VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR

Department of Electrical Engineering

Electronic Devices and Circuits (Code: ECL206)

Semester-III

Sessional Examination II

Slot: G
Date: Oct 10, 2015 (Sat)
Time: 10:30–11:30 A.M.

Time: 1 hour

Maximum Marks: 15

Weightage: 15 %

Important instructions:

- This is a closed book, closed notes examination.
- This question paper comprises total four questions printed on two pages.
- All the questions are compulsory.
- Maximum marks that can be obtained for a particular question are indicated in the brackets [ ] on the extreme right of the corresponding question.
- Non-programmable calculators are permitted for use during the examination.
- Please begin the answers to each main question on a new page of the answer booklet.
- Please indicate the important steps of reasoning/ calculations clearly.
- Unless otherwise specified, assume silicon semiconductor.
- The cut-in/ knee voltages for Si, Ge, and GaAs are 0.7 V, 0.3 V and 1.2 V respectively.
- Typical h-parameter values for a transistor in common-emitter configuration are: $h_i = 1.1k\Omega$, $h_r = 2.5 \times 10^{-4}$, $h_f = 50$, and $h_o = 25\mu A/V$
- Assume suitable data wherever *necessary*. Please mention the assumptions made, if any.

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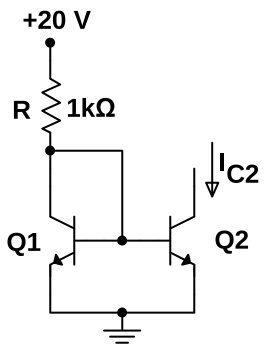
1. Answer the following.

   (a) The three important temperature dependent parameters which are responsible for the change in collector current of a transistor are ____. [1]

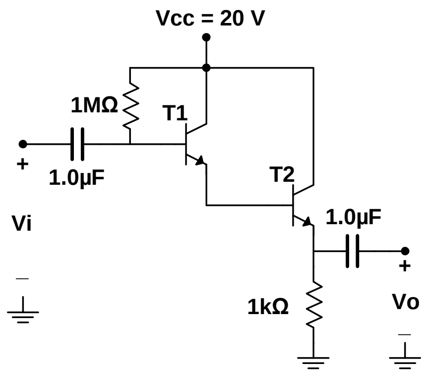
   (b) For a fixed-biased transistor circuit, let the dc $V_{cc} = 20V$, $I_c = 1mA$ and $R_c = 1k\Omega$. If the thermal resistance θ is $500°C/W$, the rate of variation of collector current with respect to the junction temperature i.e. $\frac{\partial I_c}{\partial T_j}$ is given as ____. [1]

   (c) For the circuit shown in Figure 1a, find the collector current I_{C2} flowing through the transistor Q_2. Assume both the transistors to be identical and have $\beta = 100$. [1]

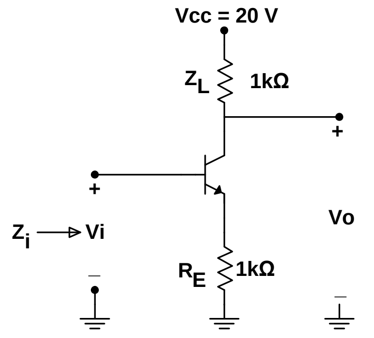
   (d) For the multi-stage transistor circuit shown in Figure 1b, determine the emitter current for transistor T_2 using dc-analysis. Assume β for both the transistors to be 100. [1]



(a) Figure for Q.1c



(b) Figure for Q.1d



(c) Figure for Q.3

Figure 1: Figures for Q.1c, Q.1d, and Q.3

2. For the multi-stage transistor circuit shown in Figure 2
   (a) Neatly draw and label the h-parameter model. (No labelling, no marks!) [1]
   (b) Calculate the following for individual stages: $(A_{I1}, Z_{i1}, A_{V1}, Z_{o1})$ and $(A_{I2}, Z_{i2}, A_{V2}, Z_{o2})$. [3]
   (c) Calculate overall (combined) gains (A_I, A_V) and impedances (Z_i, Z_o) (as shown by arrows). [2]

