Name: Solution Student ID: ____________

National Taiwan Normal University
Department of Computer Science and Information Engineering

CSU0007 - Basic Electronics
Midterm Exam (Apr. 27, 2020)

Five group questions; exam time: 2 hours 50 minutes (9:20am-12:10pm)
Clearly state each step of your answer.

1. (15 points) **Foundations.** Answer the following two questions:
   1a. (8 points) In Figure 1a, suppose v_1=2V, v_4=3V, and v_7=1V. Determine v_2, v_3, v_5, and v_6.
   1b. (7 points) In Figure 1b, find the equivalent resistance, R_{AB}, from the viewpoint of A-B.

1a. Using KVL

$V_3 = 1$ V

$V_6 = -3$ V

$V_5 = 1$ V

$V_2 = -2$ V

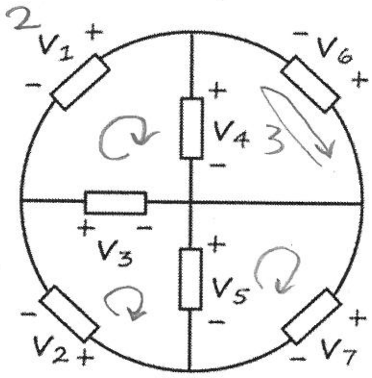

Figure 1a

1b.

$$R_{AB} = (4R /\!/ 4R) + (3R /\!/ 3R) + (3R /\!/ 3R) + (4R /\!/ 4R)$$

$$= 2R + \frac{3}{2}R + \frac{3}{2}R + 2R$$

$$= 7R$$

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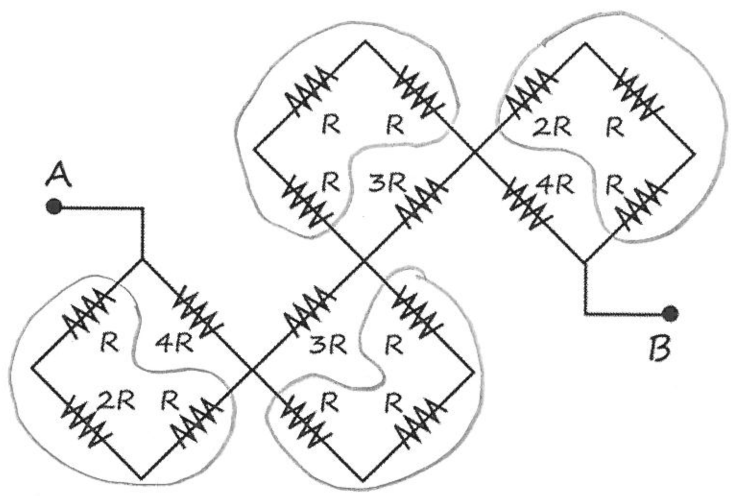

Figure 1b

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2. (30 points) **Elementary Analysis Techniques.** Answer the following three questions:

2a. (10 points) In Figure 2a, given the branch variables, perform symbolic computation to find current i_4 in terms of V_0 and $R_1 \sim R_4$. You may use equivalent resistors to simplify the process.

2b. (10 points) In Figure 2b, find current i by *applying the node method only.*

2c. (10 points) Following Question 2b, this time apply the concept of superposition to find i.

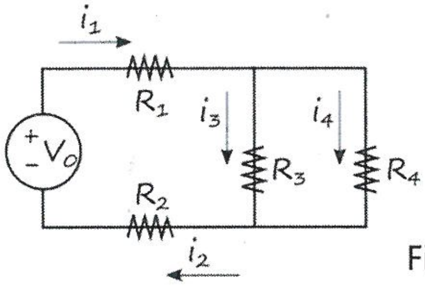


Figure 2a

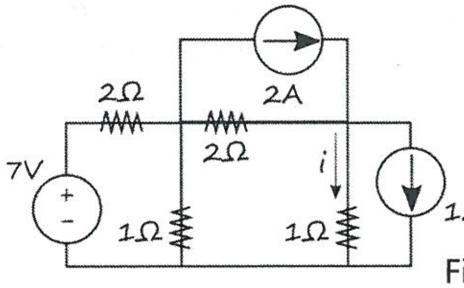
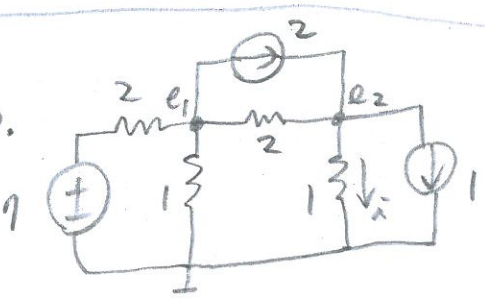


