HW 3

21 April 2020 12:00 AM

(i) $T = 300\,K$, $V_A = 100V$, $V_{GS} - V_{TH} = 500mV$, $\lambda = 0.1V^{-1}$, $C_L = 10pF$ & $I_C = I_D = 1mA$

(a) $a_v = ?$ $\frac{g_m}{I_C} = ?$ $\frac{g_m}{I_D} = ?$

Bipolar

$$g_m = \frac{I_C}{V_t} = \frac{1m}{25.87\,mV} = \frac{8}{207}\ I/V$$

$$r_o = \frac{V_A}{I_C} = \frac{100}{1m} = \underline{\underline{100\,K\Omega}}$$

$$\text{DC voltage gain} = -g_m r_o = \underline{\underline{-3864.7343\,V/V}}$$

$$\frac{g_m}{I_C} = \underline{\underline{38.647}}$$

MOS

$$g_m = \frac{2I_D}{V_{GS} - V_t} = \frac{2m}{500m} = \frac{1}{250}\ I/V$$

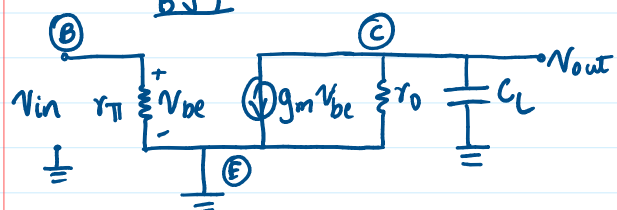
$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0.1 \times 1m} = \underline{\underline{10\,K\Omega}}$$

$$\text{DC voltage gain} = -g_m r_o = \underline{\underline{-40\,V/V}}$$

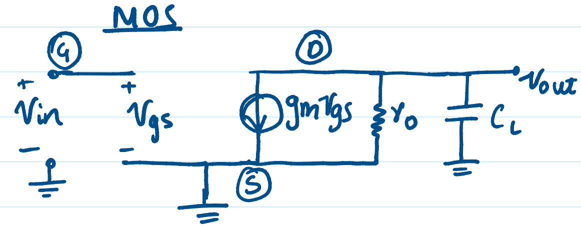
$$\frac{g_m}{I_D} = \underline{\underline{4}}$$

(b) $a_v = \frac{V_{out}}{V_{in}} = ?$

BJT



MOS



$$V_{be} = V_{in} \quad \text{——} \ (1)$$

$$g_m V_{be} + \frac{V_{out}}{r_o} + V_{out}(sC_L)$$

$$V_{out}\left(\frac{1}{r_o} + sC_L\right) = -g_m V_{in}$$

$$a_v = \frac{V_{out}}{V_{in}} = \frac{-g_m r_o}{1 + s r_o C_L} \quad \text{——} \ (2)$$

$$|V_{out}| = |V_{in}| \quad @\ f = f_T$$

$$|g_m r_o| = |1 + s r_o C_L|$$

$$(g_m r_o)^2 = 1^2 + r_o^2 C_L^2 (2\pi)^2 f_T^2$$

$$(3864.7343)^2 = 1 + (10^5 \times 10 \times 10^{-12})^2 (2\pi)^2 f_T^2$$

$$f_T = 615.\underline{09155}\,MHz$$

$$V_{gs} = V_{in} \quad \text{——} \ (3)$$

$$g_m V_{gs} + \frac{V_{out}}{r_o} + V_{out}(sC_L)$$

$$V_{out}\left(\frac{1}{r_o} + sC_L\right) = -g_m V_{in}$$

$$a_v = \frac{V_{out}}{V_{in}} = \frac{-g_m r_o}{1 + s r_o C_L} \quad \text{——} \ (4)$$

