COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SPECIAL SEMESTER 2013 / 2014

PROGRAMME	: **Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	: **EEEB273**
SUBJECT	: **ELECTRONIC ANALYSIS AND DESIGN II**
DATE	: **April 2014**
TIME	: **3 hours**

INSTRUCTIONS TO CANDIDATES:

1. This paper contains **Six** (6) questions in **Nine** (9) pages.
2. Answer **ALL** questions.
3. Write **all** answers in the answer booklet provided.
4. Write answer to different question on **a new page**.
5. For all calculations, assume that V_T **= 26 mV**.

- MODEL ANSWER -

THIS QUESTION PAPER CONSISTS OF NINE* (9) *PRINTED PAGES INCLUDING THIS COVER PAGE.

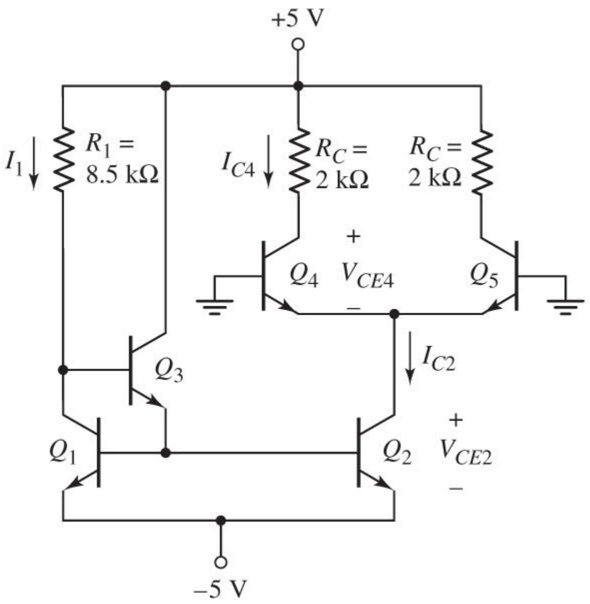
Question 1 [20 marks]

Answers:

(i) The circuit: **[L4]** The three-transistor diagram (2 marks)

The differential amplifier (2 marks)

The connection of the two circuits (1 mark)



(ii) $I_1 \approx I_{C2} = \frac{V^+ - V_{BE3} - V_{BE1} - V^-}{R_1}$ [2]

$$I_1 = \frac{5 - 0.7 - 0.7 - 5}{R_1} = 1\ mA$$

$R_1 = 8.6\ k\Omega$ [2]

$$I_{C2} = \frac{I_1}{1 + \left[\frac{2}{\beta(1+\beta)}\right]} \cong 1\ mA \text{ [2]}$$

$$\frac{I_{C2}}{2} = I_{C4} = 0.5\ mA \text{ [2]}$$

$V_{CE2} = V_E - V^-$ [1.5]

$= (0 - 0.7) — 5 = 4.3\ V$ [1.5]

$V_{CE4} = V^+ - I_{C4}R_C - V_E$ [2]

$5 - (0.5m)(2k) - (-0.7) = 4.7\ V$ [2]

Question 2 [10 marks]

Answers:

(i) ***Determine*** $\boldsymbol{I_O}$ such that the dc currents in the differential amplifier are balanced. **[L3]** [3 marks]

$I_O = I_{B3} + I_{B4}$ [1]

$\approx 2\left(\frac{I_Q}{2}\right)\left(\frac{1}{\beta}\right) \rightarrow \frac{I_Q}{\beta}$ [1]

$I_O = \frac{0.2m}{100} = 2\mu A$ [1]

(ii) ***Calculate*** the open-circuit differential-mode voltage gain. **[L3]** [4 marks]

$r_{o2} = r_{o4} = \frac{V_A}{I_{CQ}} = \frac{100}{0.1m} = 1000k$ [1]

$g_m = \frac{I_{CQ}}{V_T} = \frac{0.1m}{0.026} = 3.846\ mA/V$ [1]

$A_d = g_m(r_{o2}||r_{o4})$ [1]

$= 3.846m(1000k)(1000k) \rightarrow 1923$ [1]

(iii) ***Find*** the differential-mode voltage gain if a load resistance R_L = 250 kΩ is connected to the output. **[L3]** [3 marks]

$A_d = g_m(r_{o2}||r_{o4}||R_L)$ [1.5]

$A_d = 3.846m(1000k||1000k||250k) = 641$ [1.5]

Question 3 [15 marks]

Answers:

(a) i. Average current: $V_p/(\pi R_L)$ [1]

I_{ave}=(6)/[(3.141)(200)]=9.55mA [1]

ii. Average power delivered to load:

$P_{Lave} = V_p^2/(2R_L)$ [2]

=(6)(6)/2(200)=90mW [1]

iii. $P_{Qave} = (1/\pi)\int(V_{CC}-V_p\sin\omega t)(V_p/R_L)\sin\omega t\ \delta\omega t$; for $0 \le \omega t \le \pi$ [2]