Figure 2b

2a. $$i_4 = \frac{1}{R_4}\left(V_0 \times \frac{\frac{R_3R_4}{R_3+R_4}}{R_1+R_2+\frac{R_3R_4}{R_3+R_4}}\right)$$

$$= \frac{R_3V_0}{(R_1+R_2)(R_3+R_4)+R_3R_4}$$ #

2b.



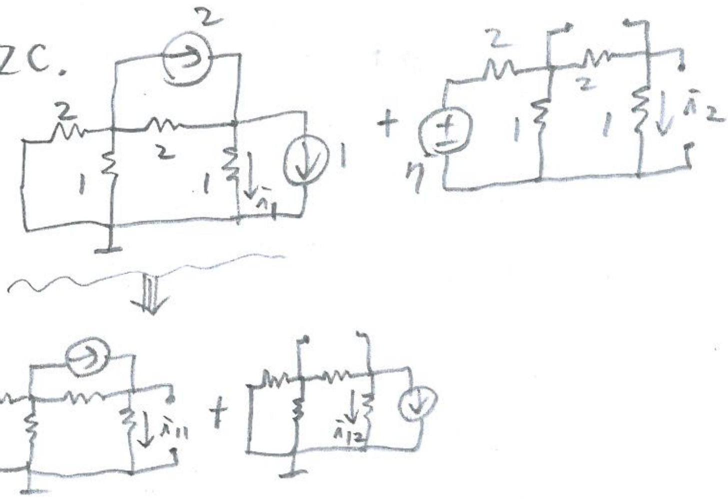
KCL at e_1: $\frac{e_1-7}{2} + e_1 + 2 + \frac{e_1-e_2}{2} = 0$

KCL at e_2: $-2 + \frac{e_2-e_1}{2} + e_2 + 1 = 0$

$\Rightarrow e_2 = 1$

$i = \frac{e_2}{1} = 1\text{ A}$ #

2c.



$i = i_1 + i_2$

$= i_{11} + i_{12} + i_2$

$i_2 = \left(7 \times \frac{\frac{3}{4}}{2+\frac{3}{4}} \times \frac{1}{2+1}\right)/1 = \frac{7}{11}\text{ A}$ → voltage divider + element law

$i_{11} = 2 \times \frac{2}{\frac{5}{3}+2} = \frac{12}{11}\text{ A}$

$i_{12} = (-1) \times \frac{\frac{8}{3}}{\frac{8}{3}+1} = \frac{-8}{11}\text{ A}$ → current divider

$\Rightarrow i = \frac{12}{11} - \frac{8}{11} + \frac{7}{11} = 1\text{ A}$ #

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3. (15 points) **Circuit Transformations.** Consider the circuit shown in Figure 3 and answer the following two questions:
   3a. (7 points) Find resistance R_{TH} in the Thévenin equivalent (Figure 3a).
   3b. (8 points) Find current i_{SC} in the Norton equivalent (Figure 3b).