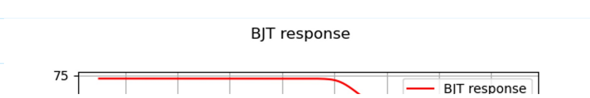
$$|V_{out}| = |V_{in}|$$

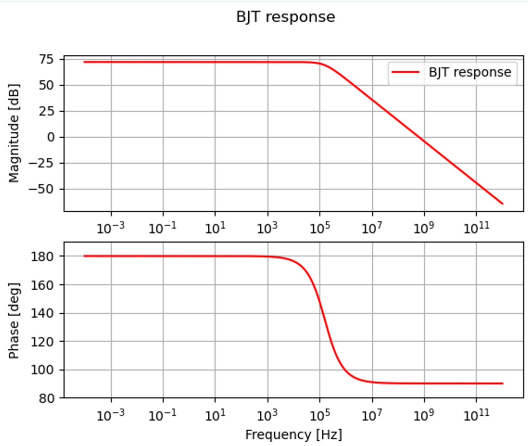
$$|g_m r_o| = |1 + s r_o C_L|$$

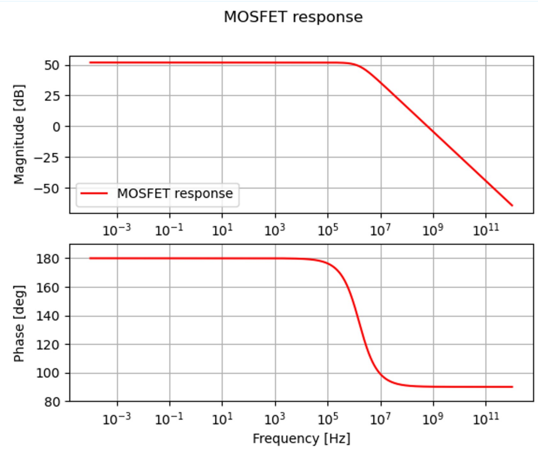
$$(g_m r_o)^2 = 1^2 + r_o^2 C_L^2 (2\pi)^2 f_T^2$$

$$(40)^2 = 1^2 + (10^4 \times 10 \times 10^{-12})^2 (2\pi)^2 f_T^2$$

$$f_T = 63.\underline{64208}\,MHz$$







$I_D = I_s e^{V_{GS}/nV_T}$ & $n = 1.5$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{1}{nV_T} I_s e^{V_{GS}/nV_T}$$

$$g_m = \frac{I_D}{nV_T} \quad \text{—— (1)}$$

$$\frac{g_m}{I_D} = \frac{1}{nV_T} = \frac{1}{1.5 \times 25.875m} = \underline{\underline{25.765}}$$

In Subthreshold region, we observe that the transistor provides better g_m & gain

(2) a) $N = 8$

$I_{C1} = I_{C2} = 50\mu A \quad T = 300K$

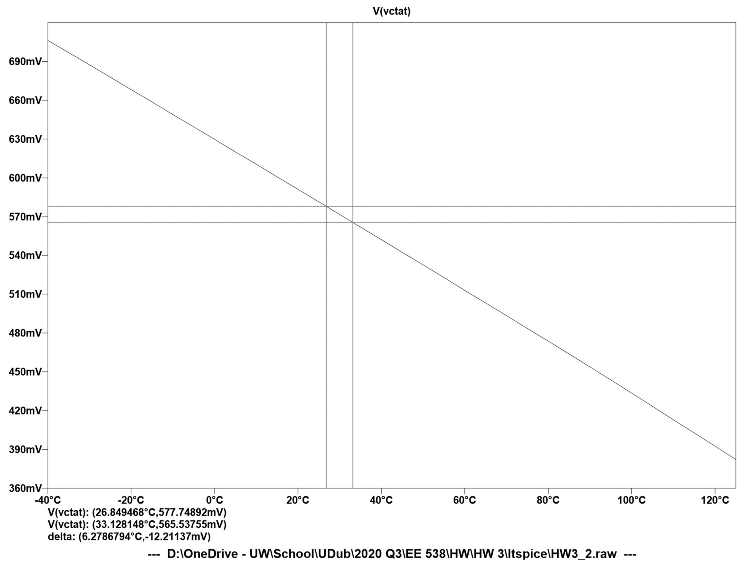
$$\Delta V_{BE} = V_{BE1} - V_{BE2}$$
$$= V_T \ln \frac{I_{C1}}{I_s} - V_T \ln \frac{I_{C2}}{NI_s}$$

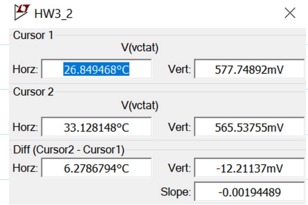
$$\Delta V_{BE} = V_T \ln\left(\frac{I_{C1}}{I_{C2}} . N\right) \Rightarrow \Delta V_{BE} = V_T \ln N$$
$$= 25.86m \cdot \ln 8$$
$$= 53.774mV$$

$$R_1 = \frac{\Delta V_{BE}}{I_{C2}} = \frac{53.774mV}{50\mu}$$

$$\boxed{R_1 = 1075.48\ \Omega}$$

b) Slope = ? & M = ?





