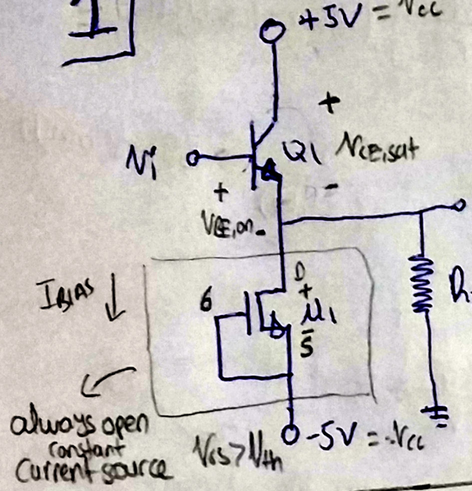
EHB-335E / HMW#4

1)



$V_{BE,on} = 0.7V$

$V_{CE,sat} = 0.2V$

$V_{th} = -1.8V$

$k_n = \frac{1}{2}\mu_n C_{ox} = \frac{12 mA}{V^2}$

$V_A = \infty$, $\lambda = 0$ } no transistor output impedance

a) $V_{cc} - V_{CE,sat} = V_{o,max}$ (At the edge of saturation)

$-V_{cc} + V_{ov1} = V_{o,min_1}$ (At the edge of triode) $V_{DS} = V_{ov}$

OR

$-I_{BIAS} R_L = V_{o,min_2}$ (Q_1 off)

$$\Rightarrow \boxed{V_{o,max} = 5V - 0.2V = 4.8V}$$

$$I_{BIAS} = k_n(\cancel{V_{GS}}^{0} - V_{th})^2 = \left(12 \frac{mA}{V^2}\right) \cdot (1.8V)^2 = 12 \cdot (1.8)^2 \, mA = 38.88 \, mA$$

→ For V_{min}

- $V_{o,min_1} = -V_{cc} + V_{ov} = -V_{cc} + (\cancel{V_{GS}}^{0} - V_{th}) = -5V + 1.8V = -3.2V$
- $V_{o,min_2} = -I_{BIAS} \cdot R_L$

i) For $R_L = \infty$ (open-circuit)

$$\boxed{V_{o,min} = -3.2V}$$

ii) For $R_L = 400\Omega = 0.4k\Omega \Rightarrow V_{o,min_2} = -(38.88)(0.4) = -15.552V$

$$\boxed{V_{o,min} = -3.2V}$$

b) Since M_1 is a constant current source, the maximum current that can flow through the load resistance is equal to the bias current, it is achieved if Q_1 is in cutoff.

Then,

$$I_{BIAS} = \frac{V_{out}}{R_L} = \frac{|V_e \sin\omega t|}{R_{L,min}} \Rightarrow R_{L,min} = \frac{|V_e|}{I_{BIAS}} = \frac{2V}{38.88mA} = 51.44\Omega.$$

c) What is power efficiency?

Given stage is an example of class-A output-stage.

$$P_{avg,L} = \frac{1}{T}\int_0^T (V_{out}) \cdot \frac{V_{out}}{R_L} = \frac{V_p^2}{TR_L}\int_0^T \sin^2 wt\, dt = \frac{V_p^2}{TR_L}\int_0^T \left(\frac{1}{2} - \cos(2wt)\right)dt$$

$(V_{out} = V_p \sin wt)$

$$P_{avg,L} = \frac{V_p^2}{T \cdot R_L} \cdot \frac{T}{2} - \cancel{\frac{V_p^2}{T \cdot R_L}\int_0^T \cos(2wt)\,dt}^{\,0} = \frac{V_p^2}{2R_L} = \frac{(2)^2}{2(51.44)} = 38.88\,mW$$

$$P_{avg,V^+} = \frac{1}{T}\int_0^T (I_{BIAS} + i_{RL})\,V_{cc} = I_{BIAS}V_{cc} + \cancel{\frac{V_{cc}}{TR_L}\int_0^T V_{out}\,dt}^{\,0}$$

