UNIVERSITI TENAGA NASIONAL

COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER 1 2011 / 2012

PROGRAMME	: **Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	: **EEEB273**
SUBJECT	: **ELECTRONIC ANALYSIS AND DESIGN II**
DATE	: **August 2011**
TIME	: **9.00 am – 12.00 pm (3 hours)**

MODEL ANSWERS

Question 1 [16 marks]

Answers:

Q1 (a) (i)

Starting from I_{E3}

$$I_{REF} = (I_{C3} + I_{B3}) + I_{B4} = I_{E3} + I_{B4}$$ **[0.5]**

$$I_{REF} = I_{E3} + I_O / \beta$$ **[0.5]**

$$I_O = I_{C4} = \frac{\beta}{\beta+1} I_{E4} = \frac{\beta}{(\beta+1)} \frac{I_{E3}}{(1+2/\beta)}$$ **[1]**

$$I_{E3} = \frac{(\beta+1)(1+2/\beta)}{\beta} I_O = \frac{(\beta+1)(\beta+2)}{\beta^2} I_O$$ **[0.5]**

$$I_{REF} = \frac{(\beta+1)(\beta+2)}{\beta^2} I_O + I_O / \beta = \frac{(\beta^2+3\beta+2)+\beta}{\beta^2} I_O$$ **[0.5]**

$$I_{REF} = \frac{\beta^2+4\beta+2}{\beta^2} I_O = \left(1 + \frac{4}{\beta} + \frac{2}{\beta^2}\right) I_O$$ **[0.5]**

$$I_{REF} \approx \left(1 + \frac{4}{\beta}\right) I_O$$ **[0.5]**

assuming $2/\beta^2 \approx 0$ or $\beta^2 >> 1$

Optional answer: Starting from I_{B1} or I_{B2}

$$I_{B1} = I_{B2}$$

$$I_{E4} = I_{C2} = \beta I_{B2} = \beta I_{B1}$$

$$I_O = I_{C4} = \frac{\beta}{\beta+1} I_{E4} = \frac{\beta}{\beta+1}(\beta I_{B1}) \Rightarrow I_{B1} = \frac{\beta+1}{\beta^2} I_O$$

$$I_{B4} = \frac{I_{E4}}{\beta+1} = \frac{\beta I_{B1}}{\beta+1} = \frac{\beta}{\beta+1} I_{B1}$$

$$I_{C1} = \beta I_{B1}$$

$$I_{E3} = I_{C1} + I_{B1} + I_{B2} = I_{C1} + 2I_{B1} = (\beta+2) I_{B1}$$

$$I_{REF} = (I_{C3} + I_{B3}) + I_{B4} = I_{E3} + I_{B4}$$

$$I_{REF} = (\beta+2) I_{B1} + \frac{\beta}{\beta+1} I_{B1} = \frac{(\beta+2)(\beta+1)+\beta}{\beta+1} I_{B1}$$

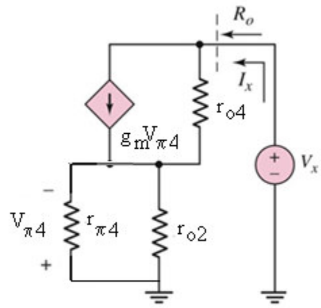
$$I_{REF} = \left(\frac{(\beta+2)(\beta+1)+\beta}{(\beta+1)}\right)\left(\frac{(\beta+1)}{\beta^2} I_O\right)$$

$$I_{REF} = \frac{\beta^2+4\beta+2}{\beta^2} I_O = \left(1 + \frac{4}{\beta} + \frac{2}{\beta^2}\right) I_O$$

$$I_{REF} \approx \left(1 + \frac{4}{\beta}\right) I_O$$

Q1 (a) (ii)

Simplified Circuit



[1] for circuit

$$I_x = g_{m4}V_{\pi 4} + \left(\frac{V_x - I_x\left(r_{o2} \parallel r_{\pi 4}\right)}{r_{o4}}\right)$$ **[1]**

$$I_x = -g_{m4}I_x\left(r_{o2} \parallel r_{\pi 4}\right) + \left(\frac{V_x - I_x\left(r_{o2} \parallel r_{\pi 4}\right)}{r_{o4}}\right)$$ **[1]**

$$\frac{V_x}{I_x} = r_{o4}\left(1+\beta\right) + r_{\pi 4} \cong \beta r_{o4}$$ **[1]**