Slope = $-1.944 \text{ mV/}^\circ\text{C}$

To operate in forward active region

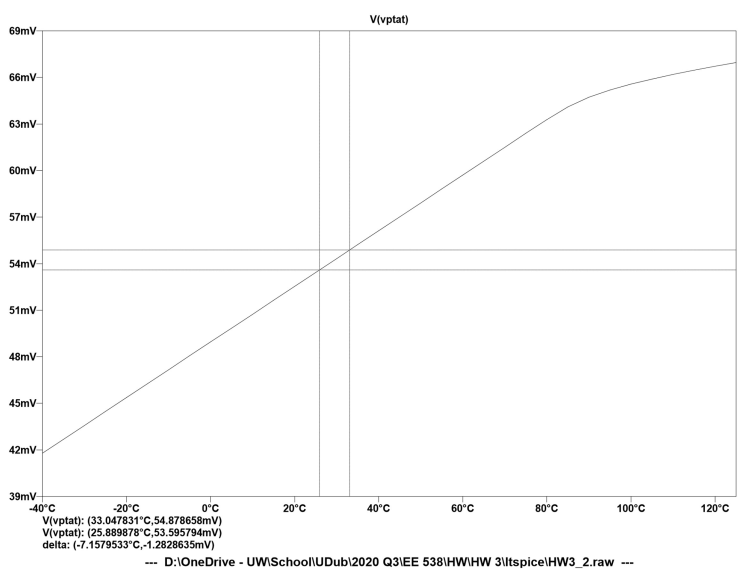
$V_{CE} \geq V_{BE}$

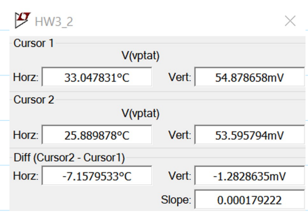
$V_{CE} \geq 0.523V$

Say $V_{CE} = 1V$

$$R_2 = \frac{V_{CC} - V_{CE}}{I_{C1}} = \frac{5-1}{50\mu} = \boxed{80K\Omega}$$

$$\frac{dV_{BE1}}{dt} = -M \frac{d}{dt} \Delta V_{BE}$$





Slope = $0.17922 \text{ mV/}^\circ\text{C}$

$$M = \frac{1.94489}{0.17922}$$

$$\Rightarrow M = 10.85$$

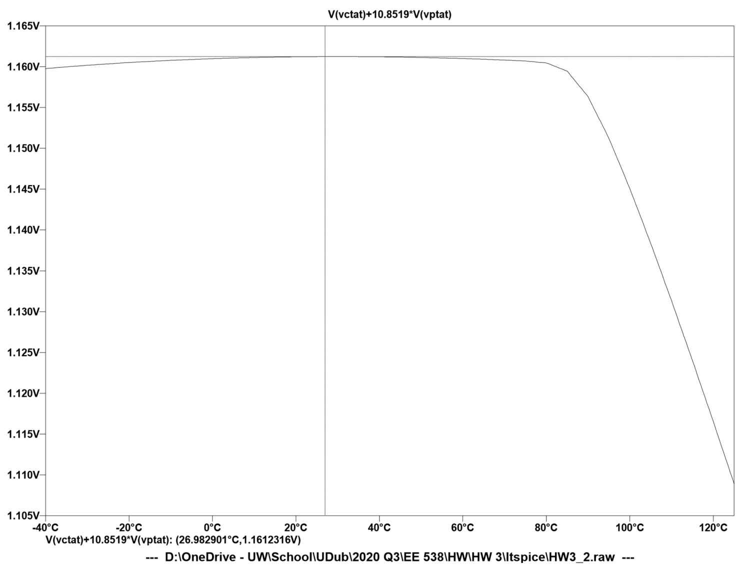
(c) 1. Value of BG at room temperature

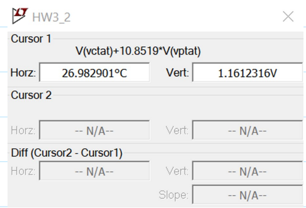
$$V_{BG} = V_{CTAT} + V_{PTAT}$$

$$= V_{BE} + M\,\Delta V_{BE}$$

$$= [577.74892 + 10.85\,(53.5958)]\ \text{mV}$$

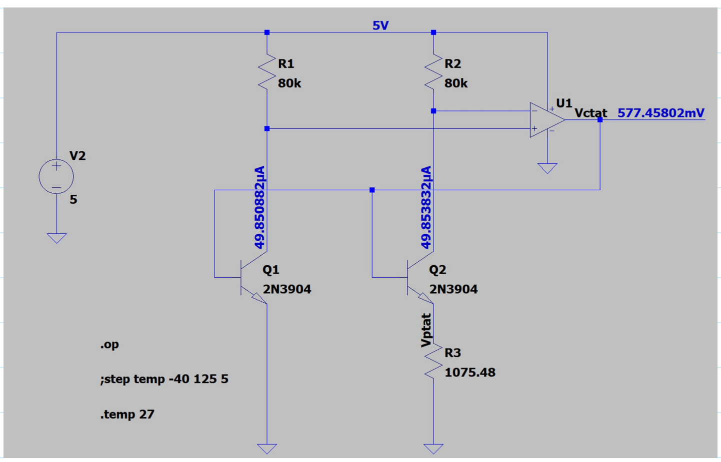
$$V_{BG} = V_{CTAT} + V_{PTAT}$$
$$= V_{BE} + M\,\Delta V_{BE}$$
$$= [577.45802 + 10.85\,(53.7948)]\ mV$$
$$V_{BG} = \underline{1.1611V} \quad \text{at} \quad 27^{\circ}C$$





