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# Solution of Mid-term Exam II

Electronics (III) 2011

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12/13/2011

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Electronics(3).2011

## Question 1

- Figs. 1(a) and 1(b) show a basic current source and Widlar current source, respectively. Assume that  $V_{BE}$  is 0.7V at a current of 1mA, the thermal voltage  $V_T=25mV$ ,  $V_{CC}=10V$ , and neglect the effect of finite  $\beta$ . **To generate a current  $I_O=10\mu A$ ,**

(a) find  $R_1$  in Fig. 1(a). (5%)

(b) for Fig. 1(b), if  $I_{REF}=1mA$ ,  
find  $R_2$  and  $R_3$ . (10%)

(c) explain the advantage of  
Widlar current source.

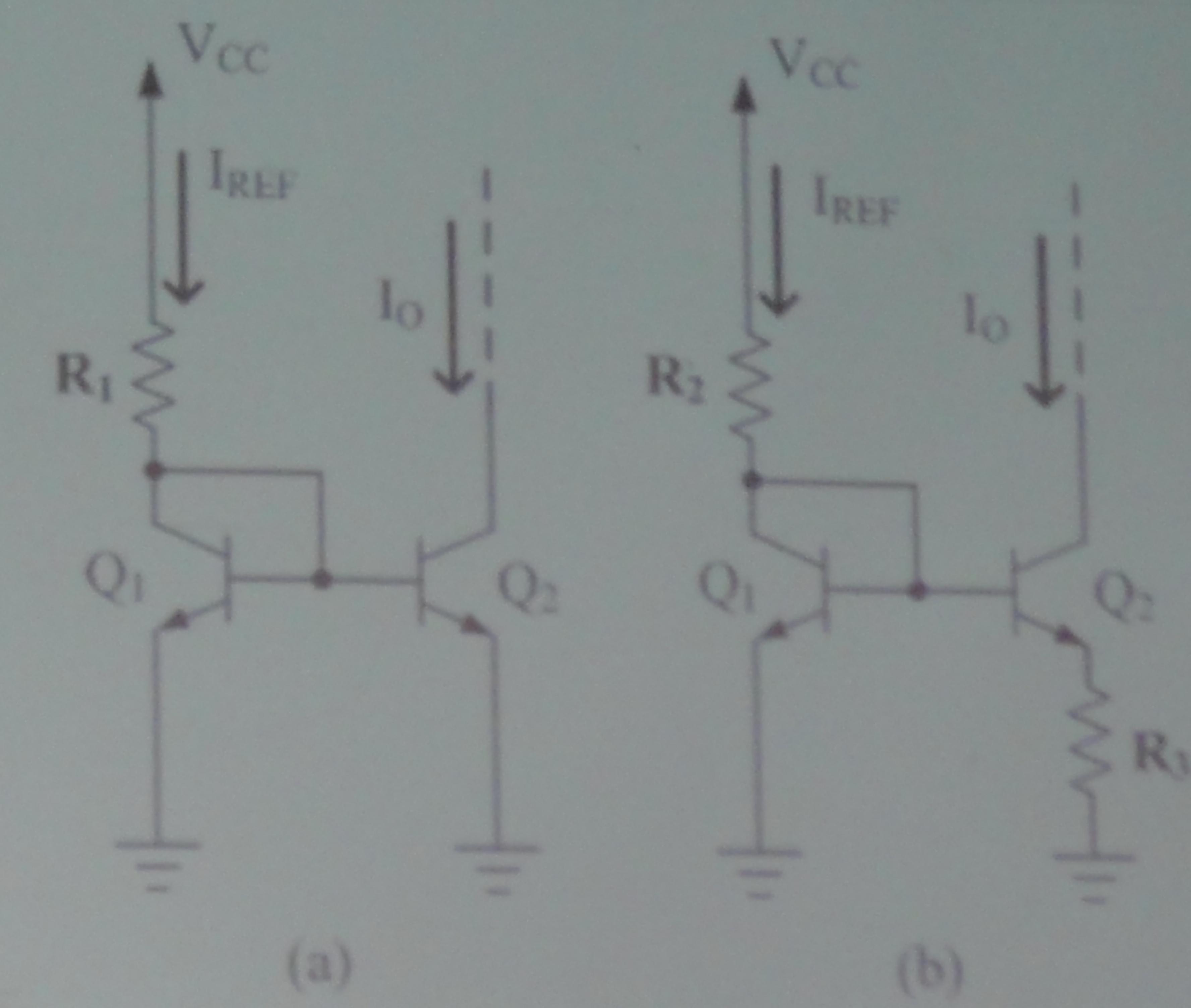


Fig. 1

# Question 1 (cont.)

photo by Hank EE102A

(a) find  $R_1$  in Fig. 1(a). (5%)

$$ImA = I_S \cdot e^{0.7/V_T}$$

$$10\mu A = I_S \cdot e^{V_{BE2}/V_T}$$

$$V_{BE2} = 0.7 + 0.025 \cdot \ln\left(\frac{10\mu}{1m}\right) \approx 0.585V$$

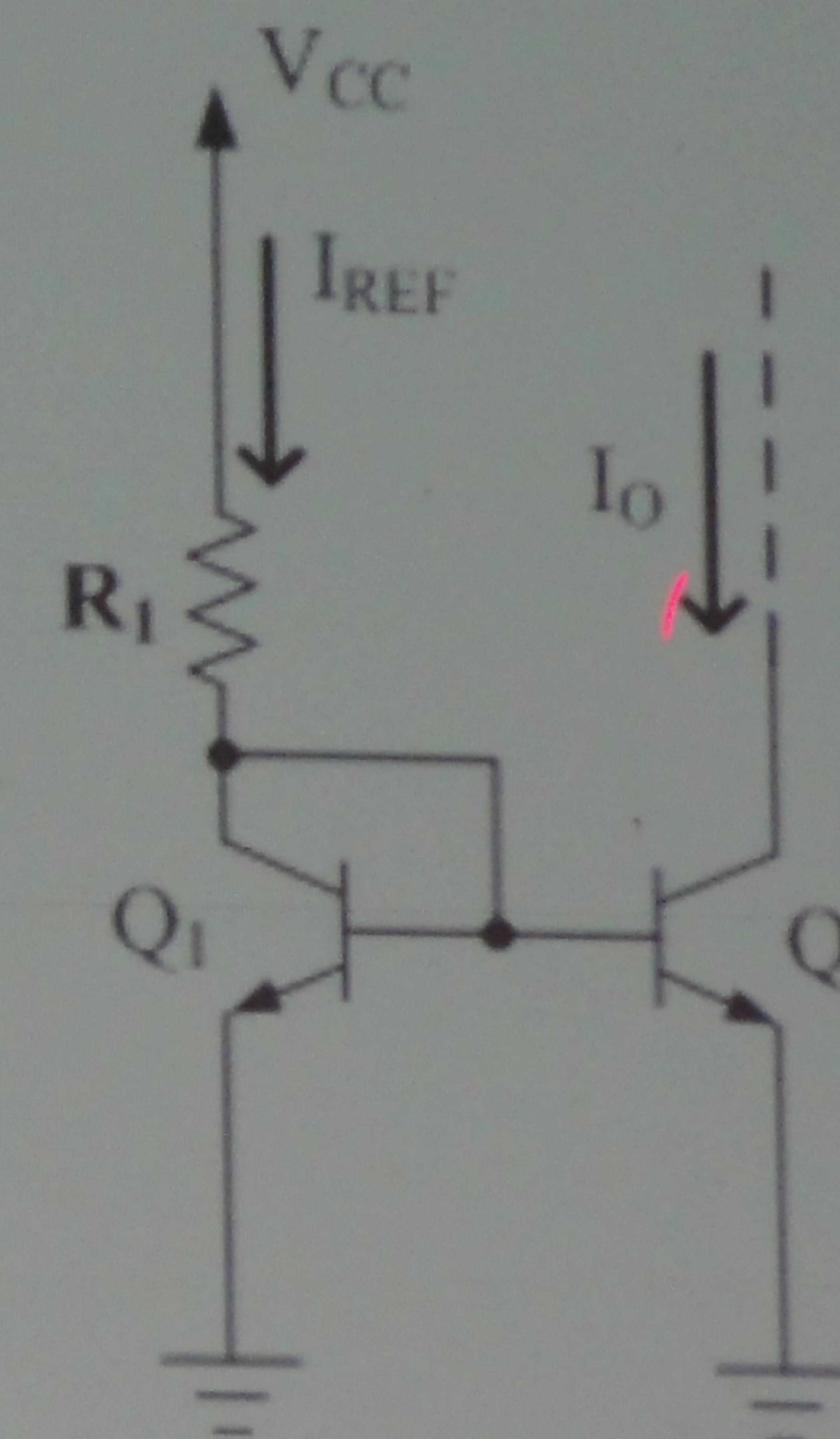
$$R_1 = \frac{10 - 0.585}{10\mu A} \approx 941.5k\Omega$$

