UNIVERSITI TENAGA NASIONAL

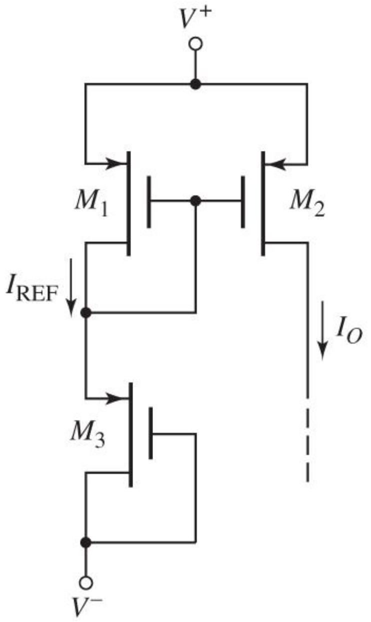
# COLLEGE OF ENGINEERING
# PUTRAJAYA CAMPUS
# FINAL EXAMINATION

## SEMESTER 1 2017 / 2018
## MODEL ANSWER

| | |
|---|---|
| PROGRAMME | **: Bachelor of Electrical & Electronics Engineering (Honours)**<br>**Bachelor of Electrical Power Engineering (Honours)** |
| SUBJECT CODE | **: EEEB273** |
| SUBJECT | **: ELECTRONIC ANALYSIS AND DESIGN II** |
| DATE | **: September 2017** |
| TIME | **: 3 hours** |

**Answers to Question 1 [20 marks]**

**(a) The PMOS version of Figure 1 [5 marks]**




Correct placements of $\boldsymbol{M_1}$, $\boldsymbol{M_2}$ and $\boldsymbol{M_3}$ [2 marks]
Labels for batteries, $\boldsymbol{V^+}$ and $\boldsymbol{V^-}$ [1 mark]
Labels for $\boldsymbol{I_{REF}}$ and $\boldsymbol{I_O}$ [2 marks]

**(b) Find IREF, IO and VSD2(sat) [15 marks]**

$I_{REF} = \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_1 (V_{SG1} + V_{TP})^2$ [2 marks]

$M_1$ and $M_3$: $I_{REF} = \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_1 (V_{SG1} + V_{TP})^2 = \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_3 (V_{SG3} + V_{TP})^2$ [2 marks]

$\left(\frac{50}{2}\right)(15)_1(V_{SG1} - 0.5)^2 = \left(\frac{50}{2}\right)(3)_3(V_{SG3} - 0.5)^2$…(1) [2 marks]

KVL: $V_{SG1} + V_{SG3} = 10 - V_{SG1}$ …(2) [2 marks]

$\sqrt{\frac{15}{3}}(V_{SG1} - 0.5) = (10 - V_{SG1}) - 0.5$ [1 mark]

$3.236V_{SG1} = 10.618$; $V_{SG1} = \underline{3.281\text{ V}}$ [1 mark]

Subs back, $I_{REF} = \left(\frac{50}{2}\right)(15)_1(3.281 - 0.5)^2 = \underline{2.900\text{ mA}}$ [2 marks]

So, IREF = IO = 2.900 mA [1 mark]

VDS2(sat) = VSG2 + VTP = 3.281 – 0.5 = <u>2.781 V</u> [2 marks]

**Answers to Question 2 [20 marks]**

**Calculation of Ad [6 marks]**

IQ =(80)/(20)IREF = 4IREF=2mA [1]
ID7=ID8=ID10 = IQ/2 = 1mA [0.5]

Ad = gm7(ro8||ro10) [1]
gm7 = 2.sqrt(Kn7.ID7) = (2)sqrt[½(100u)(10)(1m)]= 1.4142m A/V [1]
ro8 = $1/\lambda_n$.ID8 = 1/(0.02)(1m) = 50kΩ [1]
ro10 = $1/\lambda_p$.ID10 = 1/(0.03)(1m) = 33.3kΩ [1]
Ad = 1.4142m(50k||33.3k) = 1.4142(20k) = 28.28 [0.5]

**Calculation of Ro [4 marks]**

Ro = gm4.ro4.ro2 [1]
gm4 = 2.sqrt(Kn4.ID4) = (2)sqrt[½(100u)(10)(2m)]= 2m A/V [1]
ro4 = $1/\lambda_n$.ID4 = 1/(0.02)(2m) = 25kΩ = ro2 [1]
Ro = (2m)(25k)(25k) = 1.25 MΩ [1]

