UNIVERSITI
TENAGA
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COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER 2 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 : **January 2012**

TIME : **3 hours (9.00 am – 12.00 pm)**

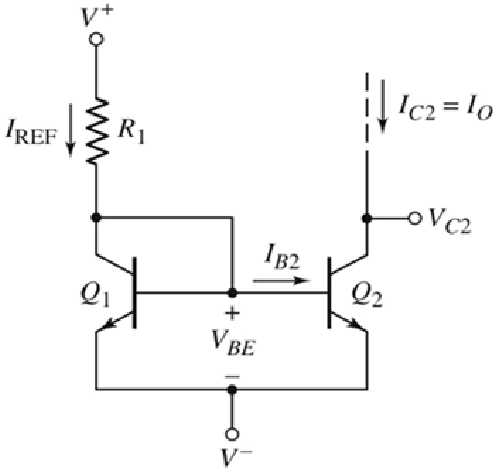
INSTRUCTIONS TO CANDIDATES:

1. This question paper contains SIX (6) questions in TWELVE (12) pages.
2. Answer **ALL** questions.
3. Write **all** answers in the answer booklet provided.
4. Write answer to each question on **a new page**.
5. For all calculations, assume that V_T **= 26 mV**.

MODEL ANSWER

THIS QUESTION PAPER CONSISTS OF TWELVE (12) PRINTED PAGES INCLUDING THIS COVER PAGE AND APPENDIX.

Q1(a)(i)



Transistors	[1]
I_{REF}	[0.5]
R₁	[0.5]
I_O	[0.5]
Connection	[0.5]
Total	**[3 marks]**

Q1(a)(ii)

$$I_{REF} = I_{S1} e^{V_{BE1}/V_T} \qquad \boxed{1}$$

$$V_{BE1} = V_T \ln\left(\frac{I_{REF}}{I_{S1}}\right) \qquad \boxed{1}$$

$$V_{BE1} = 0.026\ln\left(\frac{210\mu}{4.5x10^{-15}}\right) = 0.6387\text{V} \qquad \boxed{0.5, 0.5}$$

$$V_{BE2} = V_{BE1} = 0.6387\text{V}$$

$$I_O = I_{S2} e^{V_{BE2}/V_T} \qquad \boxed{1}$$

$$I_O = 3x10^{-15} e^{0.6387/0.026} = 139.9\mu\text{A} \qquad \boxed{0.5, 0.5}$$

Q1(b)(i)

Identical transistors, therefore aspect ratios are the same

$$I_D = \frac{k_n'}{2}\left(\frac{W}{L}\right)\left[V_{GS} - V_{TN}\right]^2 \qquad \boxed{1}$$

$$V_{GS} - V_{TN} = V_{DS}(\text{sat}) = 0.8\text{V} \qquad \boxed{1}$$

$$\frac{W}{L} = \frac{2I_D}{k_n'\left[V_{DS}(\text{sat})\right]^2} \qquad \boxed{1}$$

$$\frac{W}{L} = \frac{2(1\text{m})}{(120\mu)(0.8)^2} = 26.04 \qquad \boxed{0.5,\ 0.5}$$

Q1(b)(ii)

$$R = \frac{V^+ - V^+ - 2V_{GS}}{I_D} \qquad \boxed{1}$$

$$V_{GS} = V_{DS}(\text{sat}) + V_{TN} = 0.8 + 1.5 = 2.3\text{V} \qquad \boxed{0.5}$$

$$R = \frac{15 - (-15) - 2(2.3)}{1\text{m}} = 25.4\text{k}\Omega \qquad \boxed{0.5}$$

Q1(b)(iii)

$$R_O = \frac{1}{\lambda I_D} = \frac{1}{(0)I_D} = \infty \qquad \boxed{1}$$

$$\Delta I_O = \frac{\Delta V}{R_O} = \frac{\Delta V}{\infty} = 0 \qquad \boxed{1}$$