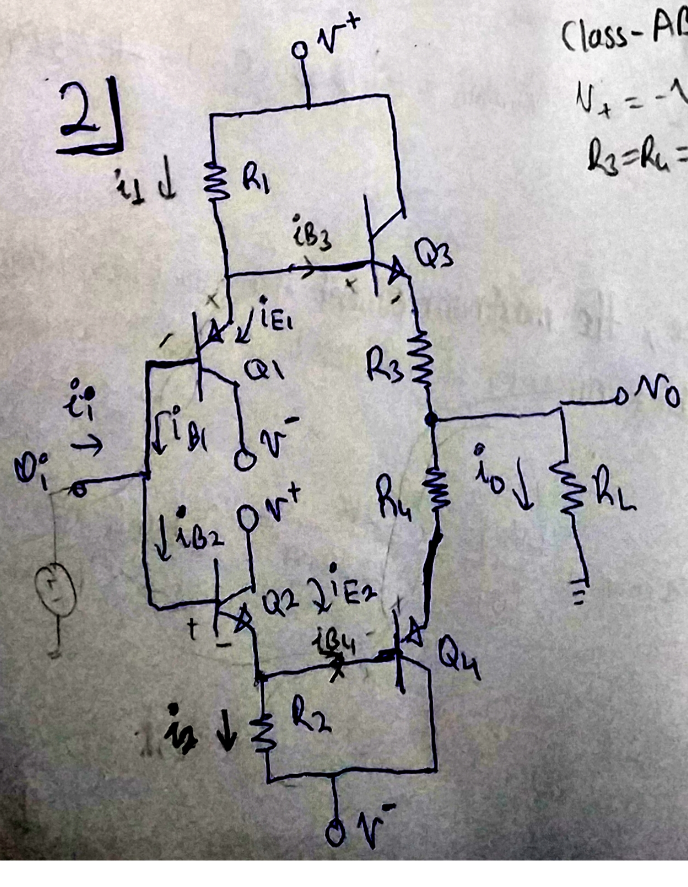
$$P_{avg,V^+} = I_{BIAS}V_{cc} + \frac{V_{cc}}{T \cdot R_L}\int_0^T V_p \sin wt\, dt = I_{BIAS}V_{cc} + \cancel{\frac{V_{cc} \cdot V_p}{T \cdot R_L}\int_0^T \sin wt\, dt}$$

$$P_{avg,V^+} = I_{BIAS}V_{cc} \;; \quad P_{avg,V^-} = I_{BIAS}V_{cc} = (38.88)(5)$$

$$\eta = \frac{P_{avg,L}}{P_{avg,V^+} + P_{avg,V^-}} = \frac{P_{avg,L}}{2P_{avg,V^-}} = \frac{38.88\,mW}{2(38.88)(5)\,mW} = \frac{1}{10} = 10\%$$

$\Rightarrow$ Since this is a class-A output stage, 10% power conversion efficiency is not surprising.

2]



Class-AB (Assume all transistors are matched)

$V_+ = -V_- = 12V$; $\beta = 40$; $V_{BE} = 0.7$; $R_1 = R_2 = 250\Omega$

$R_3 = R_4 = 0\,\Omega$; $R_L = 8\Omega$.

a) for $v_i = 0V$

$$v_i + \cancel{V_{EB_1}} - \cancel{V_{BE_3}} - V_o = 0$$

$$v_i = V_o = 0 \Rightarrow i_o = \frac{v_o}{R_L} = 0$$

$$i_1 = \frac{V^+ - V_{BE_1}}{R_1} = \frac{12-0.7}{250} = 45.2\,mA$$

$$i_2 = \frac{-V_{EB_2} - (V^-)}{R_2} = \frac{12-0.7}{250} = 45.2\,mA$$

$$i_{E_3} = i_o = 0 \Rightarrow$$

$\Rightarrow i_{E3} = i_o = 0A \Rightarrow i_{B3} = 0 \Rightarrow i_1 = i_{E_1} = 45.2mA$

$i_{B1} = i_{E_1}/(\beta+1) = \frac{45.2}{41} = 1.1mA$

and since $i_{E3} = i_o + i_{E4} \Rightarrow i_{E4} = 0 \Rightarrow i_{B4} = 0$

$i_{B4} = 0 \Rightarrow i_2 = i_{E_2} = 45.2mA \Rightarrow i_{B_2} = \frac{45.2mA}{41} = 1.1mA$

$\Rightarrow \boxed{i_{E_1} = 45.2mA}$; $\boxed{i_{E_2} = 45.2mA}$; $\boxed{i_{B_1} = 1.1mA}$; $\boxed{i_{B_2} = 1.1mA}$

b) for $V_i = 5V$

we know that $v_i + \cancel{v_{eb1}} - \cancel{v_{eb3}} - V_o = 0 \Rightarrow v_i = v_o = 5V$

Assume

$i_{E3} = i_o = \frac{v_o}{R_L} = \frac{5V}{8\Omega} = 0.625A \Rightarrow i_{B3} = \frac{i_{E3}}{\beta+1} = \frac{0.625}{41} = 15.24mA$

$i_1 = i_{E_1} + i_{B3} \Rightarrow i_{E_1} = i_1 - i_{B3} = \frac{V^+ - (V_i + V_{eb_1})}{R1} - i_{b3}$