**Evaluation of Ro for CMRR [10 marks]**

CMRR = | Ad / Acm| [2]
Acm is inversely proportional to Ro, Acm ϵ (1/Ro) [2]
71dB => CMRR = $10^{71/20}$ = 3548 [1]
80dB => $CMRR_{new}$ = $10^{80/20}$ = 10000 [1]
Thus $Ro_{new}$ = (10000/3548)Ro = 2.82Ro [1]
i.e. 2.82 is the factor of how much Ro should **increase** [2]

$Ro_{new}$ = 2.82(1.25MΩ) = 3.54 MΩ [1]

**Answers to Question 3 [20 marks]**

*(a)* Requires DC Analysis to find $I_{C2}$

$I_{C2} = I_{C5}/2 = 0.5015$ mA [1]

$R_{id} = 2r_{\pi 2} = 2(\beta V_T / I_{C2}) = 2(200)(0.026)/0.5015\text{m} = 20.74\text{k}\Omega$ [3]

$r_{o5} = V_A / I_{C5} = 80/1.003\text{m} = 79.76\ \text{k}\Omega$ [1]

$R_{icm} = (1+\beta)(R_{ocs}) = (201)(79.76\text{k}) = 16.03\text{M}\Omega$ [2]

*(b)* $g_{m2} = I_{C2} / V_T = 0.5015\text{m}/0.026 = 19.29$ mA/V [1]

$A_{d1} = (g_{m2}R_C)/2 = (19.29\text{m})(12\text{k})/2 = 115.7$ [2]

$g_{m3} = I_{C3}/V_T = 1.886\text{m}/0.026 = 72.54$ mA/V [1]

$A_2 = g_{m3}R_{C2} = (72.54\text{m})(4\text{k}) = 290.16$ [3]

*Overall gain:*

$A_d = A_{d1} \text{ x } A_2 = (115.7)(290.16) = 33{,}580$ [2]

$A_{cm} = A_{cm1} \text{ x } A_2 = (-0.0749)(290.16) = -21.73$ [1]

*(c)* $v_{o3} = A_d v_d + A_{cm} v_{cm}$

where

$v_d = v_1 - v_2 = (2.015 \sin \omega t\ m\text{V}) - (1.985 \sin \omega t\ m\text{V}) = 0.03 \sin \omega t\ m\text{V}$ [2]

$v_{o3} = (33{,}580)(0.03 \sin \omega t\ mV) = 1.007 \sin \omega t$ V. [1]

*If Acm = 0, the diff-amp is ideal. The output is a pure amplification of the differential input.*

**Answers to Question 4 [25 marks]**

**Answers to Question 4(a) [15 marks]**

**Question 4(a)(i) [5 marks]**

**Figure 4(a)** – (approximate) class-B output stage. [1]
**Figure 4(b)** – class-AB output stage. [1]

In class-AB, quiescent collector current $I_{CQ}$ exists even for a zero input signal. Hence:

1) The average power supplied by each source and the average power dissipated in each transistor in class-AB are *larger* than class-B.
2) The $\eta$ will be *less* than an approximate class-B.
3) The required power handling capability of the transistors in class-AB will be *slightly larger* than class-B. Since $I_{CQ}$ is usually small compared to $I_p$, the increase in power dissipation is not great.

However, the advantage of eliminating crossover distortion greatly overweighs the disadvantage of reduced $\eta$ and increased power dissipation. [3]

**Question 4(a)(ii) [10 marks]**

For $v_O$ = -8 V,
$i_L = V_O / R_L$ = (-8V)/(1 kΩ) = -8 mA [1]
Therefore, $Q_p$ is conducting and $Q_n$ is OFF.