Q1 (b)

$$I_{REF} = \frac{k'_n}{2}\left(W/L\right)_3\left(V_{GS3} - V_{TN}\right)^2$$ **[0.5]**

$$I_{D1} = I_{REF} = \frac{k'_n}{2}\left(W/L\right)_1\left(V_{GS1} - V_{TN}\right)^2$$ **[0.5]**

$$I_O = I_{D2} = \frac{k'_n}{2}\left(W/L\right)_2\left(V_{GS2} - V_{TN}\right)^2$$ **[0.5]**

$$V_{DS2(sat)} = V_{D2} - (-3) = 1.8V$$ **[1]**

$$V_{GS2} = V_{DS2(sat)} + V_{TN} = 1.8 + 0.5 = 2.3$$ **[1]**

$$\left(W/L\right)_2 = \frac{2I_O\left(V_{GS2} - V_{TN}\right)^2}{k'_n} = 4.05$$ **[1]**

$$V_{GS1} = 2.3$$ **[0.5]**

$$\left(W/L\right)_1 = \frac{2I_{REF}\left(V_{GS1} - V_{TN}\right)^2}{k'_n} = 12.15$$ **[1]**

$$V_{GS3} = 3 - 2.3 - (-3) = 3.7V$$ **[1]**

$$\left(W/L\right)_3 = \frac{2I_{REF}\left(V_{GS3} - V_{TN}\right)^2}{k'_n} = 38.4$$ **[1]**

Question 2 [16 marks]

Answers:

Q2 (a)

$$V_{GS1} = \sqrt{\frac{I_{D1}}{K_{n1}}} + V_{TN} = \sqrt{\frac{60\mu}{150}} + 0.3 = 0.9324V \quad \textbf{[1.5]}$$

$$R_D = \frac{V^+ - V_{DS1} + V_{GS1} - v_1}{I_{D1}} = \frac{3 - 3 + 0.9324 + 1.5}{60\mu} = 40.5k\Omega \quad \textbf{[1.5]}$$

$$I_1 = I_Q = 2I_{D1} = 120\mu A \quad \textbf{[1.5]}$$

$$V_{DS3} = V_{GS3} = V_{GS4} = \sqrt{\frac{I_Q}{K_{n4}}} + V_{TN} == \sqrt{\frac{120\mu}{100}} + 0.3 = 1.3954V \quad \textbf{[2]}$$

$$R_1 = \frac{V^+ - V_{DS3} - V^-}{I_1} = \frac{3 - 1.3954 + 3}{120\mu} = 38.37k\Omega \quad \textbf{[1.5]}$$

Q2 (b)

$$V_{DS4}(init) = v_1(init) - V_{GS1} - V^- = -1.5 - 0.9324 + 3 = 0.5676V \quad \textbf{[1.5]}$$

$$V_{DS4}(fin) = v_1(fin) - V_{GS1} - V^- = 1.05 - 0.9324 + 3 = 3.1176V \quad \textbf{[1.5]}$$

$$\Delta V_{DS4} = V_{DS4}(fin) - V_{DS4}(init) = 3.1176 - 0.5676 = 2.5501V \quad \textbf{[1]}$$

Q2 (c)

$$R_O = 1/(\lambda_4 I_Q) = 1/((0.01)(120\mu)) = 0.8333M\Omega \quad \textbf{[1.5]}$$

$$\Delta I_Q / \Delta V_{DS4} = 1/R_O \quad \textbf{[1]}$$

$$\Delta I_Q = \Delta V_{DS4} / R_O = 2.5501/0.8333M = 3.06\mu A \quad \textbf{[1.5]}$$

Question 3 [16 marks]

Answers:

Q3 (a) (i)

- In actual BJT circuits, base currents are non zero [0.5]
- For circuit to be balanced, $I_1 = I_2$ and $I_3 = I_4$ [0.5]
- Else the active load transistors Q_3 and Q_4 will not be biased in active mode [1]

Q3 (a) (ii)

$$I_{B5} = \frac{I_{E5}}{(1+\beta)} = \frac{I_{B3} + I_{B4}}{(1+\beta)} = \frac{I_{C3} + I_{C4}}{\beta(1+\beta)} \quad [1]$$