(b) for Fig. 1(b), if  $I_{REF}=1mA$ ,  
find  $R_2$  and  $R_3$ . (10%)

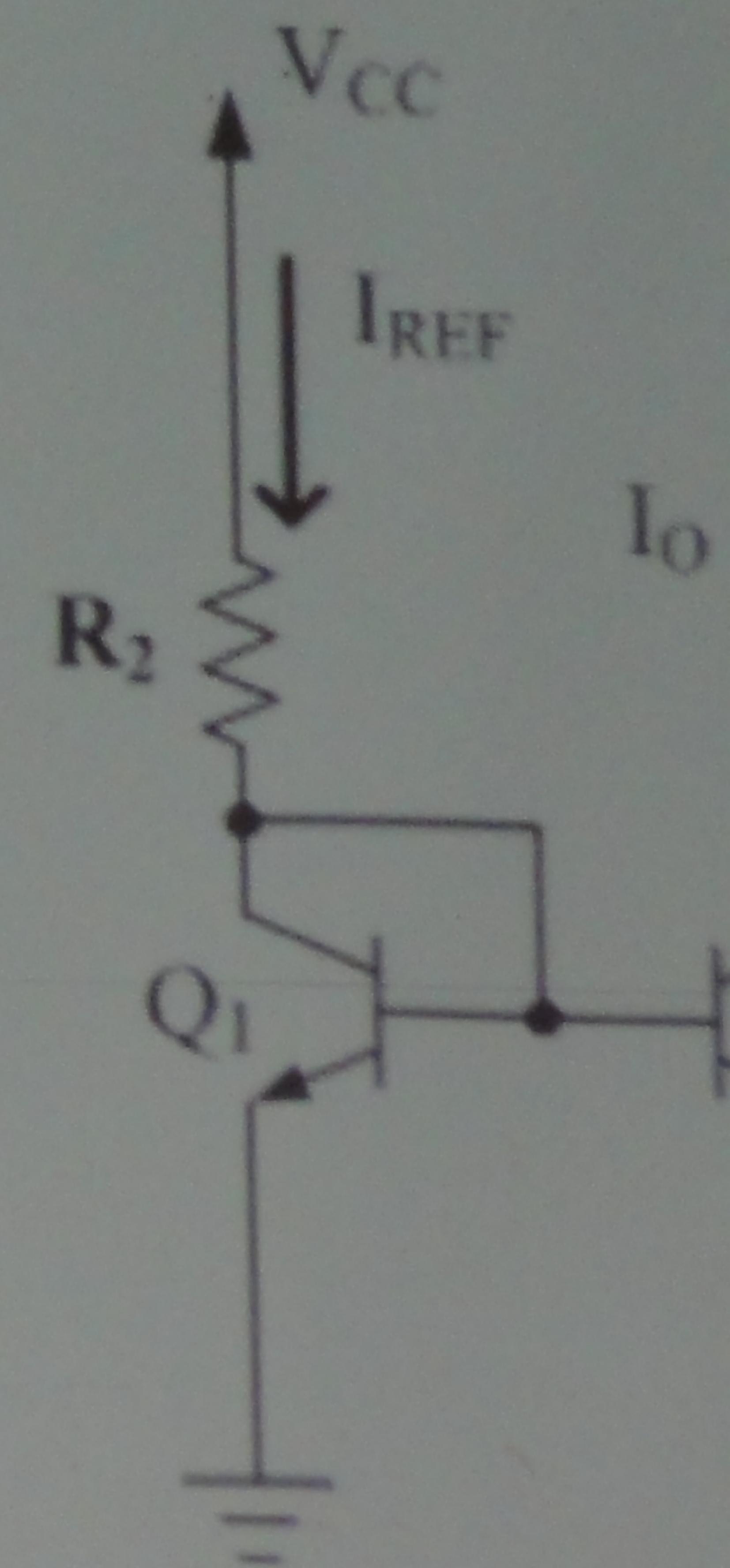
$$R_2 = \frac{10 - V_{BE1}}{1mA} = \frac{10 - 0.7}{1mA} \approx 9.3k\Omega$$

(c) explain the advantage of Widlar current source. (5%)

smaller resistors



(a)



(b)

Fig. 1

## Question 1 (cont.)

(a) find  $\mathbf{R}_1$  in Fig. 1(a). (5%)