Therefore, no change in current

Q2(a)

$$I_1 = I_Q = 2I_{D1} = 2(60\mu) = 120\mu\text{A} \qquad \boxed{1}$$

$$V_{DS5} = V_{DS3} = V_{GS3} = V_{GS4} = \sqrt{\frac{I_Q}{K_{n4}}} + V_{TN} = \sqrt{\frac{120\mu}{100\mu}} + 0.3 = 1.3954\text{V} \qquad \boxed{2}$$

$$R_1 = \frac{V^+ - V_{DS5} - V_{DS3} - V^-}{I_1} = \frac{3 - 1.3954 - 1.3954 - (-3)}{120\mu} = 26.74\text{k}\Omega \qquad \boxed{1.5}$$

$$I_{D1} = K_{n1}(V_{GS1} - V_{TN})^2 \Rightarrow V_{GS1} = \sqrt{\frac{I_{D1}}{K_{n1}}} + V_{TN} = \sqrt{\frac{60\mu}{150\mu}} + 0.3 = 0.9324\text{V} \qquad \boxed{1.5}$$

$$R_D = \frac{V^+ - V_{D1}}{I_{D1}} = \frac{V^+ - (V_{DS1} + V_{S1})}{I_{D1}} = \frac{V^+ - (V_{DS1} + V_{G1} - V_{GS1})}{I_{D1}} \qquad \boxed{1}$$

$$R_D = \frac{V^+ - V_{DS1} - v_1 + V_{GS1}}{I_{D1}} = \frac{3 - 3 - (-0.5) + 0.9324}{60\mu} = 23.87\text{k}\Omega \qquad \boxed{1}$$

Q2(b)

$$R_o \cong g_{m4} r_{o4} r_{o6} = 2\sqrt{K_{n4} I_Q}\,\frac{1}{\lambda_4 I_Q}\frac{1}{\lambda_6 I_Q} \qquad \boxed{1}$$

$$R_o = 2\sqrt{(100\mu)(120\mu)}\,\frac{1}{0.01(120\mu)}\frac{1}{0.01(120\mu)} = 152.03\text{M}\Omega \qquad \boxed{1}$$

$$A_d = \frac{g_{m2} R_D}{2} \qquad \boxed{0.5}$$

$$g_{m2} = 2\sqrt{K_{n2} I_{D2}} = 2\sqrt{(150\mu)(60\mu)} = 189.73\mu A/V \qquad \boxed{0.5}$$

$$A_d = \frac{(189.73\mu)(23.87\text{k})}{2} = 2.26 \qquad \boxed{1}$$

$$A_{cm} = -\frac{g_{m2} R_D}{1 + 2 g_{m2} R_o} \qquad \boxed{1}$$

$$A_{cm} = -\frac{(189.73\mu)(23.87\text{k})}{1 + 2(189.73\mu)(152.03\text{M})} = -8.08\text{x}10^{-6} \qquad \boxed{1}$$

$$CMRR = \left|\frac{A_d}{A_{cm}}\right| = \left|\frac{2.26}{-8.08\text{x}10^{-6}}\right| = 279502.44 \qquad \boxed{2}$$

Q3(a)

$$v_o = A_v v_d \qquad \boxed{1}$$

$$A_v = g_{m2}(r_{o2} \parallel R_o) \qquad \boxed{1}$$

$$r_{o2} = \frac{1}{\lambda_n I_{D2}} = \frac{1}{(0.02)(100\mu)} = 500\text{k}\Omega \qquad \boxed{1}$$

$$R_o \cong g_{m4} r_{o4} r_{o6} \qquad \boxed{1}$$

$$r_{o4} = r_{o6} = \frac{1}{\lambda_p I_{D4}} = \frac{2}{\lambda_p I_Q} \qquad \boxed{0.5}$$

$$r_{o4} = r_{o6} = \frac{2}{(0.03)(200\mu)} = 333.3\text{k}\Omega \qquad \boxed{0.5}$$

$$g_{m4} = 2\sqrt{\frac{k_p^{'}}{2}\left(\frac{W}{L}\right)_p I_{D2}} = \sqrt{k_p^{'}\left(\frac{W}{L}\right)_p I_Q} \qquad \boxed{0.5}$$

$$g_{m4} = \sqrt{(50\mu)(12)(200\mu)} = 0.3464\text{mA/V} \qquad \boxed{0.5}$$

$$R_o = (0.3464\text{m})(333.3\text{k})(333.3\text{k}) = 38.5\text{M}\Omega$$

$$r_{o2} \parallel R_o \cong r_{o2} = 500\text{k}\Omega \qquad \boxed{0.5}$$

$$g_{m2} = \sqrt{k_n^{'}\left(\frac{W}{L}\right)_n I_Q} = \sqrt{(100\mu)(10)(200\mu)} = 0.4472\text{mA/V} \qquad \boxed{0.5}$$

$$v_o = A_v v_d = g_{m2} r_{o2} v_d \qquad \boxed{1}$$

$$v_o = (0.4472\text{m})(500\text{k})(20\sin\omega t)\mu) \quad = 4.472\sin\omega t(\text{mV})$$

Q3(b)(i)