The current $I_{C3} + I_{C4} \cong I_Q$ [1]

$$\left. \begin{aligned} I_{C1} &= I_{C3} + I_{B5} \\ I_{C1} &= I_{C4} + I_O \end{aligned} \right\} \quad [1]$$

Hence, to keep the current balanced: $I_O = I_{B5} = \dfrac{I_Q}{\beta(1+\beta)}$ [1]

Given, $I_Q = 0.2$ mA, hence: $I_O = \dfrac{0.2\text{ m}}{100(1+100)} = 19.8\text{ nA}$ [1]

Q3 (b) (i)

- Biasing stage: R_1, R_2, R_3, Q_9, Q_{10}, Q_{11} [1]
- Input stage: Differential amplifier with active load: Q_1 to Q_5 [1]
- Second gain stage: Darlington pair: Q_6 and Q_7 [1]
- Output stage: emitter follower output stage: Q_8 and R_4 [1]

Q3 (b) (ii)

$$R_{L7} = R_{C11} \parallel R_{B8} \quad \textbf{[1]}$$

$$R_{C11} = r_{o11}\left[1 + g_{m11}(r_{\pi 11} \parallel R_3)\right] \quad \textbf{[1]}$$

$$R_{C11} = (500k)\left[1 + (5m)(3k \parallel 250)\right] = 1.08M\Omega \quad \textbf{[0.5]}$$

$$R_{B8} = r_{\pi 8} + (1+\beta)R_4 \quad \textbf{[1]}$$

$$R_{B8} = 3k + (1+100)(10k) = 1.01M\Omega \quad \textbf{[0.5]}$$

$$R_{L7} = 1.08M \parallel 1.01M = 522k\Omega \quad \textbf{[1]}$$

Question 4 [16 marks]

Answers:

Q4 (a)

$I_{D11} = I_{D12} = I_{D13} = I_{D3} = I_{D4} = I_{REF} = 50\ \mu A$ **[1.5]**

$I_{D1} = I_{D2} = I_{D11}/2 = 25\ \mu A$ **[0.5]**

$I_{D5} = I_{D3} - I_{D2} = 50\mu - 25\mu = 25\ \mu A = I_{D7} = I_{D9}$ **[0.5]**

$I_{D6} = I_{D1} - I_{D4} = 50\mu - 25\mu = 25\ \mu A = I_{D8} = I_{D10}$ **[0.5]**

Q4 (b)

$A_d = g_{m1}(R_{O6} \parallel R_{O8})$ **[1]**

$R_{O6} = g_{m6} r_{O6}(r_{O4} \parallel r_{O1})$ **[0.5]**

$R_{O8} = g_{m8} r_{O8} r_{O10}$ **[0.5]**

$$g_{m1} = 2\sqrt{\frac{K_{p1} I_{REF}}{2}} = 2\sqrt{\frac{k_P'}{2}\left(\frac{W}{L}\right)_1 \frac{I_{REF}}{2}} = 2\sqrt{\frac{20\mu}{2}(10)\frac{50\mu}{2}} = 0.1 mA/V$$ **[1]**

$$g_{m6} = 2\sqrt{\frac{K_{n6} I_{REF}}{2}} = 2\sqrt{\frac{k_n'}{2}\left(\frac{W}{L}\right)_6 \frac{I_{REF}}{2}} = 2\sqrt{\frac{40\mu}{2}(10)\frac{50\mu}{2}} = 0.141 mA/V$$ **[1]**

$$g_{m8} = 2\sqrt{\frac{K_{p8} I_{REF}}{2}} = 2\sqrt{\frac{k_p'}{2}\left(\frac{W}{L}\right)_8 \frac{I_{REF}}{2}} = 2\sqrt{\frac{20\mu}{2}(20)\frac{50\mu}{2}} = 0.141 mA/V$$ **[1]**

$r_{O6} = 1/(\lambda_n I_{REF}/2) = 1/((0.005)(25\mu)) = 8M\Omega$ **[0.5]**

$r_{O4} = 1/(\lambda_n I_{REF}) = 1/((0.005)(50\mu)) = 4M\Omega$ **[0.5]**

$r_{O1} = r_{O8} = r_{O10} = 1/(\lambda_p I_{REF}/2) = 1/((0.01)(25\mu)) = 4M\Omega$ **[0.5]**