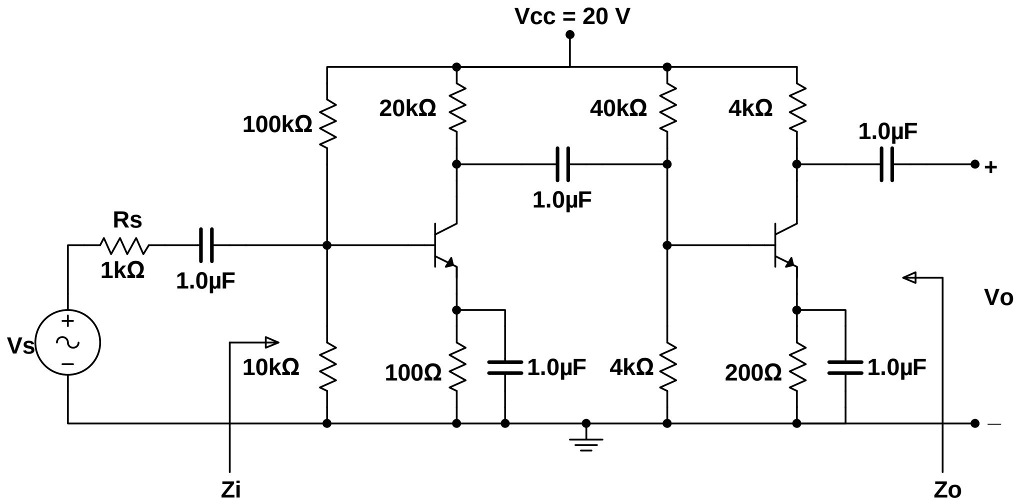


Figure 2: Figure for Q.2

3. For the circuit shown in Figure 1c, .
   (a) Neatly draw and label the hybrid (h) equivalent for small-signal ac analysis. (No labelling, no marks!) [1]
   (b) Calculate Z_i. *(Hint: Apply Kirchhoff's laws to the h-model obtained in Part (a) to obtain the voltage the current ratio.)* [4]

Q.1

(a) The three primarily important, temperature dependent parameters are

① V_{BE} (Base-to-Emitter voltage):

V_{BE} decreases at a rate of 2.5 mV (optional) & per degree change in temperature

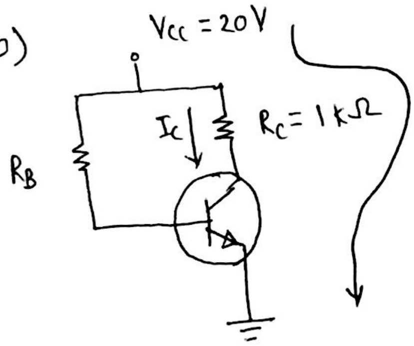
② I_{CBO}/I_{CO} (Reverse saturation current):

I_{CBO} doubles with every 10°C rise in temperature.

③ β (current gain):

Increases with an increase in the temperature.

(b)



$\theta = 500°C/W$

$I_C = 1\text{ mA}$; $R_C = 1\text{ k}\Omega$; $V_{CC} = 20\text{ V}$

The thermal runaway equation is given by

$$\frac{\partial P_c}{\partial T_j} < \frac{1}{\theta}$$

Considering threshold value

$$\Rightarrow \boxed{\frac{\partial P_c}{\partial I_c} \times \frac{\partial I_c}{\partial T_j} = \frac{1}{\theta}} \quad \text{—①}$$