$i_{E1} = \frac{12-5.7}{250} - 15.24 = 9.96mA$

$i_{B_1} = \frac{9.96}{41} = 0.243mA$

$i_{E_3} = i_o \Rightarrow i_{E4} = 0 \Rightarrow i_{B4} = 0$

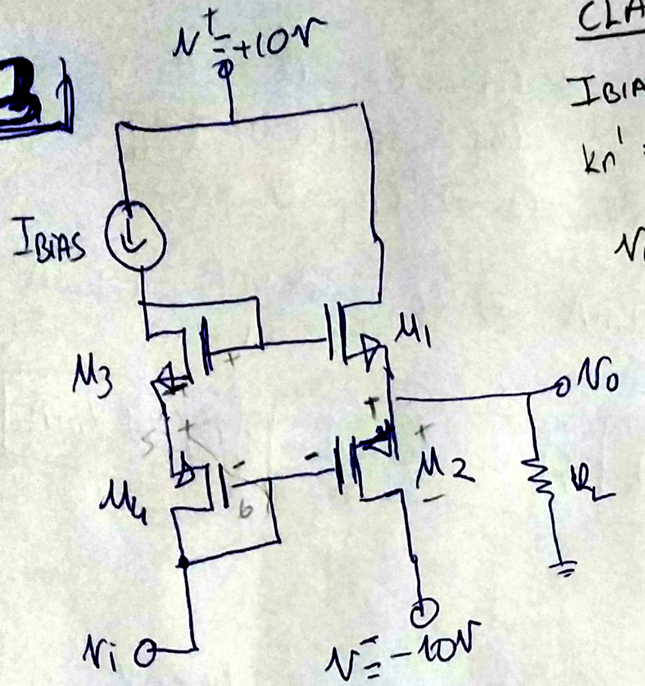
$i_{E_2} = i_2 = \frac{(v_i - v_{BE2}) - V^-}{R_2} = 65.2mA$

$i_{B_2} = \frac{i_{E2}}{\beta+1} = \frac{65.2}{41} = 1.6mA \Rightarrow i_{IN} = i_{B_2} - i_{B_1} = 1.3474mA$

$\boxed{i_{IN} = 1.347mA}$; $\boxed{i_o = 0.625A}$; $\boxed{i_{E_1} = 9.96mA}$; $\boxed{i_{E_2} = 65.2mA}$; $\boxed{i_{B_2} = 1.6mA}$; $\boxed{i_{B_1} = 0.243mA}$

c) Current Gain is calculated $A_i = \frac{i_{out}}{i_{in}} = \frac{i_o}{i_{IN}} = \frac{0.625A}{1.347mA} = 463.994$

3)



CLASS AB

$I_{BIAS} = 0.2mA$, $R_L = 1k\Omega$, $V_{th,n} = 0.8V$

$k_n' = 100\mu A/V^2$, $V_{th,p} = -0.8V$, $k_p' = 40\mu A/V^2$

$V_{GS,3} = V_{SG,4}$; $V_{GS,1} = V_{SG,2}$; $\lambda = 0$

a) $V_i = -1.5V$; $V_o = 0V$ $i_{D_1} = i_{D_2} = 0.5mA$

$$V_i + V_{SG,4} + V_{GS,3} - V_{GS,1} = V_o$$

$$V_i + 2V_{GS,3} - V_{GS,1} = 0V$$

-1.5

$$\boxed{2V_{GS,3} - V_{GS,1} = 1.5V}$$

$$V_i + V_{SG,2} = V_o \Rightarrow V_{SG,2} = -V_i$$

$$V_{SG,2} = 1.5V$$

$$2V_{GS,3} = 3V$$

$$\boxed{V_{GS,3} = 1.5V}$$

For M_1 and M_2 $i_{D_1} = i_{D_2} = 0.5mA$

$$5\times10^{-3} = (0.5)(10^{-4}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_1(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_1 = 20.4$$

$$5\times10^{-3} = (0.5)(4\times10^{-5}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_2(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_2 = 51.02$$

For M_3 and M_4 $I_{D_3} = I_{D_4} = I_{bias} = 0.2mA$

$$2\times10^{-3} = (0.5)(10^{-4}\tfrac{A}{V})\left(\tfrac{W}{L}\right)_3(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_3 = 8.16$$

$$2\times10^{-3} = (0.5)(4\times10^{-5})\left(\tfrac{W}{L}\right)_4(1.5-0.8)^2 \Rightarrow \left(\tfrac{W}{L}\right)_4 = 20.4$$

b) $V_{o,max}$

$$V_{o,max_1} = V^+ - V_{ov_1} = V^+ - (V_{GS1} - V_{th,n}) = 10V - (0.7V) = 9.3V$$

$$V_{o,max_2} = V^+ - V_{Ibias} - V_{GS,1} = 10 - (0.2 + 1.5V) = 8.3V$$

then $V_{o,max} = 8.3V$

$V_{o,min}$

$$V_{o,min_1} = V_{in} + V_{SG_2} = (-1.5V) + (1.5V) = 0$$

$$V_{o,min_2} = V^- + V_{SG1} = V^- + (V_{SG} - |V_{th}|) = -10V + (1.5 - 0.8V) = -9.3V$$

then $V_{o,min} = 0V$

$$\boxed{0V \le V_o \le 8.3V}$$