Approximation:
$i_{Cp} \approx | i_L |$ = 8 mA [1]
$v_{EBp} = V_T \ln(i_{Cp} / I_S)$
$= (0.026) \ln(8m / 4x10^{-15})$ = 0.7364 V [1]
$v_{BEn} = V_{BB} - v_{EBp} = 1.35 – 0.7364$ = 0.6136 V [1]
$i_{Cn} = I_S \exp(V_{BEn} / V_T)$
$= (4x10^{-15}) \exp(0.6136 / 0.026)$ = $7.102x10^{-5}$ A [1]
$i_{Cn} = i_{Cp} + i_L$ [1]
$i_{Cp} = i_{Cn} - i_L$ Recalculate $i_{Cp}$
$= 7.102x10^{-5} - (-8m)$ = 8.071 mA [1]
$V_I = V_O + V_{BB}/2 - v_{EBp} = -8 + 1.35/2 - 0.7364 = -8.06$ V [1]

For $Q_n$:
$V_{CEn} = V_{CC} - V_O$ = 10 – (-8) = 18 V [0.5]
$P_{Qn} = i_{Cn} V_{CEn}$ = $(7.102x10^{-5})(18)$ = 1.278 mW [0.5]

For $Q_p$:
$V_{ECp} = V_O – (-V_{CC})$ = (-8) – (-10) = 2 V [0.5]
$P_{Qp} = i_{Cp} v_{ECp}$ = (8.071m)(2) = 16.14 mW [0.5]

**Answers to Question 4(b) [10 marks]**

To calculate $I_{C16}$, need to determine $I_{C12}$ and $I_{C13B}$

$I_{C12} = [V^+ - V^- - V_{EB12} - V_{BE11}] / R_5 = [10\text{-}2(0.65)] / 40\text{k} = 0.2175\text{mA}$ [2]

$I_{C13B} = 0.75\ I_{C12} = (0.75)(0.2175\text{m}) = 0.1631\ \text{mA}$ [1]

$I_{C16} \cong I_{E16} = I_{B17} + (V_{BE17}/R_9) = I_{C17} / \beta + (V_{BE17}/R_9)$ [3]

$I_{C17} = I_{C13B} = 0.1631\ \text{mA}$ [1]

$I_{C16} = (0.1631\text{m}/200) + (0.65/50\text{k}) = 0.8155\mu + 13\mu = 13.82\ \mu\text{A}$ [2]

Either logical reason: [1]

Example: *shifts dc voltage level at output, increases bias current, increase out resistance thus increases small signal voltage gain of the circuit.*

**<u>Answers to Question 5 [15 marks]</u>**

**<u>Question 5(a) [5 marks]</u>**

| | | |
|---|---|---|
| $v_O$ | $= (-R_4/R_3)v_{O1}$ | [1] |
| $v_{O1}$ | $= (R_2/(R_1+R_2))v_I$ | [1] |
| $v_O$ | $= (-R_4/R_3)\ (R_2/(R_1+R_2))v_I$ | [1] |
| $v_O / v_I$ | $= -(R_4/R_3)\ (R_2/(R_1+R_2))$ | [1] |
| | $= -[(75k/80k)(100k/150k)] = 0.625$ V/V | [1] |

**<u>Question 5(b)(i) [7 marks]</u>**

$$i_1 = \frac{v_{I1} - v_{I2}}{R_{1f} + R_{1POT}} \qquad [1]$$

$$v_{O1} = v_{I1} + i_1 R_2 = \left(1 + \frac{R_2}{R_{1f} + R_{1POT}}\right) v_{I1} - \frac{R_2}{R_{1f} + R_{1POT}} v_{I2} \qquad [2]$$

$$v_{O2} = v_{I2} - i_1 R_2 = \left(1 + \frac{R_2}{R_{1f} + R_{1POT}}\right) v_{I2} - \frac{R_2}{R_{1f} + R_{1POT}} v_{I1} \qquad [2]$$

$$v_O = \frac{R_4}{R_3}\left(v_{O2} - v_{O1}\right)$$

$$v_O = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_{1f} + R_{1POT}}\right)\left(v_{I2} - v_{I1}\right) \qquad [2]$$

**<u>Question 5(b)(ii) [3 marks]</u>**

$$A_v = \frac{v_O}{\left(v_{I2} - v_{I1}\right)} = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_{1f} + R_{1POT}}\right) \qquad [1]$$

$$A_v = \frac{2.5R_3}{R_3}\left(1 + \frac{2(495k)}{15k + 40k}\right) = 47.5 \text{ V/V} \qquad [1]$$

$$v_O = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_{1f} + R_{1POT}}\right)\left(v_{I2} - v_{I1}\right)$$

$$v_O = A_v (v_{I2} - v_{I1}) = (47.5)(0.115 - 0.090) = 1.1875 \text{ V} \qquad [1]$$