For $\frac{\partial P_c}{\partial c}$, $\boxed{P_c = I_c V_{CE}}$ —②

By applying KVL at collector-emitter loop; $V_{CC} - I_C R_C - V_{CE} = 0$

$\therefore \boxed{V_{CE} = V_{CC} - I_C R_C}$ —③

{ from ③ & ②

$\therefore P_c = I_c(V_{CC} - I_c R_c)$

$\therefore P_c = I_c V_{CC} - I_c^2 R_c$

$$\frac{\partial P_c}{\partial I_c} = V_{CC} - 2 I_c R_c$$

$$= 20 - 2 \times 1 \times 10^{-3} \times 1 \times 10^{3} = 18$$

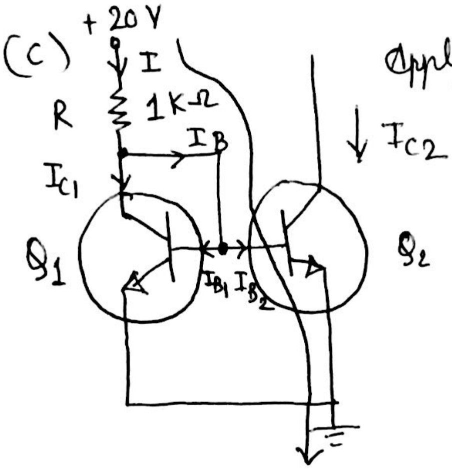
$\therefore$ From ①,

$$\frac{\partial I_c}{\partial T_j} = \frac{1/\theta}{18} = \frac{1}{500 \times 18}$$

$$\boxed{\frac{\partial I_c}{\partial T_j} = 0.111\ \text{mA}/°C}$$

Q1

(c)



Applying KCL at the collector node of Q_1

$$I = I_{C1} + I_B$$

$$= \beta I_{B1} + I_{B1} + I_{B2}$$

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

$$\boxed{I = (2+\beta) I_{B1}}$$

Since for identical transistors $I_{B1} = I_{B2}$

$\cancel{I = 20}$

Applying KVL

$$20 - I \times 1k - 0.7 = 0 \Rightarrow I = \frac{20 - 0.7}{1k\Omega}$$

Assuming Silicon transistor

$$\therefore \boxed{I = 19.3 \text{ mA}}$$

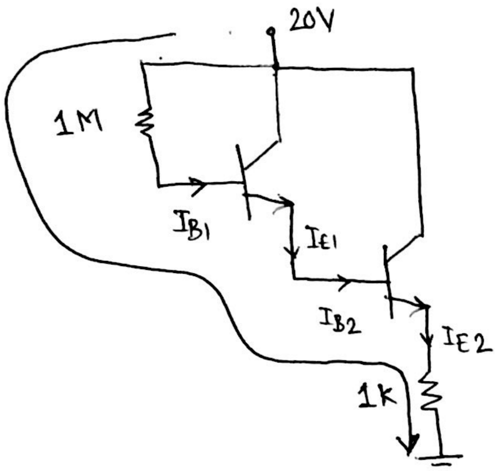
$$\therefore I_{B1} = I_{B2} = \frac{19.3\text{m}}{(2+\beta)} = 189.21 \text{ μA}$$