Differential amp circuit	[0.5]
3-transistor active load circuit	[0.5]
Darlington pair circuit OR gain circuit	[0.5]
Output stage	[0.5]

Q3(b)(ii)

Reflection rule

$$R_i = r_{\pi 6} + (1+\beta) r_{\pi 7} \qquad \boxed{1}$$

$$\beta = g_m r_{\pi 6} \qquad \boxed{1}$$

$$\beta = (5\text{m})(3\text{k}) = 15$$

$$R_i = 3\text{k} + (1+15)(3\text{k}) = 51\text{k}\Omega \qquad \boxed{1}$$

$$R_O = R_2 \parallel \frac{r_{\pi 8} + r_{o7} \parallel r_{o11}}{(1+\beta)} \qquad \boxed{1}$$

$$R_O = 10\text{k} \parallel \frac{3\text{k} + 500\text{k} \parallel 500\text{k}}{(1+15)} = 6.125\text{k}\Omega \qquad \boxed{1,\ 1}$$

Q4(a)(i)

$$R_5 = \frac{V^+ - V_{EB12} - V_{BE11} - V^-}{I_{REF}} \qquad \boxed{0.5}$$

$$V_{EB12} = V_{BE11} = V_T \ln\frac{I_{REF}}{I_S} = 0.026 \ln\frac{1x10^{-3}}{10^{-14}} = 0.658\text{V} \qquad \boxed{1.5}$$

$$R_5 = \frac{15 - 0.658 - 0.658 - (-15)}{1\text{m}} = 28.68\text{k}\Omega \qquad \boxed{0.5}$$

$$I_{C10} = I_{C9} = 10x10^{-6}\,\text{A} \qquad \boxed{0.5}$$

$$R_4 = \frac{V_T}{I_{C10}}\ln\frac{I_{REF}}{I_{C10}} = \frac{0.026}{10x10^{-6}}\ln\frac{1x10^{-3}}{10x10^{-6}} = 11.97\text{k}\Omega \qquad \boxed{1}$$

Q4(a)(ii)

$$I_{C1} = \frac{I_{C8}}{2} = \frac{I_{C9}}{2} = \frac{10\mu\text{A}}{2} = 5\mu\text{A} \qquad \boxed{1}$$

$$r_{\pi 6} = \frac{\beta V_T}{I_{C6}} = \frac{200x0.026}{5\mu} = 1.04\text{M}\Omega \qquad \boxed{1}$$

Q4(a)(iii)

$$V_{C5} = V_{BE7} + V_{BE6} + I_{C6}R_2 + V^- \qquad \boxed{1}$$

$$V_{C5} = 0.6 + 0.6 + (5\mu\text{A})(1\text{k}\Omega) + (-15) = -13.795\text{V} \qquad \boxed{1}$$

Q4(b)(i)

$$I_Q = I_{D6} = I_{D5} \qquad \boxed{0.5}$$

$$I_{D5} = K_p\left(V_{SG5} + V_{TP}\right)^2 = (100\mu\text{A/V}^2)x(1.5 - 0.5)^2 = 100\mu\text{A} \qquad \boxed{1}$$

$$\Rightarrow I_Q = I_{D5} = 100\mu\text{A} = 0.1\text{mA} \qquad \boxed{0.5}$$

Q4(b)(ii)

$$A_v = A_d A_{v2} \qquad \boxed{0.5}$$

$$A_d = g_m\left(r_{o2} \parallel r_{o4}\right) \qquad \boxed{0.5}$$

$$g_m = \sqrt{2K_pI_Q} = \sqrt{2(100\mu)(100\mu)} = 141.42\mu\text{A/V} \qquad \boxed{0.5}$$

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02x50\mu} = 1\text{M}\Omega \qquad \boxed{0.5}$$

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01x50\mu} = 2\text{M}\Omega \qquad \boxed{0.5}$$

$$A_d = (141.42\mu)\left(1\text{M} \parallel 2\text{M}\right) = 94.286 \qquad \boxed{0.5}$$

$$A_{v2} = g_{m7}\left(r_{o7} \parallel r_{o8}\right) \qquad \boxed{0.5}$$

$$g_m = 2\sqrt{K_{n7}I_{D7}} = 2\sqrt{(125\mu)(100\mu)} = 223.6\mu\text{A/V} \qquad \boxed{0.5}$$

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01x100\mu} = 1\text{M}\Omega \qquad \boxed{0.5}$$

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02x100\mu} = 0.5\text{M}\Omega \qquad \boxed{0.5}$$

$$A_{v2} = (223.6\mu)\left(1\text{M} \parallel 0.5\text{M}\right) = 74.53 \qquad \boxed{0.5}$$

$$A_v = A_d A_{v2} = 94.286x74.53 = 7027.45 \qquad \boxed{0.5}$$

Q5(a)