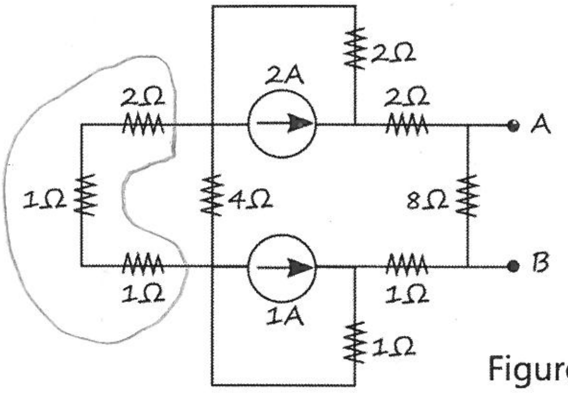


Figure 3

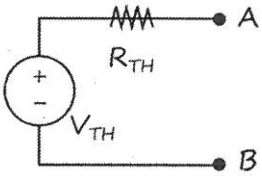


Figure 3a

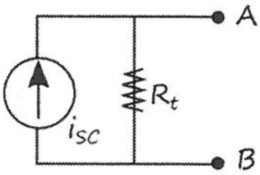
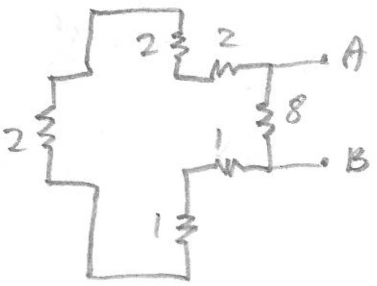
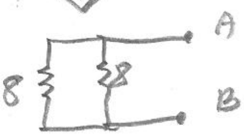


Figure 3b

3a.



⇓



$\Rightarrow R_{TH} = 4\,\Omega$

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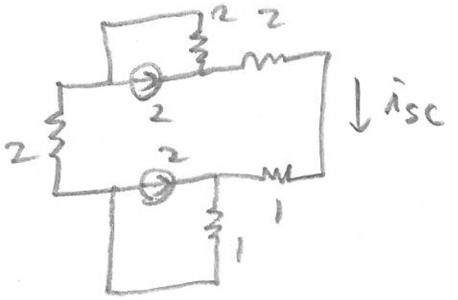
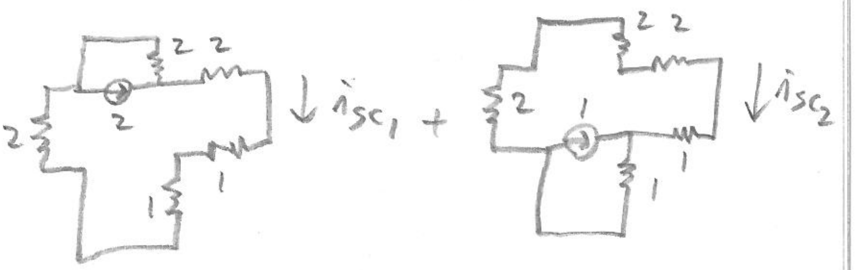
3b.



⇓ using superposition



$i_{sc} = i_{sc_1} + i_{sc_2}$

$i_{sc_1} = 2 \times \frac{2}{6+2} = \frac{1}{2}\ A$

$i_{sc_2} = (-1) \times \frac{1}{7+1} = \frac{-1}{8}\ A$

both using current divider

$\Rightarrow i_{sc} = \frac{1}{2} - \frac{1}{8} = \frac{3}{8}\ A$

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4. (15 points) **Applications.** Answer the following two questions:

4a. (7 points) As shown in Figure 4a, we have an embedded electronic system that can supply 5V voltage to power some other electronic devices. We have a sensor device that can only operate at ~~3.2~3.4V~~ 3.1~3.5V. Given a set of linear resistors, you are asked to use some of those resistors to construct a circuit that connects the four wires with some appropriate voltage transformation. Draw your answer directly on Figure 4a.