$$\therefore \boxed{I_{C2} = 18.92 \text{ mA}}$$

Q.1

~~(a) The given multistage transistor is of CC – CC configuration.~~

(b) For dc - analysis open-circuit the capacitors



Applying KVL,

$$\boxed{20 - 1M \times I_{B1} - 0.7 - 0.7 - 1k \times I_{E2} = 0}$$

Now, $I_{E1} = I_{B2} = \cancel{\beta I_{B1}}\ (1+\beta) I_{B1}$

$I_{E2} = \cancel{\beta I_{B2}}\ (1+\beta) I_{B2}$

$$\boxed{I_{E2} = (1+\beta)(1+\beta) I_{B1}}$$

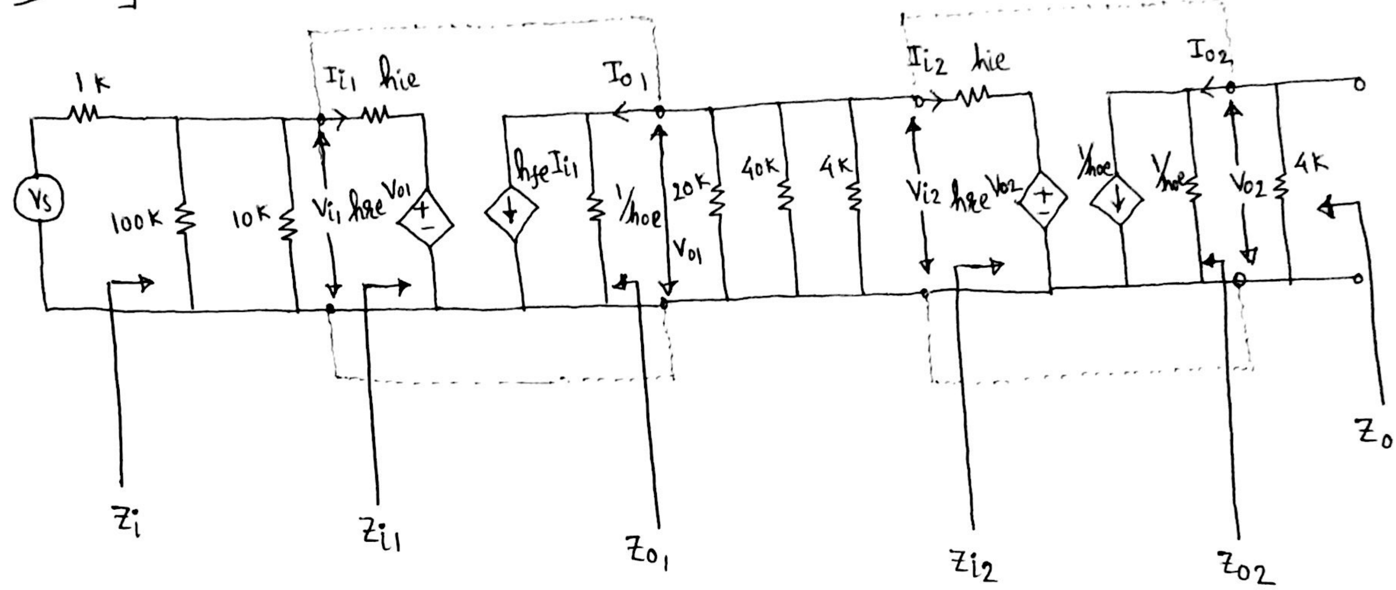
Darlington Pair

$$20 - 1M \times I_{B1} - 1.4 - 1k(101 \times 101) I_{B1} = 0$$

$$\therefore I_{B1} = \frac{20 - 1.4}{1M + 1k(10201)} = \cancel{1.66\,m}\ 1.66\ \mu A$$

$$\therefore \boxed{I_{E2} = 16.93\ mA}$$

Q.2 a]



b] $h_{ie} = 1.1\ k\Omega$; $h_{re} = 2.5 \times 10^{-4}$; $h_{fe} = 50$; $h_{oe} = 25\ \mu A/V$

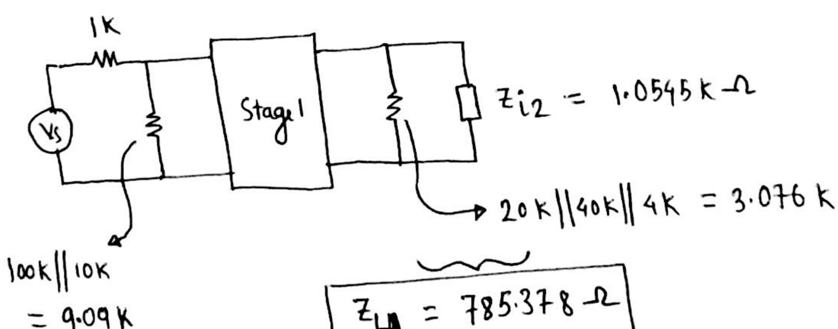
Stage 2 :

$$\boxed{A_{I2} = \frac{-h_{fe}}{1 + h_{oe} Z_{L2}}} = -45.45$$

$$\boxed{Z_{i2} = h_{ie} + h_{re} Z_{L2} A_I} = 1.05455\ k\Omega$$

$$\boxed{A_{V2} = \frac{A_{I1} \times Z_{L2}}{Z_{i2}}} = -172.39$$

Stage 1



$$\boxed{Z_{L1} = 785.378\ \Omega}$$

$$Z_{L1} = 20k \| 40k \| 4k \| Z_{i1} = 785.378\ \Omega$$

$$R_{S1} = 100k \| 10k \| 1k = 900.90\ \Omega$$

$$A_{I1} = \frac{-h_{fe}}{1 + h_{oe} Z_{L1}} = \frac{-50}{1 + 25\mu \times 785.378} = -49.037$$