- **Class A: Output transistor is *biased at a quiescent current I_Q* and conducts for the *entire cycle of the input signal*.**

[2]

- **Class B: Output transistor conducts for only *one-half of each sine-wave input cycle*.**

[1]

- **Class AB: Output transistor biased *at a small quiescent current I_Q*, and conducts for *slightly more than half a cycle*.**

[2]

- **Class C: Output transistors conducts for *less than half a cycle*.**

[1]

Q5(b)

$$v_O(\max) = V^+ - V_{CE}(\text{sat}) = 10 - 0.4 = 9.6\text{V} \qquad \boxed{1}$$

$$I_Q = \left|-i_L(\max)\right| = \frac{v_O(\max)}{R_L} = \frac{9.6}{5\text{k}} = 1.92\text{mA} \qquad \boxed{1}$$

$$I_1 = I_Q = \frac{8 - V_{BE}(\text{on}) - V^-}{R} \qquad \boxed{1}$$

$$R = \frac{8 - 0.7 - (-10)}{1.92\text{m}} = 9.01\text{k}\Omega \qquad \boxed{1}$$

$$\eta = \frac{P_L}{P_S} = \frac{(1/2)(i_L(\max))^2 R_L \;\; \boxed{1}}{I_Q(V^+ - V^-) + I_1(8 - V^-) \;\; \boxed{1}} \qquad \boxed{1}$$

$$\eta = \frac{(1/2)(1.92\text{m})^2(5\text{k})}{(1.92\text{m})(20) + (1.92\text{m})(18)} = \frac{9.216\text{mW} \;\; \boxed{1}}{72.96\text{mW} \;\; \boxed{1}}$$

$$\eta = 0.1263 @ 12.63\% \qquad \boxed{1}$$

Question 6 [20 marks]

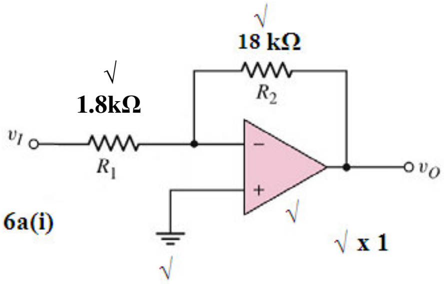
(a) Using **feedback resistor** of **18 kΩ**, **draw** the following circuits using **inverting op-amp** configuration:

(i) An **inverting amplifier** with a closed-loop gain of -**10**.

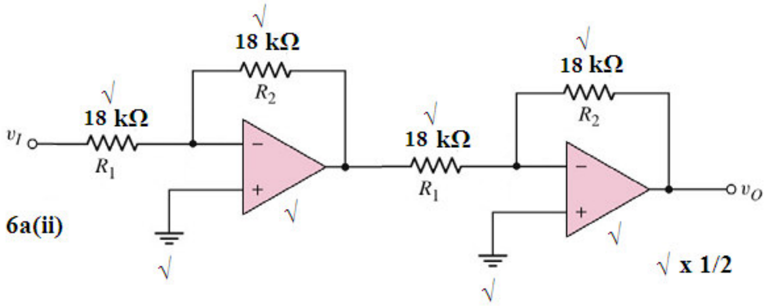
[4 marks]

(ii) A **voltage follower**.

[4 marks]



6a(i)



6a(ii)

(b) Consider the **non-inverting op-amplifier** shown in **Figure 6a**. Assume the op-amp is ideal. Determine the resistor values of R_1 and R_2 to produce a closed-loop gain of **15**, with the minimum resistance in the circuit is to be **20 kΩ**.

[4 marks]

$A_v = 1 + R_2/R_1 = 15$ [1]

$R_2/R_1 = 15 - 1 = 14$ ➔ $R_2 = 14\ R_1$ [1]

Select $R_1 = 20$ kΩ, [1]

Then $R_2 = 14 \times 20$ kΩ $= 280$ kΩ [1]