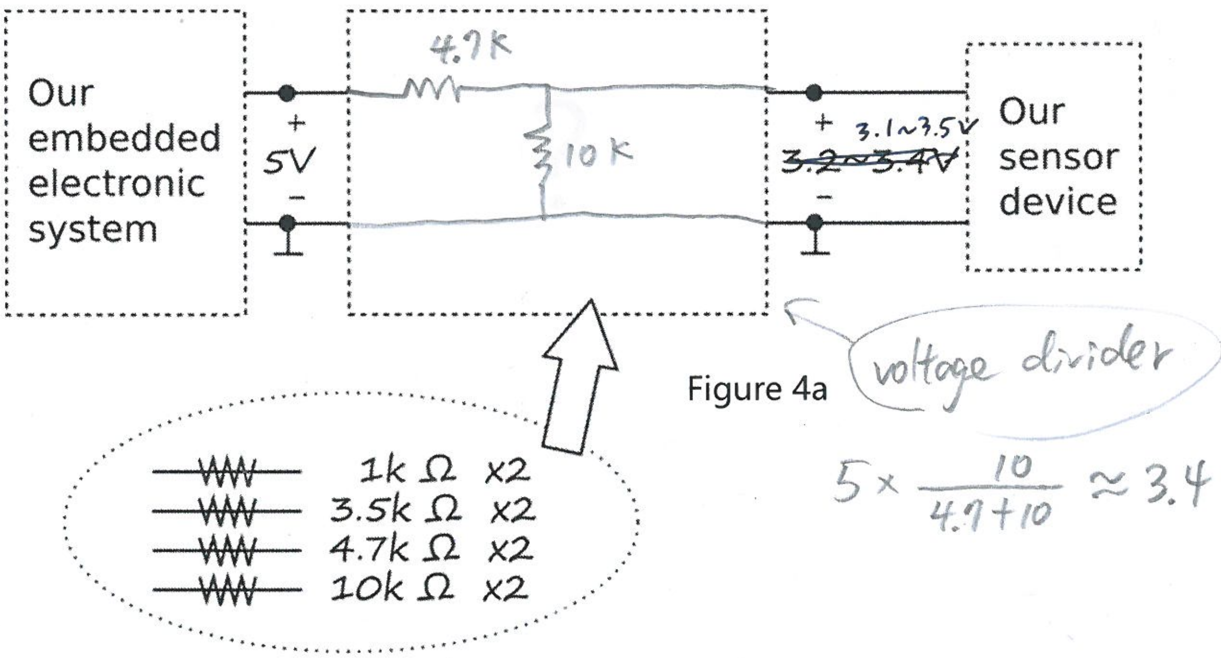

Figure 4a

$$5 \times \frac{10}{4.7+10} \approx 3.4$$

4b. (8 points) Given an arbitrary linear circuit, we may determine its Thévenin equivalent in two steps. First, we connect the circuit with a linear resistor and measure the branch voltage across that resistor. Then, we replace the resistor by a different linear resistor and again measure its branch voltage. Think about why that would help us determine the Thévenin equivalent. Now, with the two steps shown in Figure 4b, determine resistance R_{TH} of the Thévenin equivalent of our target linear circuit.

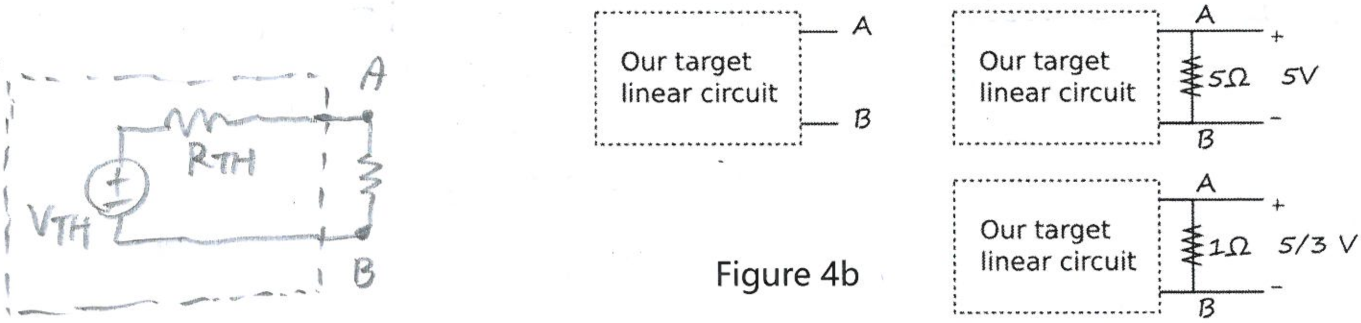

Figure 4b

It is indeed a voltage divider :

$$\begin{cases} 5 = V_{TH} \times \dfrac{5}{5+R_{TH}} \\ \dfrac{5}{3} = V_{TH} \times \dfrac{1}{1+R_{TH}} \end{cases} \Rightarrow \begin{cases} R_{TH} = 5 \\ V_{TH} = 10 \end{cases}$$

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Name: Solution Student ID: ____________

5. (25 points) **Nonlinear Analysis.** Answer the following three questions:

5a. (7 points) For the circuit in Figure 5a, if we changed the linear resistor so that R decreased, would i_D increase or decrease? Give your reason based on the graphical analysis.

5b. (8 points) In Fgure 5b, apply the analytical method to find current i.