$$\ln A = I_S \cdot e^{0.7/V_T}$$

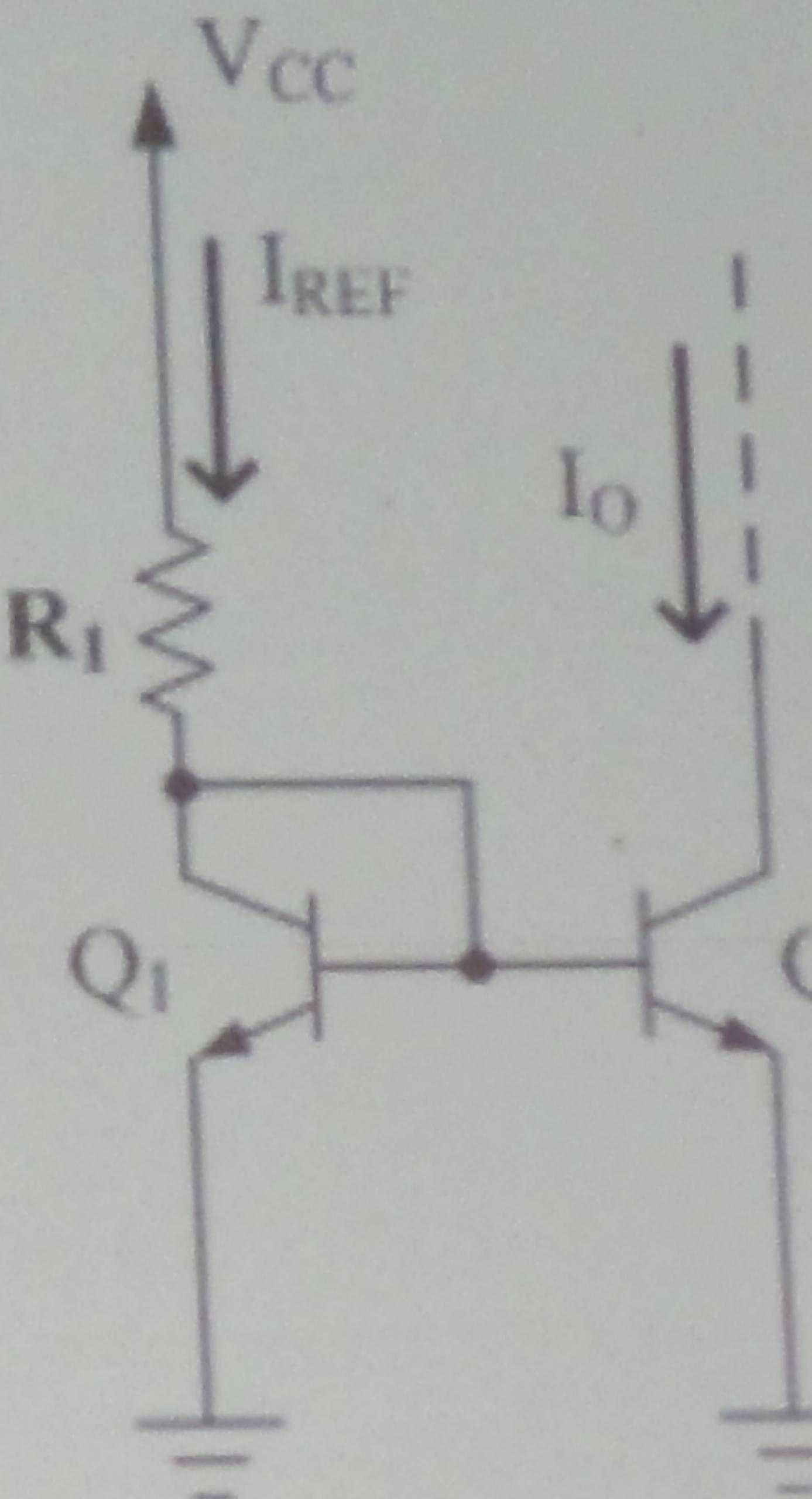
$$10\mu A = I_S \cdot e^{V_{BE2}/V_T}$$

$$V_{BE2} = 0.7 + 0.025 \cdot \ln\left(\frac{10\mu}{1m}\right) \approx 0.585V$$

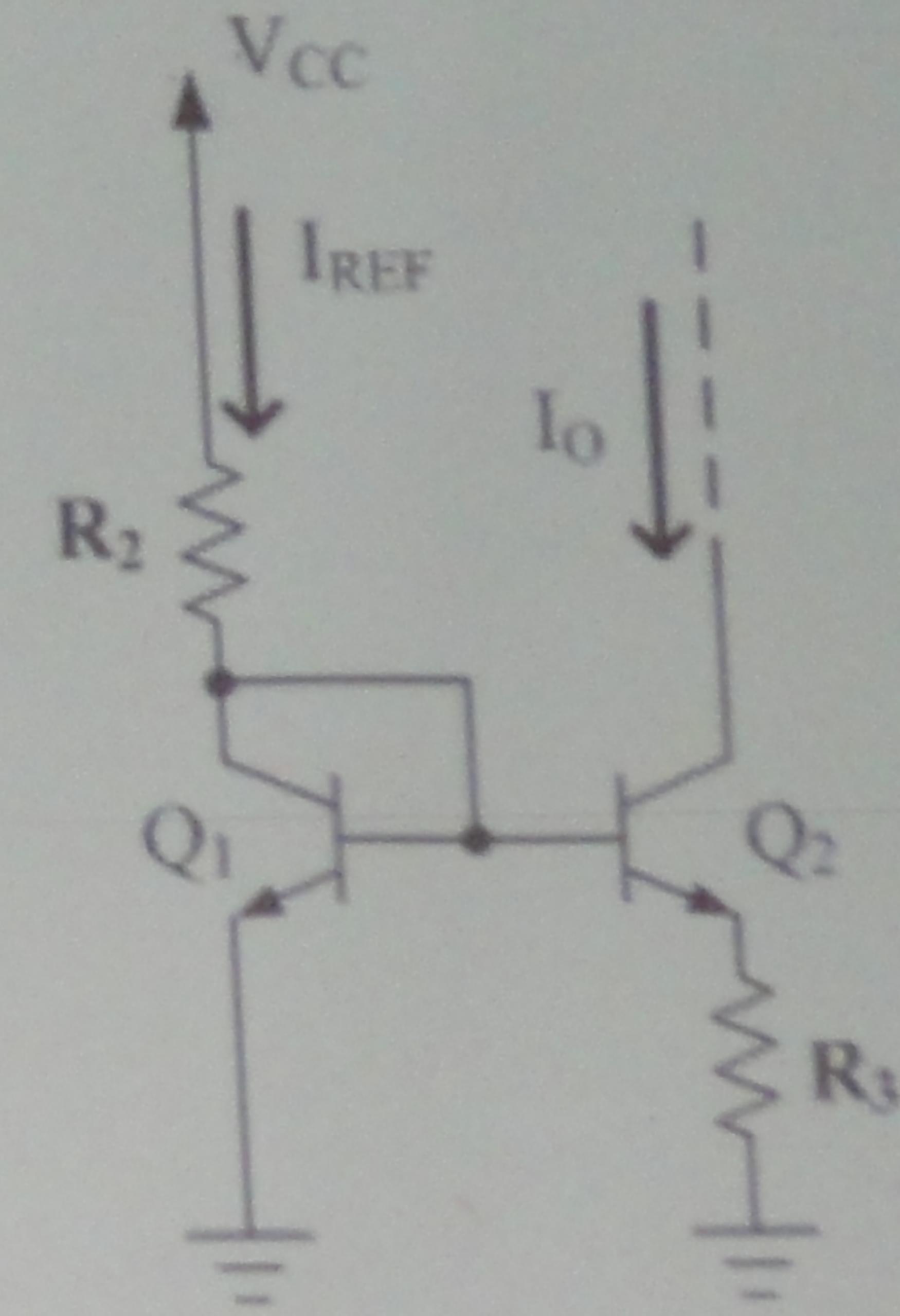
$$R_1 = \frac{10 - 0.585}{10\mu A} \approx 941.5k\Omega$$

(b) for Fig. 1(b), if  $I_{REF}=1mA$ ,  
find  $\mathbf{R}_2$  and  $\mathbf{R}_3$ . (10%)

$$R_2 = \frac{10 - V_{BE1}}{1mA} = \frac{10 - 0.7}{1mA} \approx 9.3k\Omega$$



(a)



(b)

Fig. 1

$$R_3 = \frac{V_{BE1} - V_{BE2}}{10\mu A} \approx 11.5k\Omega$$

(c) explain the advantage of Widlar current source. (5%)  
smaller resistor

## Question 2

- Figs. 2(a) and 2(b) show two different types of output stage, respectively. Assume that  $V_T = 25\text{mV}$ ,  $I_s = 3 \times 10^{-14}\text{A}$  for  $Q_{14}$  and  $Q_{20}$ , while  $I_s = 10^{-14}\text{A}$  for the other BJTs,  $R_{10} = 40\text{kW}$ , and  $I_{C13A} = 280\text{mA}$ . Neglect the base currents of all BJTs.

(a) In Fig. 2(a), if  $V_{BE18}$  is found to be  $0.6\text{V}$  iteratively, find  $I_{C18}$ ,  $I_{C19}$ , and  $I_{C20}$ . (10%)

(b) In Fig. 2(b), if  $Q_{25}$  and  $Q_{26}$  are used to establish the voltage drop between the bases of  $Q_{14}$  and  $Q_{20}$ , find  $I_{C14}$ . (5%)