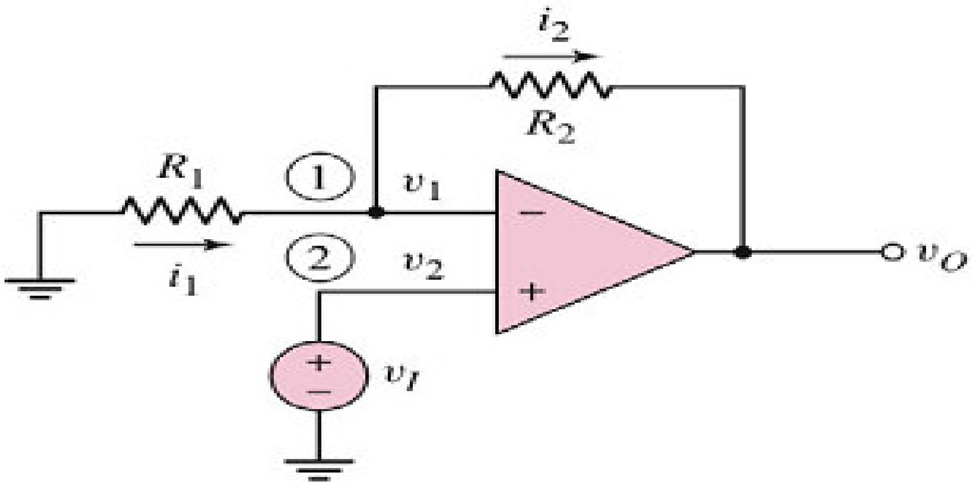


Figure 6a

(c) For a **generalized summing op-amp** as shown in **Figure 6b** the total output voltage is the sum of the individual terms, or

$$v_O = -\frac{R_F}{R_1}v_{I1} - \frac{R_F}{R_2}v_{I2} + \left(1+\frac{R_F}{R_N}\right)\left(\frac{R_P}{R_A}v_{I3} + \frac{R_P}{R_B}v_{I4}\right)$$

where $R_N = R_1 \| R_2$

$$R_P = R_A \| R_B \| R_C$$

Design a summing op-amp similar to **Figure 6b** to produce the output

$$v_O = -5v_{I1} - 10v_{I2} + 5v_{I3} + 2v_{I4}$$

The smallest resistor value allowable in the design is **15 kΩ**.

[8 marks]

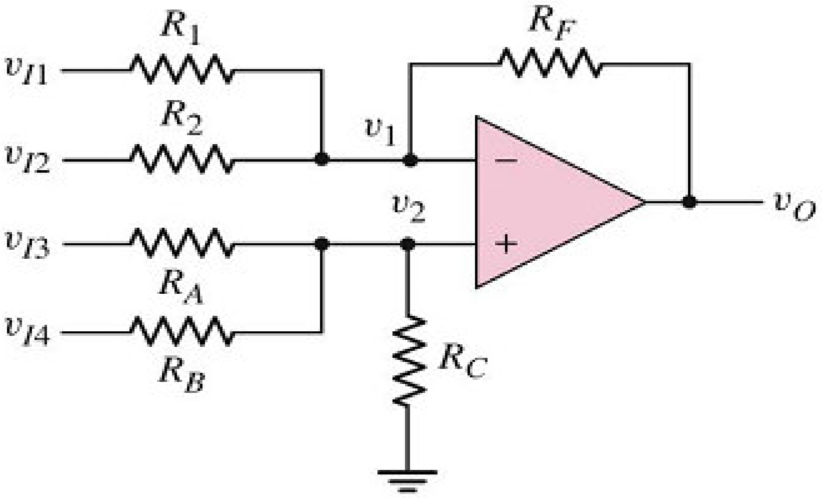


Figure 6b

$R_F / R_1 = 5$ ➔ $R_F = 5\ R_1$ **[0.5]**

and $R_F / R_2 = 10$ ➔ $R_F = 10\ R_2$ **[0.5]**

So, resistor R_2 will be the **smallest** value. Set **R_2 = 15 kΩ**. **[1]**

➔ **R_F** = $10\ R_2 = 10 \times 15\ k\Omega$ **= 150 kΩ** **[0.5]**

and **R_1** = $R_F / 4 = 150k\Omega / 5$ **= 30 kΩ** **[0.5]**

$R_N = R_1 \parallel R_2 = 30\ k\Omega \parallel 15\ k\Omega$ = 10 kΩ

$1 + R_F / R_N = 1 + 150k / (10k)$ = 16

$(1 + R_F / R_N)(R_P / R_A) = (16)\ (R_P / R_A) = 5$ **[0.5]**

and $(1 + R_F / R_N)(R_P / R_B) = (16)\ (R_P / R_B) = 2$ **[0.5]**

So, $(R_A / R_B) = 2/5$. **[0.5]**

Choose **R_A = 80 kΩ**, **[1]**

then **R_B = 200 kΩ** **[1]**

and **R_P = 25 kΩ** **[0.5]**

R_C = 44.45 kΩ **[1]**

-END OF QUESTION PAPER-