5c. (10 points) In Figure 5c, apply the small-signal analysis to find current i_D.

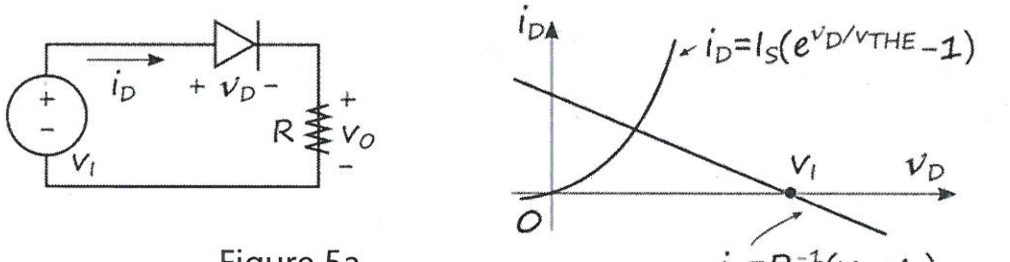
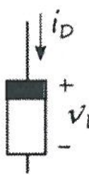


Figure 5a



$i_D = \begin{cases} K \cdot v_D^2 & \text{for } v_D > 0 \\ 0 & \text{otherwise} \end{cases}$

Assuming K = 1 mA/V²

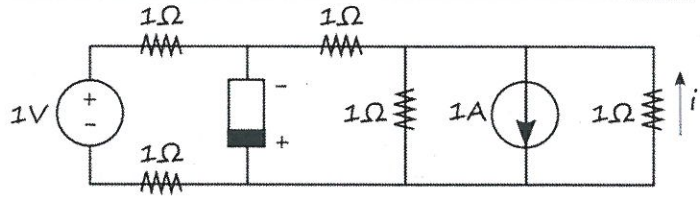
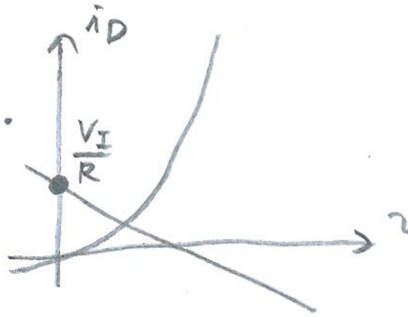


Figure 5b

5a.



therefore, $i_D \uparrow$ if $R \downarrow$ #

for small signal:

$$r_d = \frac{1}{\left.\frac{d f(v_D)}{d v_D}\right|_{v_D = V_D}}$$

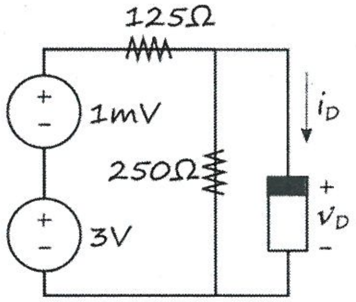
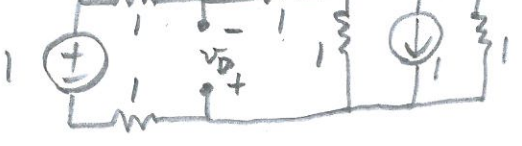


Figure 5c

5b. First, we need to determine whether $v_D > 0$:



using superposition (I prefer that)

$v_D = v_{D_1} + v_{D_2}$

$$v_{D_1} = (-1)\times\frac{\frac{3}{2}}{2+\frac{3}{2}} = -\frac{3}{7}V$$

$$v_{D_2} = 2\times\left(\left(1\times\frac{1}{\frac{3}{4}+1}\right)\times\frac{1}{3+1}\right) = \frac{2}{7}$$

$$\Rightarrow v_D = \frac{-3}{7}+\frac{2}{7} = \frac{-1}{7} < 0$$

$$\Rightarrow i_D = 0$$

Then we may reuse the superposition

$$i = i_1 + i_2 = \frac{(-1)}{1}\times\frac{\frac{1}{2}}{3+\frac{1}{2}} + 1\times\frac{\frac{3}{4}}{\frac{3}{4}+1} = \frac{2}{7}A$$