$R_{O6} = (0.141m)(8M)(4M \parallel 4M) = 2256M\Omega$ **[0.5]**

$R_{O8} = (0.141m)(4M)(4M) = 2256M\Omega$ **[0.5]**

$A_d = (0.1m)(2256M \parallel 2256M) = 112800V/V$ **[0.5]**

Q4 (c)

$$A_d' = 2A_d = 2(112800) = 225600$$ **[1]**

$$A_d' = g_{m1}'\left(R_{O6} \parallel R_{O8}\right)$$ **[1]**

$$\left(R_{O6} \parallel R_{O8}\right) = 1128M\Omega$$

$$g_{m1}' = 225600/(1128M) = 0.2mA/V$$ **[1]**

$$g_{m1}' = 2\sqrt{\frac{k_p'}{2}\left(\frac{W}{L}\right)_1 \frac{I_{REF}}{2}} = 2\sqrt{\frac{20\mu}{2}\left(\frac{W}{L}\right)_1 \frac{50\mu}{2}}$$ **[1]**

$$0.2m = 31.62\mu\sqrt{\left(\frac{W}{L}\right)_1}$$

$$\sqrt{\left(\frac{W}{L}\right)_1} = 6.3245$$

$$\left(\frac{W}{L}\right)_1 = 40$$ **[1]**

Question 5 [16 marks]

Answers:

Q5 (a)

Diagrams **[1]**

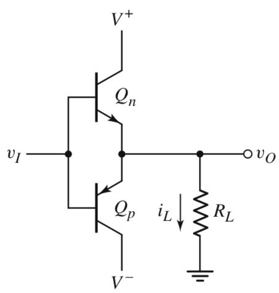


Figure (a)

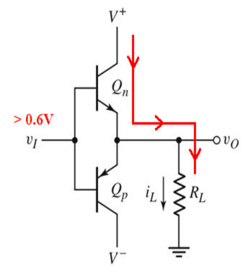


Figure (b)

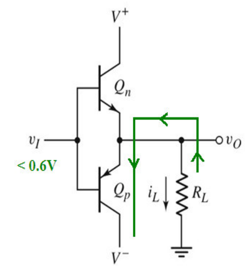


Figure (c)

- Figure (a) ➔ $v_I = 0$: both Q_n & Q_p cut-off, $v_O = 0$. Assume V_{BE}(on) = 0.6V: v_O **remains 0** as long as **-0.6V ≤ v_I ≤ +0.6V** **[1]**
- Figure (b) ➔ $v_I > +0.6$V: Q_n **turns on** and operates as emitter follower, I_L is **positive** (**supplied thru Q_n**), B-E junction of Q_p **is reverse-biased** **[1]**
- Figure (c) ➔ $v_I < -0.6$V: Q_p **turns on** and operates as emitter follower, Q_p **sinks I_L** (which is **negative),** B-E junction of Q_n **is reverse-biased** **[1]**

Q5 (b)

Class-AB output stage **[2]**

Q5 (c)

Q_{18} and Q_{19} establish $2V_{BE}$ drops between base terminals of Q_{14} & Q_{20}. This V_{BB} produces quiescent collector currents in Q_{14} and Q_{20}, therefore **biasing** both Q_{14} and Q_{20} "on" with no signal present at the input. **[2]**

Q5 (d)

Class-AB output stage **had removed crossover distortion** experienced in the approximate class-B output stage. **[2]**

Q5 (e)

If we **assume V_{BE19} = 0.6 V**, then the current in R_{10} is

$$I_{R10} = V_{BE19} / R_{10} = 0.6 / 50\text{k} = 0.012 \text{ mA} \qquad [1]$$

The current in Q_{19} is

$$I_{C19} \approx I_{E19} = I_{Bias} - I_{R10} = 0.18\text{m} - 0.012\text{m} = 0.168 \text{ mA} \qquad [1]$$

For that value of collector current, the B-E voltage of Q_{19} is

$$V_{BE19} = V_T \ln(I_{C19} / I_S) = (0.026) \ln(0.168\text{m}/10^{-14}) = 0.612 \text{ V} \qquad [1]$$

