Quiz 1

Solution & Marking Scheme

The mark breakdown and solution of Quiz 1 are shown below.

If you have questions regarding the marking scheme, please contact:

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After contacting the TA, if you are still not satisfied with your quiz marking, please contact Prof. Hamoui.

Note: This quiz was marked out of 36, but your mark for Quiz1 was taken out of 30.
So, for example, if you scored 36 here,
your mark for Quiz 1 in your final grade will be 36/30 = 120%.

- BJT Parameters:
  - npn BJT: $V_{BEon} = 0.7\text{V}$, $V_{BCon} = 0.4\text{V}$, $V_{CEsat} = 0.3\text{V}$, $\beta = 250$, $V_A = 125V$.
  - pnp BJT: $|V_{BEon}| = 0.7\text{V}$, $|V_{BCon}| = 0.4\text{V}$, $|V_{CEsat}| = 0.3\text{V}$, $\beta = 50$, $|V_A| = 80V$.
  - Thermal voltage: $V_T = 25\text{mV}$.

<u>Specifications</u>:

$V_{CC} = +5\text{V}$

$I_{REF} = 0.5\text{mA}$

$R_E = 475\Omega$

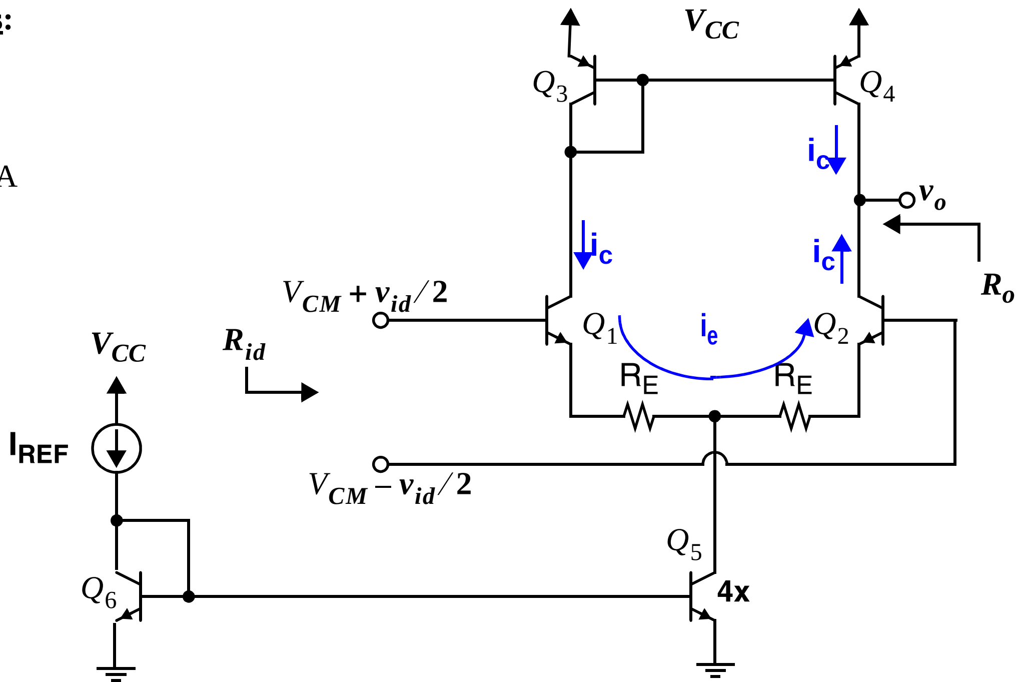


Fig. 1

<u>Question 1</u> [30 marks]

<u>Note</u>: This question corresponds to the active-loaded differential pair with emitter-degeneration resistances (presented in Section 7.5.5, solved in class during Lecture # 6 on Jan. 22, and solved during the Tutorial for Prob. 7.68).

1.1) [2 marks]

$$I_{E1,2} \cong \frac{4 \times I_{REF}}{2} = \frac{4 \times 0.5\text{mA}}{2} = 1\text{mA}$$

$$r_{e1,2} = \frac{V_T}{I_{E1,2}} \cong \frac{25\text{mV}}{1\text{mA}} = 25\Omega$$

$$R_{id} = 2(\beta + 1)(r_{e1,2} + R_E) = 2(250 + 1)(25\Omega + 475\Omega) = 251\text{k}\Omega$$

1.2) [4 marks]

$\alpha \cong 1$, since the base currents are neglected.

$$I_{C2,4} = \alpha I_{E2} \cong 1\text{mA}$$

$$r_{o2} = \frac{V_{An}}{I_{C2}} = \frac{125\text{V}}{1\text{mA}} = 125\text{k}\Omega$$

$$r_{o4} = \frac{V_{Ap}}{I_{C2}} = \frac{80\text{V}}{1\text{mA}} = 80\text{k}\Omega$$

$$R_o = r_{o2} \| r_{o4} = 125\text{k}\Omega \| 80\text{k}\Omega = 48.78\text{k}\Omega$$