$= \frac{V_{CC}V_p}{\pi R_L} - \frac{V_p^2}{4R_L} = \frac{(10)(6)}{\pi(200)} - \frac{6^2}{4(200)}$ =95.51mW-45mW=50.5mW [2]

iv. $P_{Save} = 2V_{CC}[V_p/(\pi R_L)]$=2(95.51mW)=191mW [2]

$\eta = P_{Lave}/P_{Save}$ = 90/191 =47.1% [1]

(b) ***Any of the following key-phrases***:

(I) v_I > +0.7V, Q_n turns on and operates as emitter follower [1]

I_L is positive, supplied thru Q_n

B-E junction of Q_p is reverse-biased

(II) v_I < -0.7V, Q_p turns on and operates as emitter follower [1]

Q_p sinks I_L, which is negative

B-E junction of Q_n is reverse-biased

(III) v_O remains zero as long as $-0.7\text{V} \le v_I \le +0.7\text{V}$ [1]

Dead band: range of input voltage where v_O is zero

→ Where both transistors are cut-off

Question 4 [20 marks]

Answers:

i. $r_{\pi 6} = \beta V_T / I_{C6}$ where $I_{C6} = I_{C7}/(1+\beta)$ [2]

$r_{\pi 6} = \beta(1+\beta)V_T / I_{C7}$ = (90)(91)(0.026)/(0.5m) =426 kΩ [2]

$r_{\pi 7} = \beta V_T / I_{C7}$ = (90)(0.026)/0.5m)= 4.68 kΩ [2]

$R_i = r_{\pi 6} + (1+\beta)r_{\pi 7}$ =426kΩ +(91)(4.68kΩ) = 852 kΩ [2]

ii. $v_{o3} = i_{c7}R_{L7} = (\beta i_{b7})R_{L7} = \beta(1+\beta)i_{b6}R_{L7}$ [2]

$$i_{b6} = \frac{v_{o2}}{R_i}$$

$$A_v = \frac{v_{o3}}{v_{o2}} = \frac{\beta(1+\beta)R_{L7}}{R_i}$$ [2]

$Find \Rightarrow r_{o11}, g_{m11}, r_{\pi 11}, r_{\pi 8} \Rightarrow I_{c11} = I_{c7}, I_{c8} = given$ [4]

$r_{o11} = V_A / I_{C7}$ = 120/0.5m = 240 kΩ

$g_{m11} = V_T / I_{C7}$ = 0.026/0.5m = 5.2 kΩ

$r_{\pi 11} = \beta V_T / I_{C7}$ = (90)(0.026)/0.5m = 4.68 kΩ

$r_{\pi 8} = \beta V_T / I_{C8}$ = (90)(0.026)/2m = 1.17 kΩ

$$R_{c11} = r_{o11}\left(1 + g_{m11}R_E^{'}\right) = (240k)[1 + (5.2k)(4.68k // 0.1k) = 124T\Omega$$

$R_{b8} = r_{\pi 8} + (1+\beta)R_4 = 1.17k + (91)(5k) = 456k\Omega$ [1]

$R_{L7} = R_{c11} \| R_{b8} \cong R_{b8}$ = 456kΩ [2]

$$A_v = \frac{90(91)(456k)}{852k} = 4383$$ [1]

<u>Question 5 [15 marks]</u>

<u>Answers:</u>

Q5(i)

I_{C1}	$= 8\ \mu A$		[1]
	$= I_{C8} / 2 = I_{C9} / 2$	$= I_{C10} / 2$	[1]
I_{C10}	$= 2 \times I_{C10}$	$= 16\ \mu A$	[1]

$I_{C10} R_4$	$= V_T \ln(I_{REF} / I_{C10})$	[1]
I_{REF}	$= I_{C10} \exp[I_{C10} R_4 / V_T]$	[1]
	$= (16\mu) \exp[(16\mu \times 5k) / (26m)]$	[1]
	$= 0.347$ mA	[1]

I_{REF}	$= (V^+ - V^- - V_{EB12} - V_{BE11}) / R_5$	
R_5	$= (V^+ - V^- - V_{EB12} - V_{BE11}) / I_{REF}$	[1]
	$= (12 - (-12) - 0.6 - 0.6) / (0.347m)$	[1]
	$= 65.694\ k\Omega$	[1]

Q5(ii)

I_{C6}	$= I_{C1} = 8\ \mu A$	[1]
V_{C6}	$= V_{BE7} + V_{BE6} + I_{C6} R_2 + V^-$	[2]
	$= 0.6 + 0.6 + (8\mu)(1k) + (-12)$	[1]
or V_{C6}	≈ -10.8 V	[1]

Question 6 [20 marks]

Answers:

Q6(a)

Calculation:

A_v $= 1 + R_2/(R_{1F} + R_{1V})$ [1]

R_2 $= 250\ k\Omega$. R_{1F} is a fixed-value resistor.