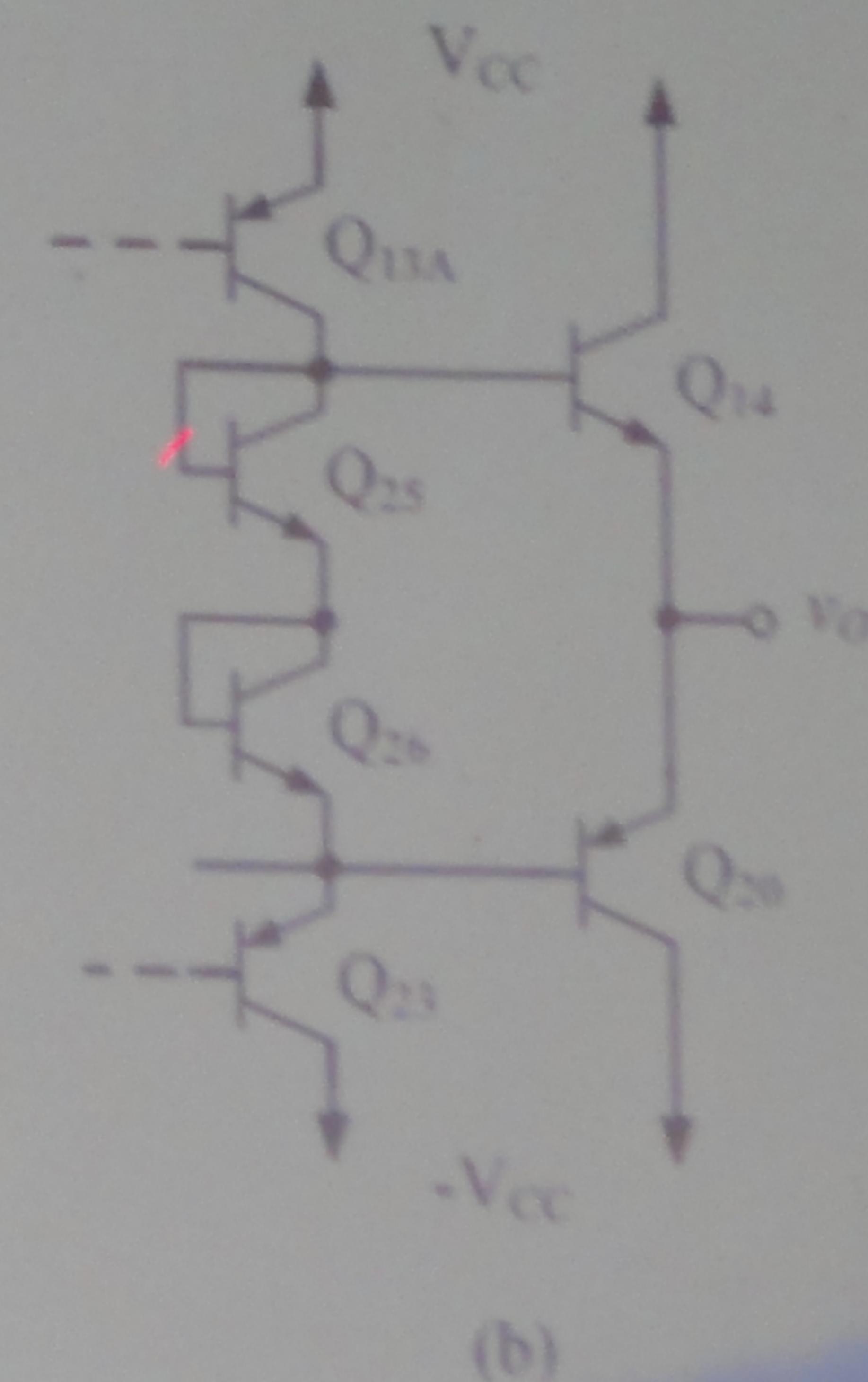
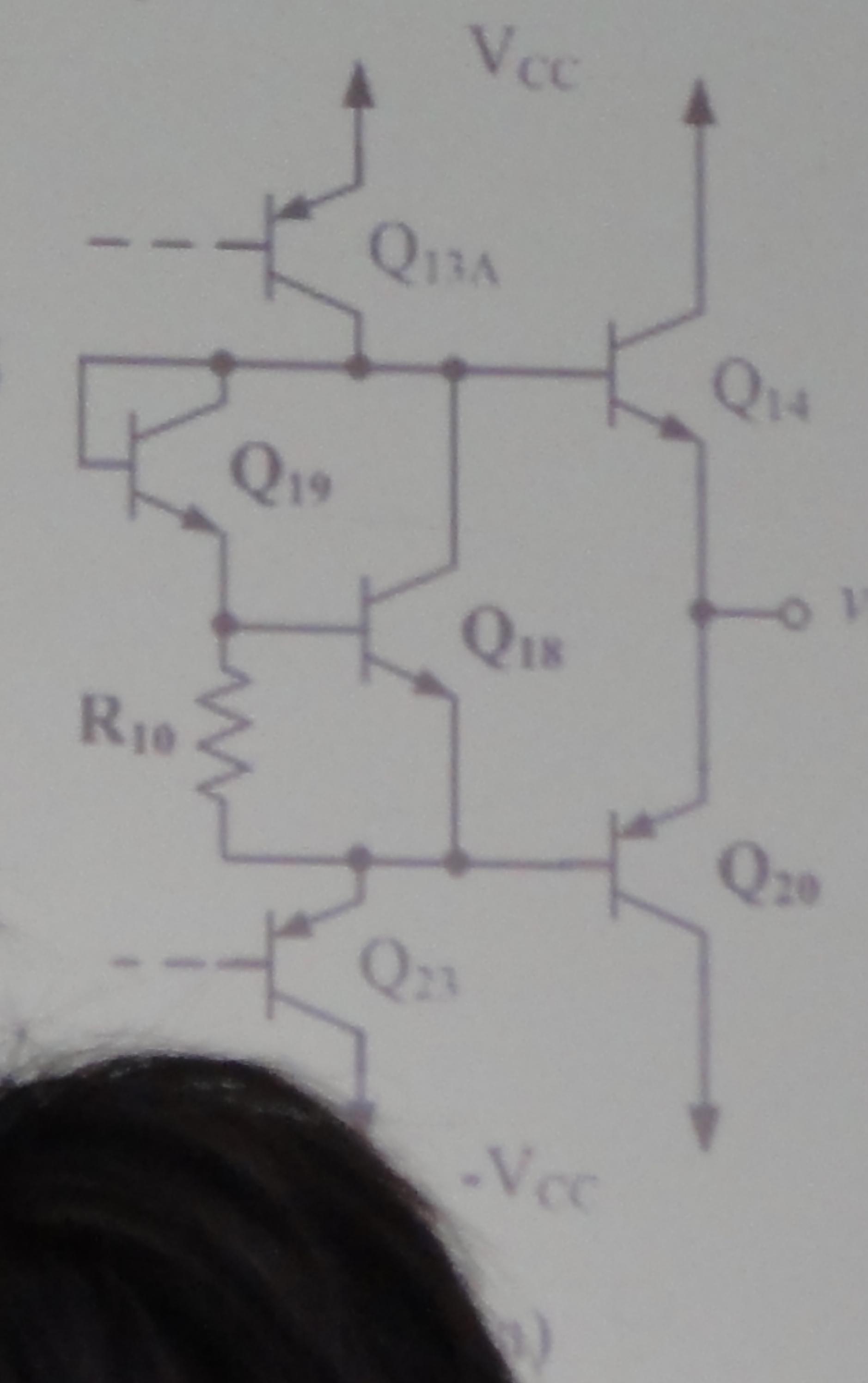


Fig. 2

Question 2 (cont.)