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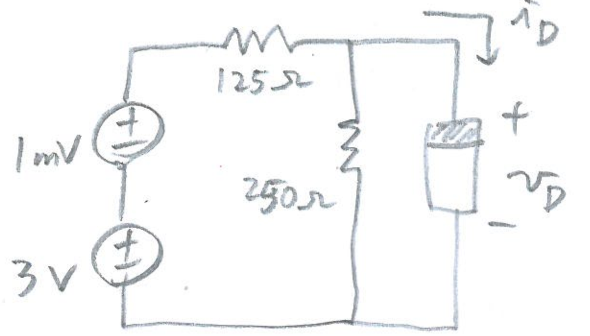
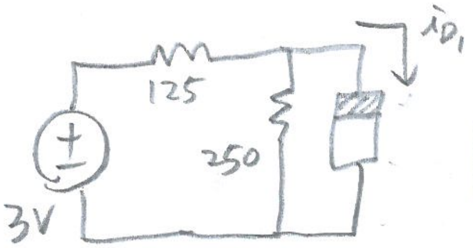
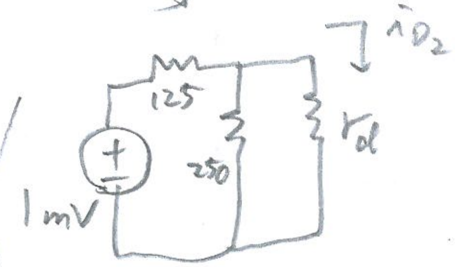
5c.

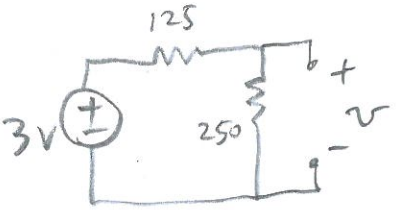


$$i_D = \begin{cases} \mathbb{K} \cdot v_D^2 & \text{if } v_D > 0 \\ 0 & \text{otherwise} \end{cases}$$

and $\mathbb{K} = 1 \ mA/V^2$







$$v = 3 \times \frac{250}{125+250} = 2\text{ V}$$

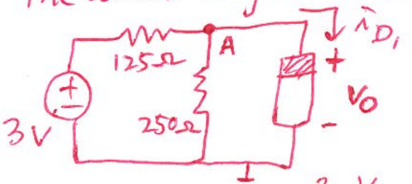
$v > 0$ ensures that the diode is ON.

$$\cancel{\Rightarrow i_{D_1} = 1 \times 10^{-3} \times 2^2}$$

AND THEN $\cancel{= 4 \text{ mA}}$

To compute i_{D_1}, it is wrong to directly apply $i_D = \mathbb{K} \cdot v_D^2$ because $v_D \neq v$

The correct way is as follows:



KCL on A: $\frac{3-V_0}{125} - \frac{0-V_0}{250} - i_{D_1} = 0$

Diode characteristic: $i_{D_1} = \mathbb{K} \cdot V_0^2$

$\Rightarrow V_0 = -6 + 2\sqrt{15} \approx 1.75\text{ V}$ (not 2V)

$\Rightarrow i_{D_1} = 10^{-3} \times V_0^2 = 3.0625 \text{ mA}$

$$r_d = \frac{1}{\left.\frac{d(\mathbb{K} v_D^2)}{d v_D}\right|_{v_D = V_D}} = \frac{1}{\left. 2\mathbb{K} v_D \right|_{v_D = V_D}}$$

$= \cancel{2}\ 1.75$

$$= \frac{1}{2 \times 10^{-3} \times \cancel{2}\ 1.75} = \cancel{250\ \Omega} \approx 286\ \Omega$$

$(250\Omega) // (286\Omega) \approx 133.4\Omega$

$$\Rightarrow i_{D_2} = \frac{1 \times 10^{-3} \times \frac{\cancel{\frac{250 \times 250}{250+250}}\ 133.4}{125 + \cancel{\frac{250 \times 250}{250+250}}\ 133.4}}{\cancel{250}\ 286}$$

$= \cancel{2}\ 1.79\ \mu A$

$i_D = i_{D_1} + i_{D_2} = \cancel{4.002 \text{ mA}}$

$\approx 3.0625 \text{ mA} + 0.00179 \text{ mA}$

$\approx 3.0643 \text{ mA}$ #