$$Z_{i1} = h_{ie} + h_{re} Z_{L1} A_{I1} = 1.090\ k\Omega$$

$$A_{V1} = \frac{A_{I1} Z_{L1}}{Z_{i1}}$$

$$= \frac{-49.037 \times 785.378}{1.090\,K} \Rightarrow \boxed{A_{V1} = -35.33}$$

$$1/Z_{o1} = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_{S1}} = 18.75\ \mu\mho$$

$$\boxed{Z_{o1} = 53.325\ K\Omega}$$

<u>Calculation of Z_{o2} :</u> First calculate R_{S2}

$$\cancel{R_{S2} = Z_{o1} \parallel Z_{L1} = 773.978\,\Omega}$$

$$\cancel{R_{S2} = Z_{o1} \parallel 20k \parallel 40k}$$

$$R_{S2} = Z_{o1} \parallel 20k \parallel 40k \parallel 4k = 2.909\ K\Omega$$

$$\therefore 1/Z_{o2} = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_{S2}}$$

$$\boxed{Z_{o2} = 45.69\ K\Omega}$$

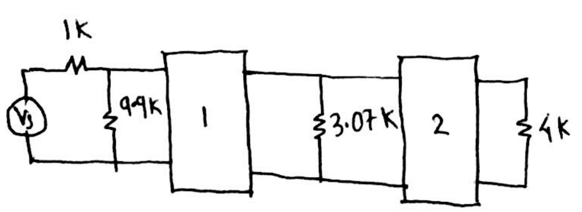
<u>Combined Gains :</u>

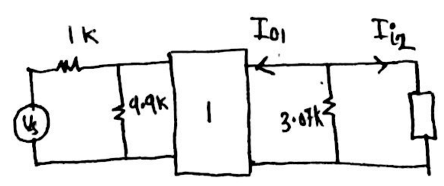
Voltage gain

$$\frac{V_{o2}}{V_{i1}} = A_V = \underbrace{\frac{V_{o2}}{V_{i2}}}_{A_{V1}} \times \underbrace{\frac{V_{o1}}{V_{i1}}}_{A_{V2}}$$

But $V_{i2} = V_{o1}$

$$\therefore A_V = (-172.39) \times (-35.33) \Rightarrow \boxed{A_V = 6090.53}$$





$Z_{i2} = 1.054\,K\Omega$

<u>Current Gain from intermediate stage:</u>

$$A_{Im} = \frac{I_{i2}}{-I_{o1}}$$

But $I_{i2} = \frac{-I_{o1} \times 3.07k}{3.07k + 1.054k}$

$$\therefore -\frac{I_{i2}}{I_{o1}} = 0.74442 = A_{Im}$$

$$A_I = A_{I1} \times A_{Im} \times A_{I2}$$

$$= -49.037 \times 0.7442 \times -45.45$$

$$\therefore \boxed{A_I = 1658.62}$$

$$Z_o = Z_{o2} \parallel 4k$$

$$\boxed{Z_o = 3.67\ k\Omega}$$

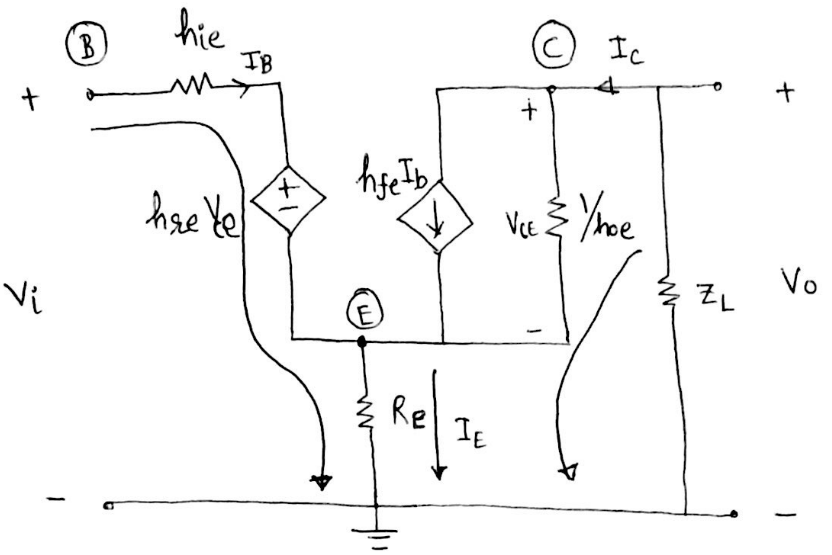
$$Z_i = 100k \parallel 10k \parallel Z_{i1}$$