- (a) In Fig. 2(a), if  $V_{BE18}$  is found to be 0.6V iteratively, find  $I_{C18}$ ,  $I_{C19}$ , and  $I_{C20}$ . (10%)

$$I_{C19} = I_{R10} = \frac{V_{BE18}}{R_{10}} = \frac{0.6}{40k} = 15 \mu A$$

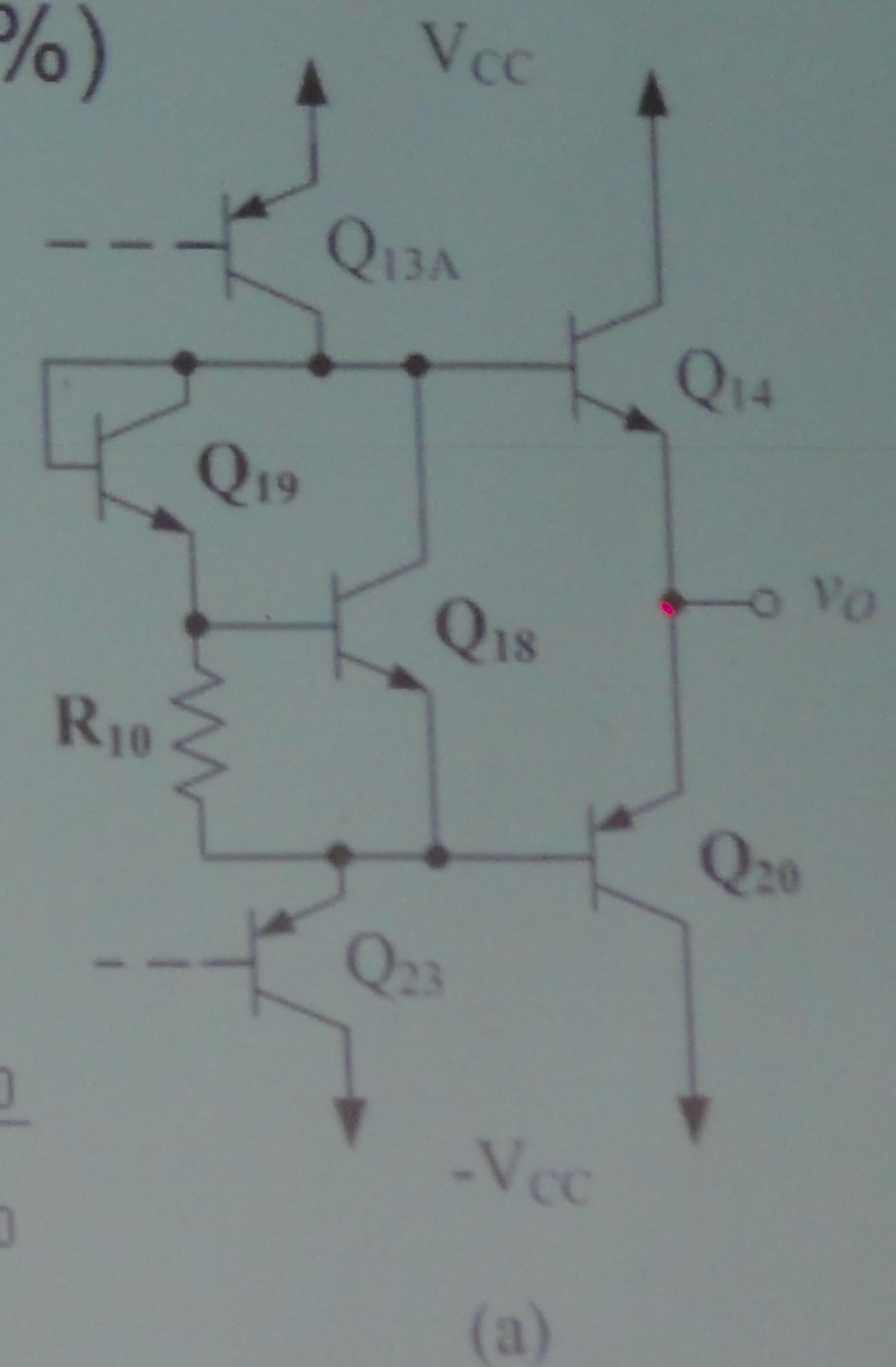
$$I_{C18} = I_{C13A} - I_{C19} = 280 - 15 = 265 \mu A$$

$$V_{BE18} + V_{BE19} = V_{BE14} + V_{BE20}$$

$$\Rightarrow V_T \ln \frac{I_{C18}}{I_{S18}} + V_T \ln \frac{I_{C19}}{I_{S19}} = V_T \ln \frac{I_{C14}}{I_{S14}} + V_T \ln \frac{I_{C20}}{I_{S20}}$$

$$\Rightarrow \frac{I_{C18}}{I_{S18}} \frac{I_{C19}}{I_{S19}} = \frac{I_{C14}}{I_{S14}} \frac{I_{C20}}{I_{S20}} = \frac{I_{C20}^2}{I_{S14} I_{S20}}$$

$$\Rightarrow I_{C20} = 3 \cdot \sqrt{I_{C18} \cdot I_{C19}} = 3 \cdot \sqrt{15 \mu A \times 265 \mu A} \approx 189 \mu A$$

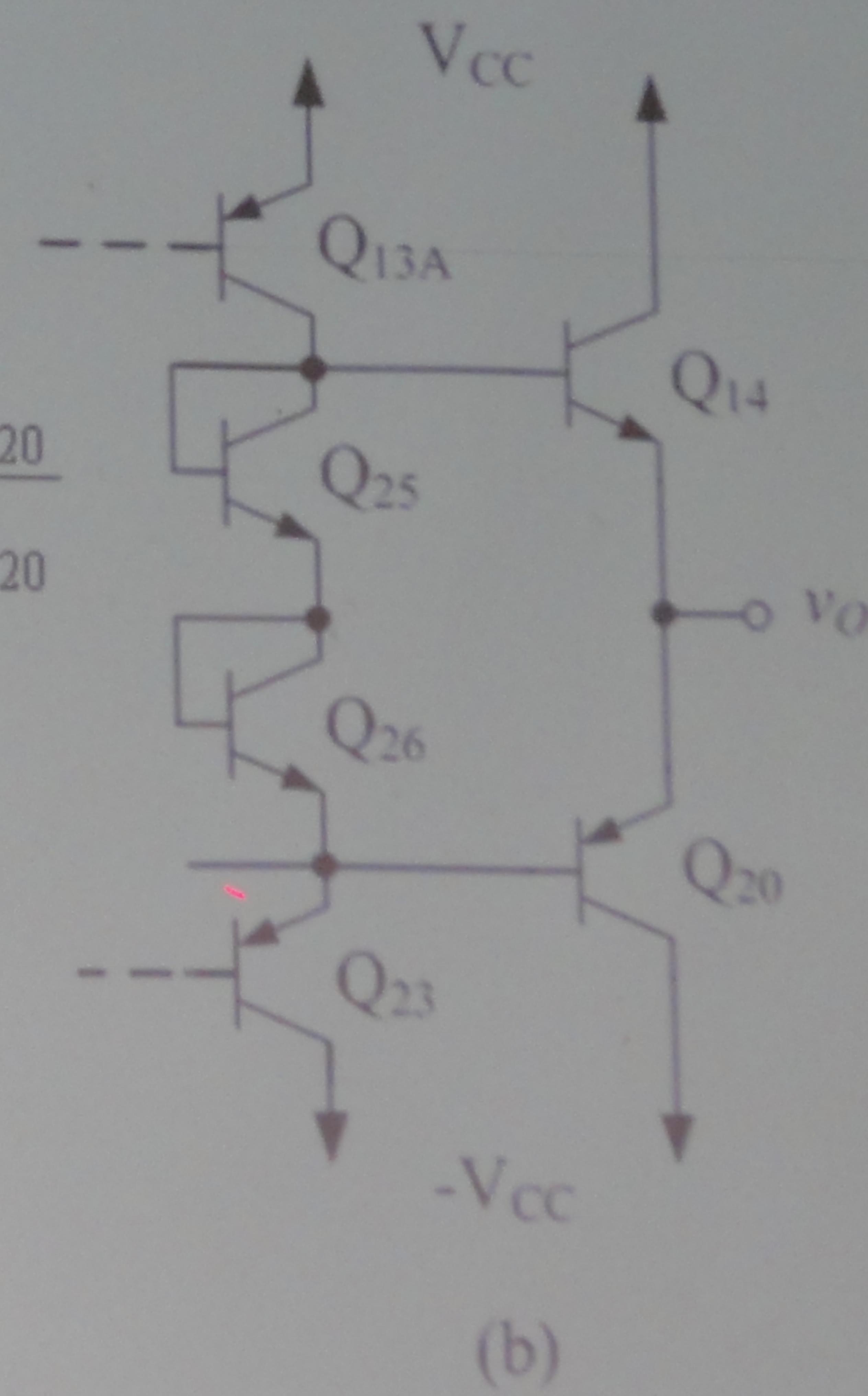


(a)

Question 2 (cont.)