Solving directly on the circuit diagram:

$$i_e = \frac{v_{id}}{2(r_e + R_E)} \qquad \text{(see the circuit diagram)}$$

$$i_c = \alpha\, i_e$$

$$v_o = +\,\mathbf{2} i_c\, R_o \qquad \text{(Note: the 2 factor is due to the current-mirror action of the active load Q3-Q4)}$$

$$A_d = \frac{v_o}{v_{id}} = \alpha \frac{2R_o}{2(r_e + R_E)} = (1)\frac{(2 \times 48.78\text{k}\Omega)}{2(25\Omega + 475\Omega)} = +\,97.56\text{V/V}$$

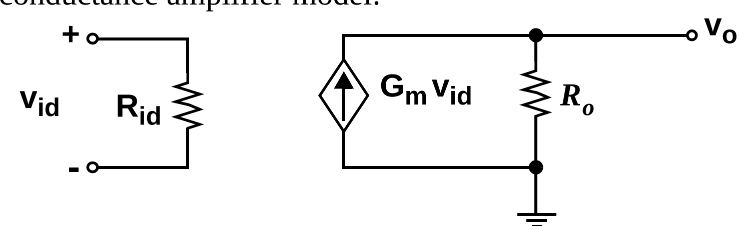
1.3) [3 marks]

$$G_m \equiv \left|\frac{i_o}{v_{id}}\right|\Bigg|_{R_L = 0} = \frac{\mathbf{2} i_c}{v_{id}} = \frac{\alpha}{r_e + R_E} \cong \frac{1}{25\Omega + 475\Omega} = 2\text{mA/V}$$

Note: you can also express G_m as: $G_m \equiv \dfrac{\alpha}{r_e + R_E} = \dfrac{g_m}{1 + R_E \backslash r_e}$

1.4) [3 marks]

The equivalent transconductance amplifier model:



1.5) [6 marks]

<u>For Q1 in active mode</u>:

$$V_{BC1} \le V_{BC,\text{on}}$$

$$\Rightarrow V_{CM} - V_{C1} \le V_{BC,\text{on}} \text{ where } V_{C1} = V_{CC} - |V_{BE,\text{on}}|$$

$$\Rightarrow V_{CM} \le V_{BC,\text{on}} + V_{CC} - |V_{BE,\text{on}}|$$

$$\Rightarrow V_{CM,\text{max}} = 0.4\text{V} + (5\text{V-}0.7\text{V}) = 4.7\text{V}$$

<u>For proper operation of current source (Q5 in active mode)</u>:

$$V_{CE5} \ge V_{CE,\text{sat}}$$

$$\Rightarrow V_{CM} - (V_{BE,\text{on}} + I_{E1} R_E) \ge V_{CE,\text{sat}}$$

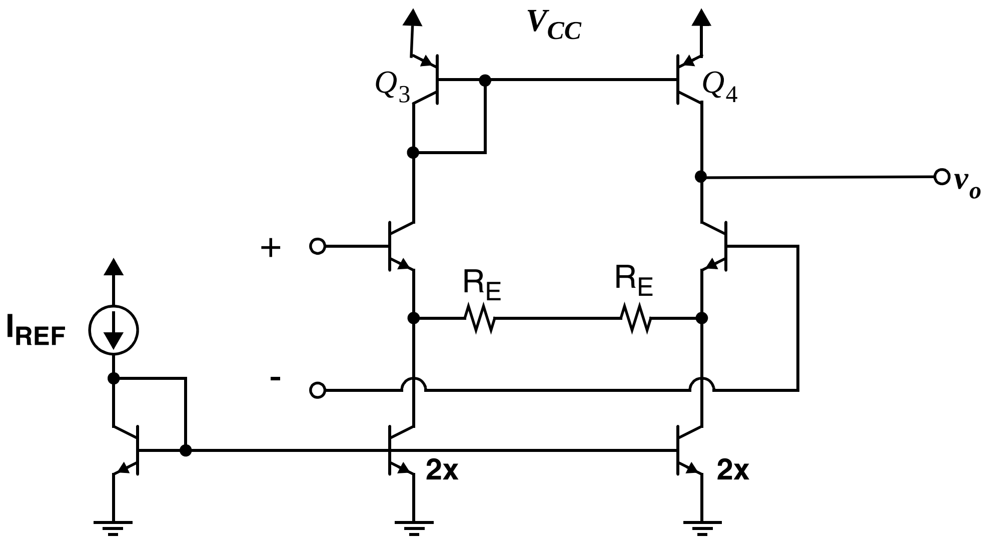
$$\Rightarrow V_{CM} \ge V_{CE,\text{sat}} + \left(V_{BE,\text{on}} + \frac{4 \times I_{REF}}{2} R_E\right)$$

$$\Rightarrow V_{CM,\text{min}} = 0.4\text{V} + (0.7\text{V} + 1\text{mA} \times 475\Omega) = 1.475\text{V}$$