The base current in Q_{19} is

$$I_{B19} = I_{C19} / \beta_n = 0.168\text{m} / 200 = 0.84 \ \mu\text{A} \qquad [0.5]$$

The current in Q_{18} is now

$$I_{C18} \approx I_{E18} = I_{R10} + I_{B19} = 0.012\text{m} + 0.84\mu = 12.84 \ \mu\text{A} \qquad [0.5]$$

The B-E voltage of Q_{18} is therefore

$$V_{BE18} = V_T \ln(I_{C18} / I_S) = (0.026) \ln(12.84\mu/10^{-14}) = 0.545 \text{ V} \qquad [1]$$

The voltage difference V_{BB} is thus

$$V_{BB} = V_{BE18} + V_{BE19} = 0.545 + 0.612 = 1.157 \text{ V} \qquad [1]$$

<u>Question 6 [20 marks]</u>

<u>Answers:</u>

Q6 (a)

- A_{od}: Internal differential gain (open loop gain) is considered to be ∞.
- $(v_2 - v_1)$: Differential input voltage is assumed to be 0. If $A_{od} \rightarrow \infty$ and v_O is finite, then $v_2 \approx v_1$.
- R_i: Effective input resistance is assumed to be ∞, so input currents i_1 and i_2 are essentially 0.
- R_o: Effective output resistance is assumed to be 0, so output voltage is independent of any load connected to the output.
- Bandwidth $\rightarrow \infty$.
- *CMRR*: Common mode rejection ratio = ∞.

⇨ **Each answer above give [1] mark**

Q6 (b)

$$v_{I2} = 0: \quad v_{O1}(v_{I1}) = (-R_F / R_1)\, v_{I1} = (-100k / 100k)\, v_{I1} = -\, v_{I1}$$

[0.5] [0.5] [0.5] [0.5]

$$v_{I1} = 0: \quad v_{O1}(v_{I2}) = (-R_F / R_2)\, v_{I2} = (-100k / 100k)\, v_{I2} = -\, v_{I2}$$

[0.5] [0.5] [0.5] [0.5]

$$v_{O1} = v_{O1}(v_{I1}) + v_{O1}(v_{I2}) = (-\, v_{I1}) + (-\, v_{I2}) = -(v_{I1} + v_{I2})$$

[0.5] [0.5] [0.5]

$$v_O = (-R_F / R_1)\, v_{O1} = (-100k / 100k)[\, -(v_{I1} + v_{I2})\,] = v_{I1} + v_{I2}$$

[0.5] [0.5] [0.5]

Q6 (c)

(i) Difference amplifier **[1]**

(ii) $R_3 = R_4 = 100\ \mathrm{k\Omega}$

$$A_v = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \frac{100k}{100k}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \left(1+\frac{2R_2}{R_1+R_{1POT}}\right)$$

[1]

A_v is maximum (i.e. $A_v = 100$) when $R_{1POT} = 0$, i.e.

$$100 = \left(1+\frac{2R_2}{R_1+0}\right)$$ **[1]**

$99\,R_1 = 2\,R_2$ **{Eqn 1}** **[0.5]**

A_v is minimum (i.e. $A_v = 10$) when $R_{1POT} = 100\ \mathrm{k\Omega}$, i.e.

$$10 = \left(1+\frac{2R_2}{R_1+100k}\right)$$ **[1]**

$9(R_1 + 100\mathrm{k}) = 2\,R_2$ **{Eqn 2}** **[0.5]**

{Eqn 1} = {Eqn 2}

$99\,R_1 = 9\,R_1 + 900\mathrm{k}$ **[1]**

➔ **$R_1 = 10\ \mathrm{k\Omega}$** **[1]**

➔ **$R_2 = (99\,R_1)/2 = 495\ \mathrm{k\Omega}$** **[1]**

(iii) $v_{I1} = 1.00$ V, $v_{I2} = 1.15$ V, $R_4 = 2\,R_3$, $R_{1POT} = 40\ \mathrm{k\Omega}$

$$A_v = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \frac{2R_3}{R_3}\left(1+\frac{2(495k)}{10k+40k}\right) = 41.6$$ **[1.5]**

$$v_O = A_v(v_{I2}-v_{I1}) = (41.6)(1.15-1.00) = 6.24V$$ **[1.5]**