(b) In Fig. 2(b), if  $Q_{25}$  and  $Q_{26}$  are used to establish the voltage drop between the bases of  $Q_{14}$  and  $Q_{20}$ , find  $I_{C14}$ . (5%)

$$\begin{aligned} V_{BE25} + V_{BE26} &= V_{BE14} + V_{BE20} \\ \Rightarrow V_T \ln \frac{I_{C25}}{I_{S25}} + V_T \ln \frac{I_{C26}}{I_{S26}} &= V_T \ln \frac{I_{C14}}{I_{S14}} + V_T \ln \frac{I_{C20}}{I_{S20}} \\ \Rightarrow \frac{I_{C25}}{I_{S25}} \frac{I_{C26}}{I_{S26}} &= \frac{I_{C14}}{I_{S14}} \frac{I_{C20}}{I_{S20}} = \frac{I_{C14}^2}{I_{S14} I_{S20}} \\ \Rightarrow I_{C14} &= 3 \cdot \sqrt{I_{C25} \cdot I_{C26}} \\ &= 3 \cdot \sqrt{280\mu \times 280\mu} \approx 840\mu A \end{aligned}$$



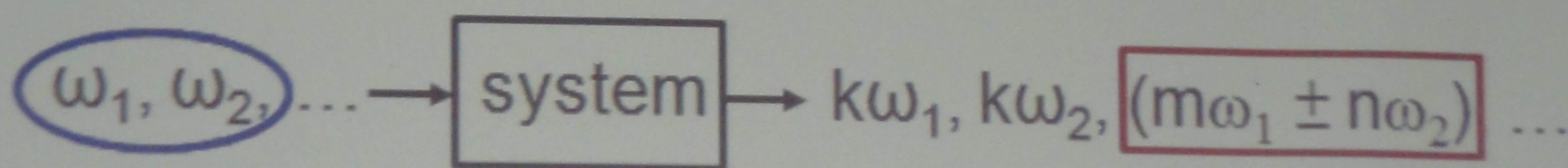
### Question 3

- Please give definitions of the following terms.

(a) slew rate (5%)

$$\frac{dv_o}{dt} \Big|_{\text{max}}$$

(b) inter-modulation distortion (5%)



(c) total harmonic distortion (5%)

$$i_o = B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + \dots$$

$$D_N = \left| \frac{B_N}{B_1} \right|$$

$$THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + \dots}$$

## Question 4

- For a class-B output stage in Fig. 4, let dual-supply voltage  $V_{CC}=10V$  and  $R_L=8\Omega$ . If the output  $v_O$  is an **8-V-peak** sinusoid.

(a) Neglecting the crossover distortion, please find the **average power delivered to the load  $R_L$** , the **average power drawn from the supplies**, and the **power-conversion efficiency  $\eta$** . (15%)

(b) Please explain the crossover distortion for the output stage in Fig. 4 (5%)

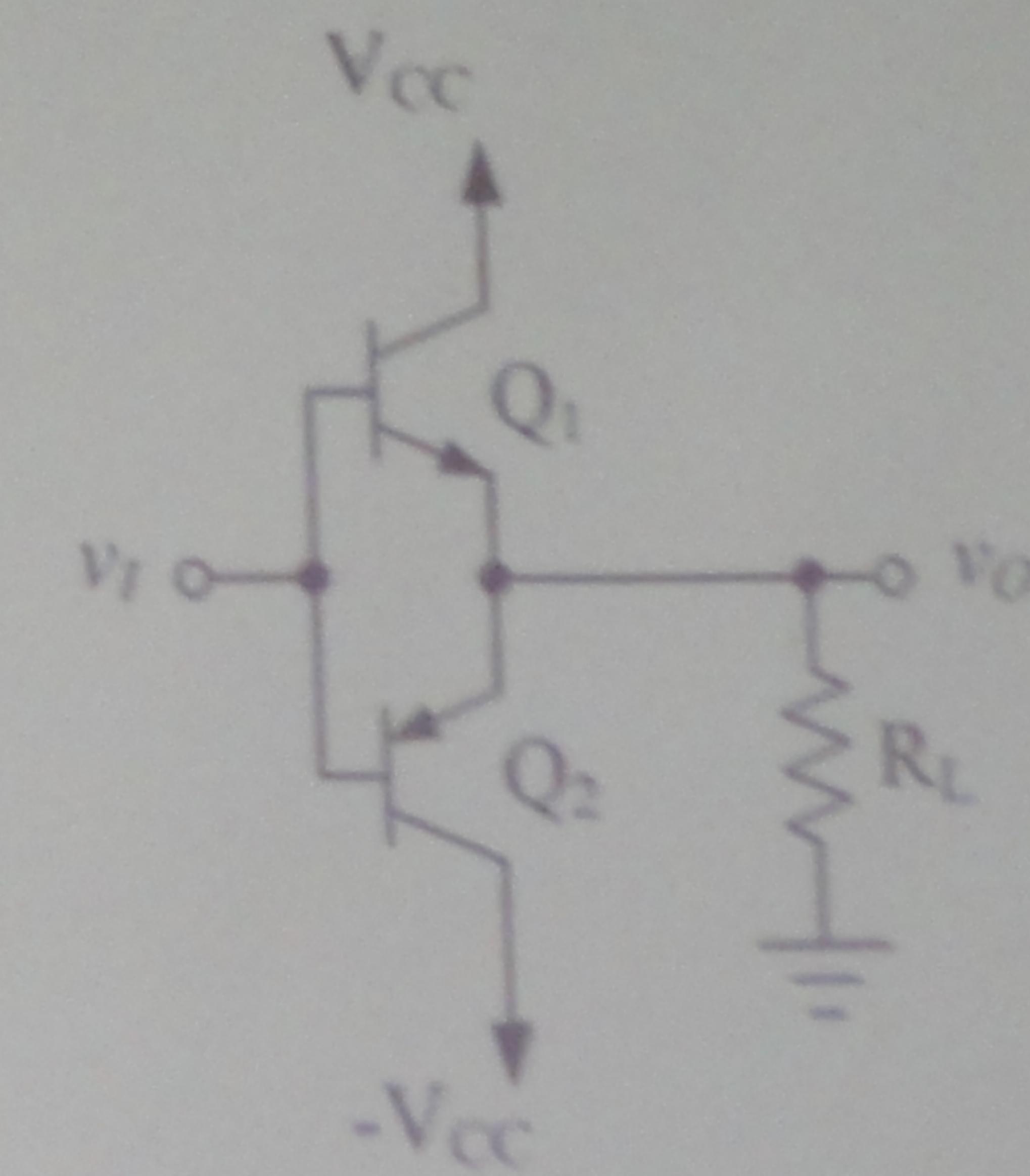


Fig. 4

## Question 4 (cont.)

(a) Neglecting the crossover distortion, please find the **average power delivered to the load  $R_L$ , the average power drawn from the supplies, and the power-conversion efficiency  $\eta$ .** (15%)

$$P_L = \frac{V_m^2}{2R_L} = \frac{8^2}{2 \times 8} = 4W$$

$$P_{\text{supply}} = 2 \times V_{CC} \times \left( \frac{V_m}{R_L} \cdot \frac{2}{2\pi} \right) = \frac{20}{\pi} \approx 6.37W$$