2. Maximum deviation occurs at $T = 125^{\circ}C$

$$\%\ \text{error} = \frac{1.1611 - 1.1089}{1.1611} = 4.49\%\ \text{deviation}$$



Bonus:

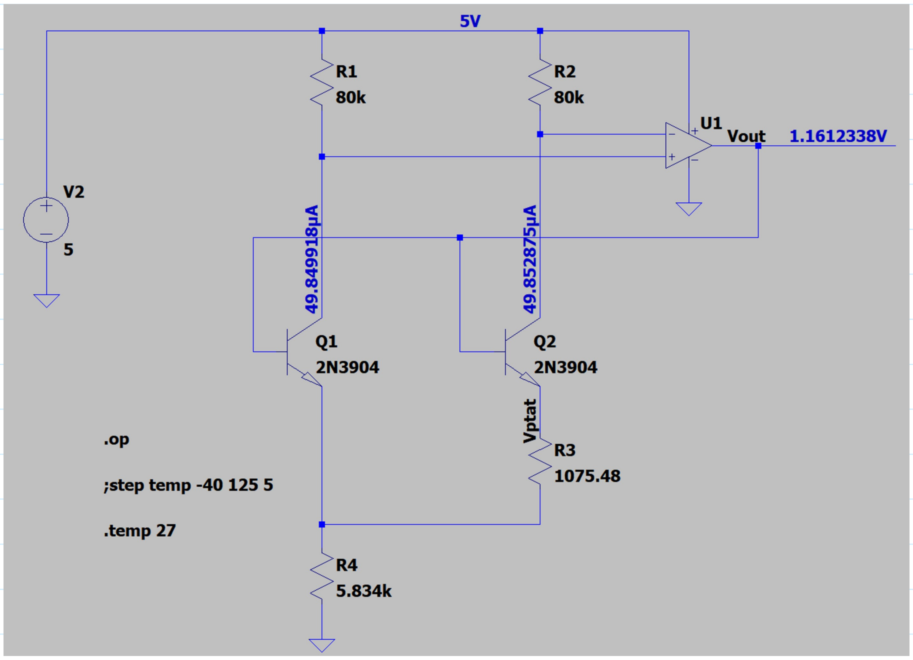
Need to add a resistor R_4. $\quad V_{R4} = I_4 R_4 = (2I_{C1}) R_4$

$$V_{BG} = V_{R4} + V_{BE1}$$
$$V_{BG} = R_4\left(2\,\frac{\Delta V_{BE}}{R_1}\right) + V_{BE1}$$

$$V_{BG} = R_4\left(2\,\frac{\Delta V_{BE}}{R_1}\right) + V_{BE1}$$

$$1.1611 = R_4\left[\frac{2\times 53.79m}{1075.48}\right] + 577.458m$$

$$\boxed{R_4 = 5.834\ k\Omega}$$



③ $$V_{out} = V_{DD} - K(V_{in} - V_{th})^2 R_D$$

a) $$V_{in} = a_{in}\,Sin(2\pi f_0 t) + V_{DC}$$

$$V_{DC} - V_{th} = 500mV$$

$$V_{out} = V_{DD} - K\left[a_{in}\,Sin(2\pi f_0 t) + V_{DC} - V_{th}\right]^2 R_D$$

$$V_{out} = V_{DD} - K\left[a_{in}^2\,Sin^2(2\pi f_0 t) + 0.25 + a_{in}\,Sin(2\pi f_0 t)\right]R_D$$

$$V_{out} = V_{DD} - K\left[\frac{a_{in}^2}{2}\left(1 - Cos(4\pi f_0 t)\right) + 0.25 + a_{in}\,Sin(2\pi f_0 t)\right]R_D$$

$$V_{out} = V_{DD} - \frac{K}{2}a_{in}^2 R_D - 0.25\,K R_D - K\,a_{in}\,Sin\,2\pi f_0 t\,R_D + \frac{K a_{in}^2}{2}\,Cos\,4\pi f_0 t \cdot R_D$$

$$a_1 = -K\,a_{in} R_D$$

$$a_2 = \frac{K a_{in}^2 R_D}{2}$$

(b) $a_{in} = 1mV$, $a_{in} = 10mV$

$\frac{a_2}{a_1} = \frac{1}{2} a_{in}$, $\frac{a_2}{a_1} = \frac{1}{2} a_{in}$

$\boxed{\frac{a_2}{a_1} = 0.5m}$, $\boxed{\frac{a_2}{a_1} = 5m}$