R_{1V} is a potentiometer. Gain is maximum, i.e. 26, when $R_{1V} = 0\ \Omega$.

A_{v1} $= 26$ $= 1 + R_2/(R_{1F} + R_{1V})$ $= 1 + 250k/(R_{1F} + 0)$ [1]

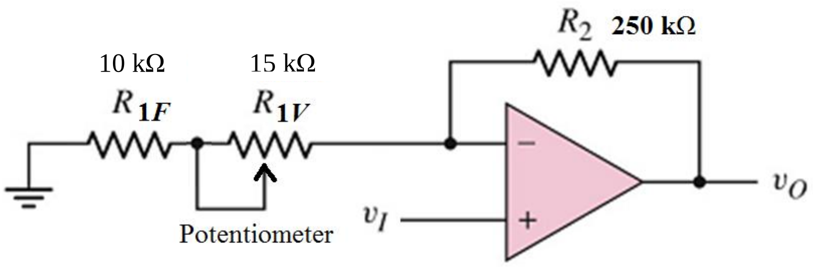
R_{1F} $= 10\ k\Omega$ [0.5]

Gain is minimum, i.e. 11, when R_{1V} is maximum.

A_{v2} $= 11$ $= 1 + R_2/(R_{1F} + R_{1V})$ $= 1 + 250k/(10k + R_{1V})$ [1]

R_{1V} $= 15\ k\Omega$ [0.5]

Circuit: [2]



Q6(b)

Using superposition theorem:

$v_{I2} = 0$:	$v_{O1}(v_{I1})$	$= (-R_F/R_1)\ v_{I1}$	$= (-100k/100k)\ v_{I1}$	$= -v_{I1}$
		[0.5]	**[0.5]**	**[0.5]**
$v_{I1} = 0$:	$v_{O1}(v_{I2})$	$= (-R_F/R_2)\ v_{I2}$	$= (-100k/100k)\ v_{I2}$	$= -v_{I2}$
		[0.5]	**[0.5]**	**[0.5]**

v_{O1} $= v_{O1}(v_{I1}) + v_{O1}(v_{I2})$ **[0.5]** $= (-v_{I1}) + (-v_{I2})$ **[0.5]** $= -(v_{I1} + v_{I2})$ **[0.5]**

$v_O = (-R_F/R_1)v_{O1}$ **[0.5]** $= (-100k/100k)[-(v_{I1} + v_{I2})]$ **[0.5]** $= v_{I1} + v_{I2}$ **[0.5]**

Note: Student can use any method that leads to the same answer.

Q6(c)

	$\boldsymbol{R_F / R_1 = 5}$ ➔ $\boldsymbol{R_F = 5\, R_1}$		**[0.5]**
and	$\boldsymbol{R_F / R_2 = 10}$ ➔ $\boldsymbol{R_F = 10\, R_2}$		**[0.5]**

So, resistor R_2 will be the **smallest** value. Set $\boldsymbol{R_2 = 25\ k\Omega}$. **[1]**

➔	$\boldsymbol{R_F} = 10\, R_2 = 10 \times 25\ k\Omega$	$\boldsymbol{= 250\ k\Omega}$	**[0.5]**
and	$\boldsymbol{R_1} = R_F / 4 = 250k\Omega / 5$	$\boldsymbol{= 50\ k\Omega}$	**[0.5]**

	$R_N = R_1 \parallel R_2 = 50\ k\Omega \parallel 25\ k\Omega$	$= \boldsymbol{16.667\ k\Omega}$	
	$1 + R_F / R_N = 1 + 250k / (16.667k)$	$= 16$	
	$(1 + R_F / R_N)(R_P / R_A) = (16)\ (R_P / R_A) = 5$		**[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	$\boldsymbol{R_A = 80\ k\Omega}$,	**[1]**
then	$\boldsymbol{R_B = 200\ k\Omega}$	**[1]**
	$R_P = (2\, R_B) / 16 \qquad = (5\, R_A) / 16$	
➔	$\boldsymbol{R_P = 25\ k\Omega}$	**[0.5]**
	$R_P = R_A \parallel R_B \parallel R_C$	
➔	$\boldsymbol{R_C = 44.45\ k\Omega}$	**[1]**

APPENDIX

BASIC FORMULA

BJT

$$i_C = I_S e^{v_{BE}/V_T} ;\text{NPN}$$

$$i_C = I_S e^{v_{EB}/V_T} ;\text{PNP}$$

$$i_C = \beta i_B = \alpha i_E$$

$$i_E = i_B + i_C$$

$$\alpha = \frac{\beta}{\beta + 1}$$

;Small signal

$$\beta = g_m r_\pi$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

MOSFET

;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{\mu_n C_{ox} W}{2L} = \frac{k_n'}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{\mu_p C_{ox} W}{2L} = \frac{k_p'}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$