$$\eta = \frac{P_L}{P_{\text{supply}}} \approx 62.8\%$$

(b) Please explain the crossover distortion

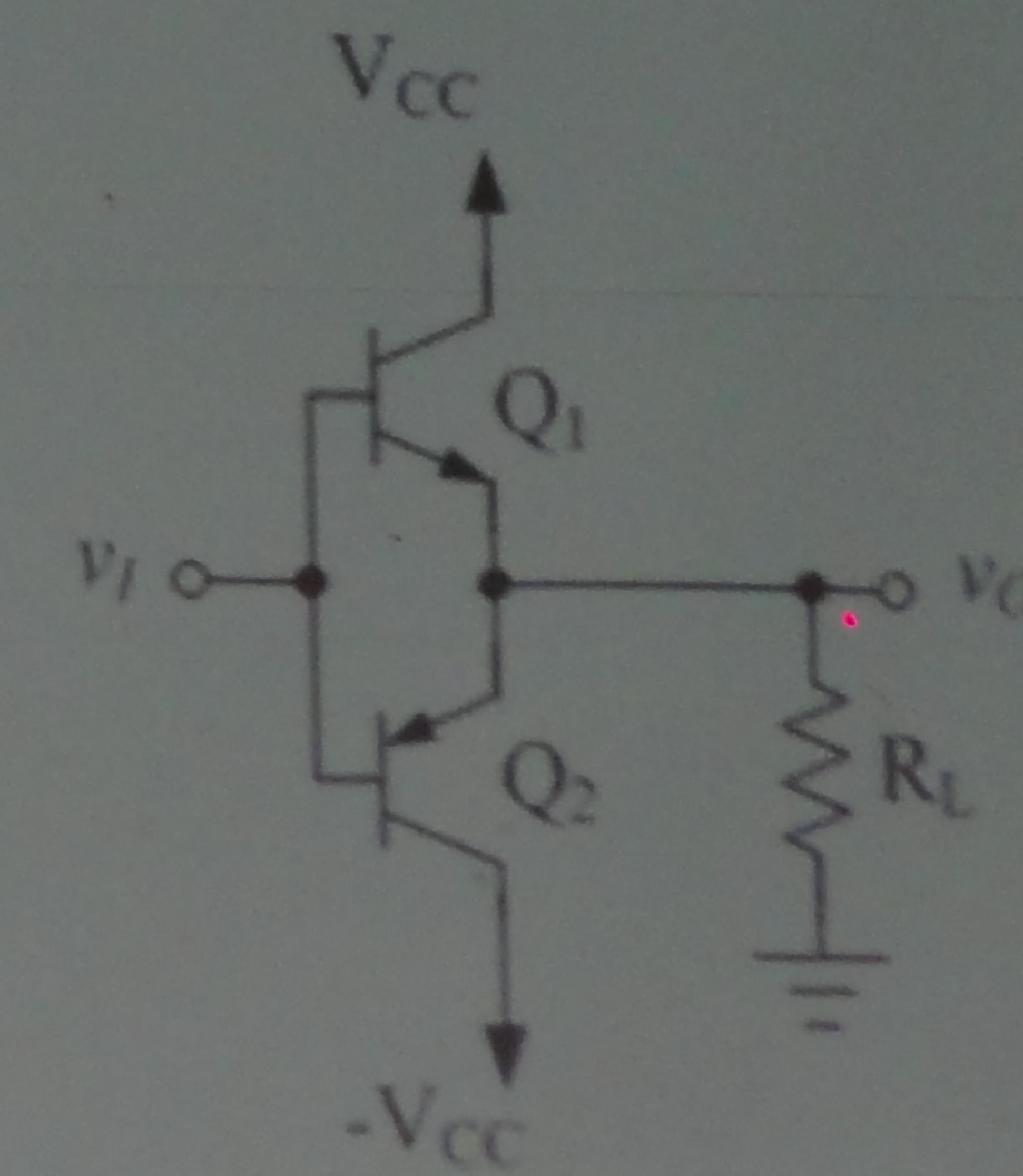
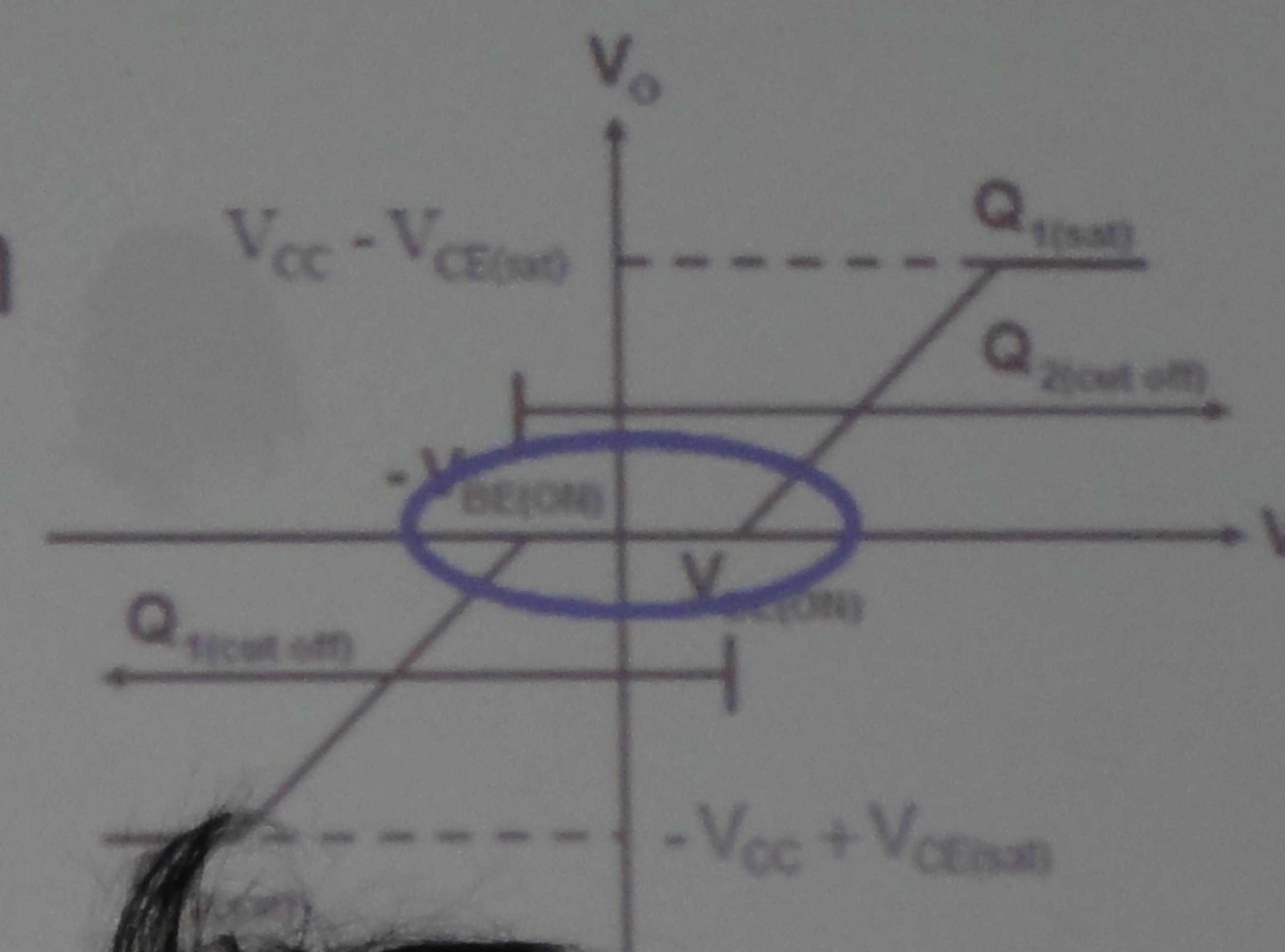
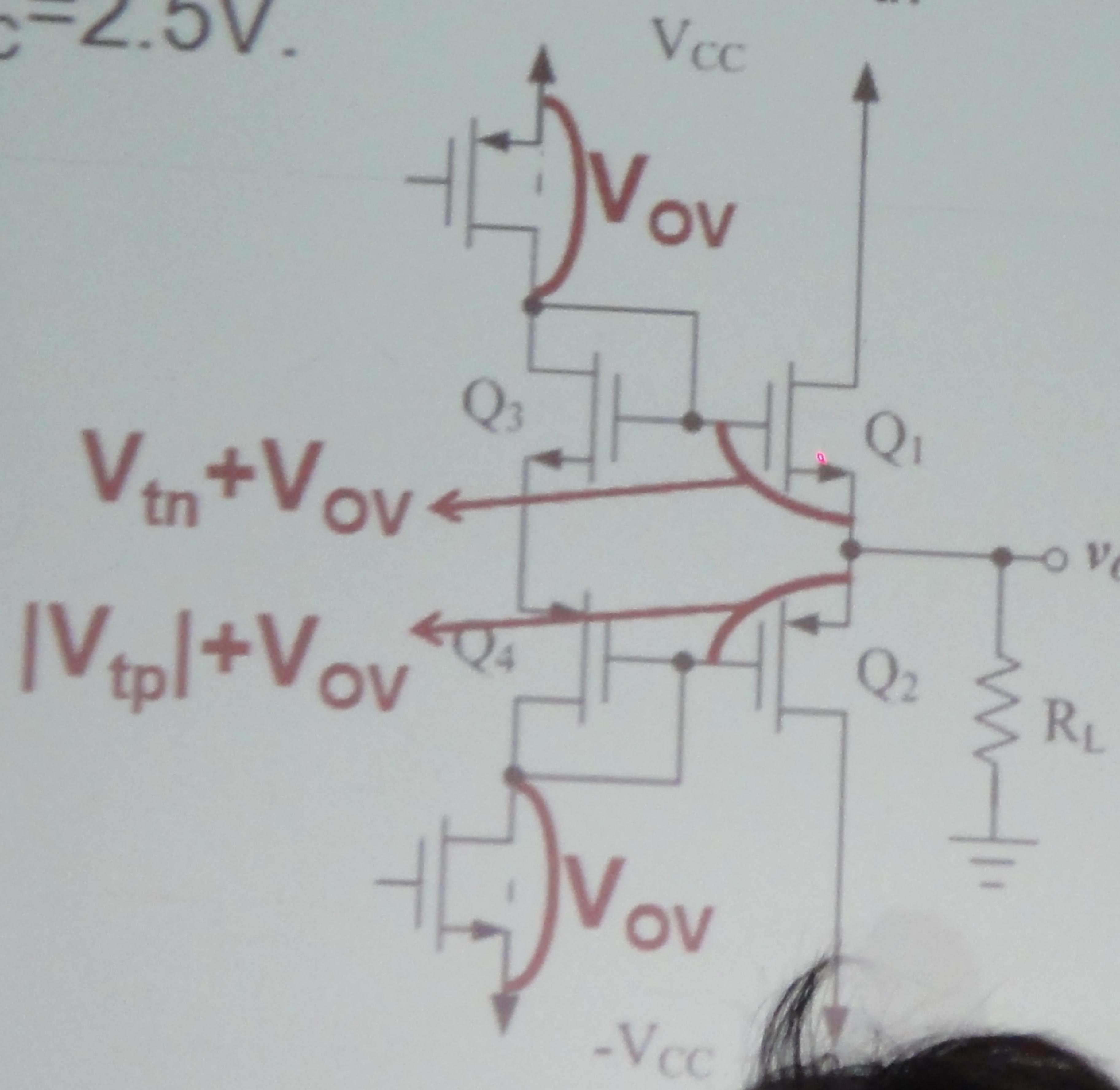