$$\boxed{Z_i = 973.30\ \Omega}$$

Comparison :

	Stage 1	Stage 2	Combined
A_I	-49.037	-45.45	1658.62
Z_i	$1.090\ k\Omega$	$1.05455\ k\Omega$	$973.30\ \Omega$
A_V	-35.33	-172.39	6090.53
Z_o	$53.325\ k\Omega$	$45.69\ k\Omega$	$3.67\ k\Omega$

Q3 (a)



(b)

To obtain Z_i

$$\boxed{Z_i = \frac{V_i}{I_B}}$$

KCL at (E)

$$\left.\begin{aligned} &\boxed{I_E = I_B + h_{fe} I_B + h_{oe} V_{CE}} \\ &\boxed{I_E = I_B(1+h_{fe}) + V_{CE}\, h_o} \checkmark \end{aligned}\right\} \text{—— (1)}$$

Applying KVL at the input side,

$$\boxed{V_i = h_{ie} I_B + h_{re} V_{ce} + R_E I_E} = \left[h_{ie} + R_E(1+h_{fe})\right] I_b + R_E V_{CE} h_o + h_{re} V_{CE}$$

Eliminating V_{CE} (expressing them in terms of I_b)

$$\boxed{V_i = I_b\left(h_{ie} + R_E(1+h_{fe})\right) + V_{CE}\left(R_E h_o + h_{re}\right)} \text{—— (2)}$$

∴ Applying KVL at the output side,

$$-V_o = V_{CE} + I_E R_E$$

But $\boxed{-V_o = Z_L I_c = Z_L\left(h_{fe} I_B + h_{oe} V_{CE}\right)}$

$$-\left(Z_L h_{fe} I_B + Z_L h_{oe} V_{CE}\right) = V_{CE} + I_E R_E$$

From (1), $-Z_L h_{fe} I_B - Z_L h_{oe} V_{CE} = V_{CE} + I_B R_E(1+h_{fe}) + V_{CE} h_{oe} R_E$

$$\therefore V_{CE}\left(Z_L h_{oe} + 1 + h_{oe} R_E\right) = I_B\left(R_E(1+h_{fe}) + Z_L h_{fe}\right)$$

$$\therefore \boxed{V_{CE} = -\frac{I_B\left(Z_L h_{fe} + R_E(1+h_{fe})\right)}{1 + h_{oe}(R_E + Z_L)}}$$

Therefore,

$$\therefore V_{CE} = I_B \left(\frac{Z_L h_{fe} + R_E(1+h_{fe})}{1 + h_{oe}(R_E + Z_L)} \right)$$

$$\& \quad V_i = I_b \left(h_{ie} + R_E(1+h_{fe}) \right) + V_{CE} \left(h_{re} + R_E h_{oe} \right)$$

$$\frac{V_i}{I_b} = h_{ie} + R_E(1+h_{fe}) + \left(h_{re} + h_{oe} R_E \right) \left(\frac{Z_L h_{fe} + R_E(1+h_{fe})}{1 + h_{oe}(R_E + Z_L)} \right)$$

$$\therefore \boxed{Z_i = \frac{V_i}{I_b} = h_{ie} + R_E(1+h_{fe}) - \left(h_{fe} + h_{oe} R_E \right) \left[\frac{Z_L h_{fe} + R_E(1+h_{fe})}{1 + h_{oe}(R_E + Z_L)} \right]}$$

$$\therefore \boxed{Z_i = 49.67\,k\Omega}$$