

$$-V_{gs_2} - V_{out} = 0$$

$$V_{out} = -V_{gs_2} \quad \text{— (ii)}$$

Putting eq. (i) & eq. (ii) in eq. (iii)

$$g_{m_1} V_{in} + \frac{V_{out}}{r_{o_1}} + \frac{V_{out}}{r_{o_2}} + g_{m_2} V_{out} = 0$$

$$V_{out}\left(\frac{1}{r_{o_1}} + \frac{1}{r_{o_2}} + g_{m_2}\right) = -g_{m_1} V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{-g_{m_1}}{\frac{1}{r_{o_1}} + \frac{1}{r_{o_2}} + g_{m_2}}$$

$$\frac{1}{6} + \frac{1}{6}$$

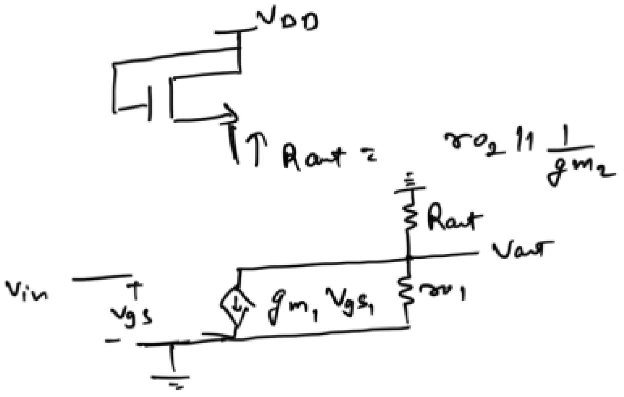
$$\frac{2}{6} \qquad \frac{1}{3} \times 10^{-6} + 600 \times 10^{-6}$$

$$= \frac{-300 \times 10^{-6}}{600.33 \times 10^{-6}}$$

$$\left(\frac{1}{3} + 600\right)$$

$$\boxed{\frac{V_{out}}{V_{in}} = -0.499}$$

Alternative soln:-



$$\frac{V_{out}}{V_{in}} = -g_{m_1}(r_{o_1} \,||\, R_{out})$$

$$= -g_{m_1}\left(r_{o_1} \,||\, r_{o_2} \,||\, \frac{1}{g_{m_2}}\right)$$

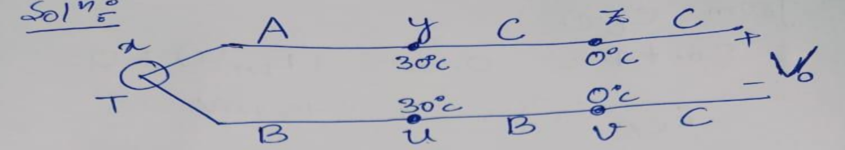
As $(r_{o_1} \,||\, r_{o_2}) >> \frac{1}{g_{m_2}}$

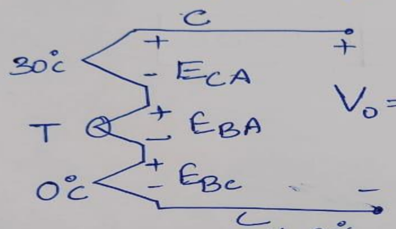
$$r_{o_1} \,||\, r_{o_2} \,||\, \frac{1}{g_{m_2}} \approx \frac{1}{g_{m_2}}$$

$$\frac{V_o}{V_{in}} = \frac{-g_{m_1}}{g_{m_2}} = \underline{-0.5}$$

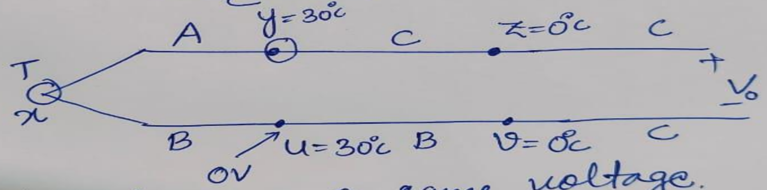
12.

Soln:





$V_0 = 26.74 mV$



⇒ u and z are on same voltage.

1st thermocouple,

$V_0 = E_{CA}(30) + E_{BA}(T) + E_{BC}(0°C)$ —①

$E_{CA}(30°C) = E_{CB}(30°C) - E_{AB}(30°C) = 1.196 - 1.801 = -0.605 mV$

$E_{BC} = 0V$, $V_0 = 26.74 mV$

from eq-①

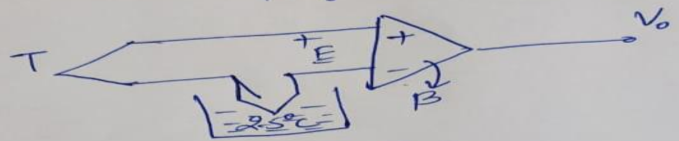
$26.74 = -0.605 + E_{BA}(T) + 0$

$E_{BA}(T) = 27.345 mV$

from table, $\boxed{T = 380°C}$

13.

→ Solⁿ → 1(a) Given. $\beta = 1000$
$V_o = 2.050$
$T = ?$



$E = S\,(T_H - T_c)$

$E = S\,(T - 25°C)$ —①

$E = V_{in}$ —②

$V_o = V_{in} \times \beta$

$2.050 = V_{in} \times 1000$

$\boxed{V_{in} = 2.050 \times 10^{-3}\ V}$

from eq ① & ②

$2.050 \times 10^{-3} = 41 \times 10^{-6}\,(T - 298)$

$T - 298 = \dfrac{2.050 \times 10^{-3}}{41 \times 10^{-6}} \Rightarrow T = 50 + 298$

$T = 348K \Rightarrow \boxed{T = 75°C}$

14.

⇒ Solⁿ ①(a) $\beta = 25$, $V_o = 96mV$

$\theta_{ref} = 0$

$S = 40\mu V/°C$

$\theta = ?$

$E = S\,(\theta - \theta_{ref})$ —①

$E = V_{in}$

$V_o = \beta \times V_{in}$

$V_{in} = \dfrac{96}{25} = 3.84mV$

$\theta = \dfrac{3.84mV}{40\mu V} + 0$

$\boxed{\theta = 96°C}$ Ans