Therefore, the common-mode input range is: $1.475\text{V} \le V_{CM} \le 4.7\text{V}$

<u>Note</u>: The input common-mode range of the BJT differential pair (section 7.4.4 in the textbook) was derived in class during Lecture #5 on Jan. 20, and solved during the Tutorial for Prob. 7. 68, 7.37, and 7.38)

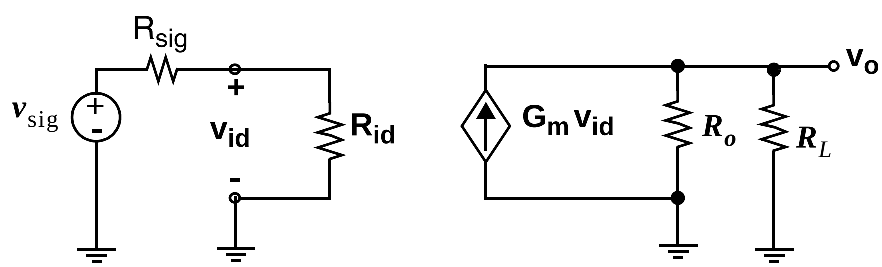
1.6) [6 marks]



Here, no dc current flows through R_E. Hence, $V_{CM,min}$ is increased.

<u>Note</u>: This idea was presented in class during lecture #10 on Feb. 5 and in the tutorials through Prob. 7.37 and 7.38.

1.7) [6 marks]



$$v_{id} = \frac{R_{id}}{R_{sig} + R_{id}} v_{sig}$$

$$v_o = +(G_m v_{id})(R_o \parallel R_L)$$

$$A_{d,\,sig} \equiv \frac{v_o}{v_{sig}} = \frac{R_{id}}{R_{sig} + R_{id}} \cdot G_m \cdot (R_o \parallel R_L) = \frac{251\text{k}}{251\text{k} + 50\text{k}} \cdot 2\text{m} \cdot (48.78\text{k} \parallel 100\text{k}) = +54.68\text{V/V}$$

<u>Question 2</u>: [6 marks]

2.1) [3 marks]

Although there are many advantages to using transistors as active loads for the implementation of differential amplifier stages in an integrated circuit (IC), there is a major advantage in using resistors as loads, which is:

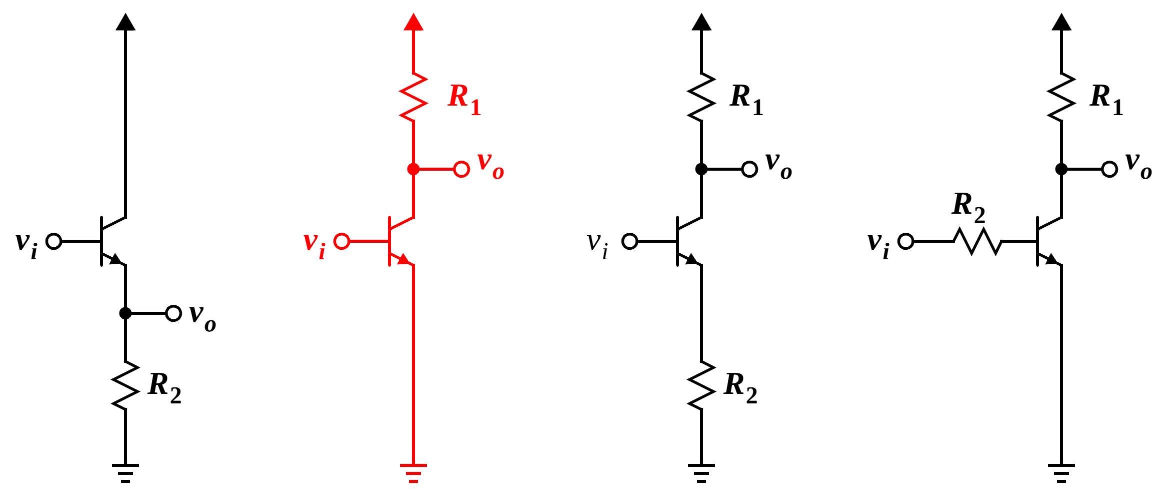
1. For small load values, resistances occupy smaller silicon area.
2. The matching between resistors is better than the matching between transistors.
3. **The dc level at the output nodes can be accurately predicted.**
4. Less power is dissipated when resistors are used.

2.2) [3marks]

Which of the following 4 gain stages has the largest voltage-gain $A_v = \left|\frac{v_o}{v_i}\right|$?

Assume identical transistors, same dc bias currents, and large values for the resistors.

You can ignore the finite output resistance of the BJT.



(1) (2) (3) (4)