Fig. 4

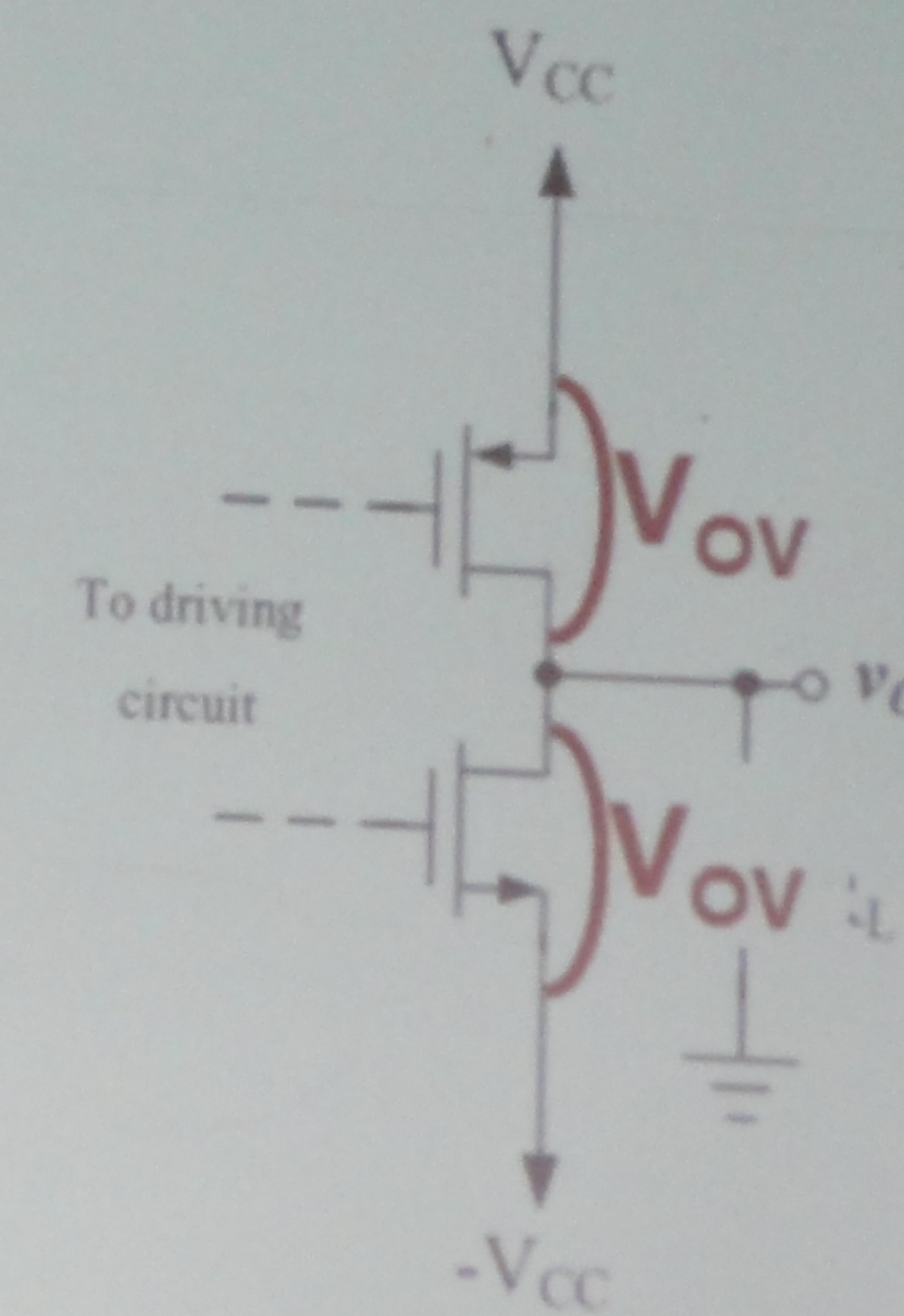


## Question 5

- Figs. 5(a) and 5(b) show two different types of CMOS class AB output stage, respectively. Assume  $|V_{ov}|=0.2V$  for all transistors,  $|V_{tp}|=0.8V$ ,  $V_{tn}=0.7V$ , and dual-supply voltage  $V_{cc}=2.5V$ .



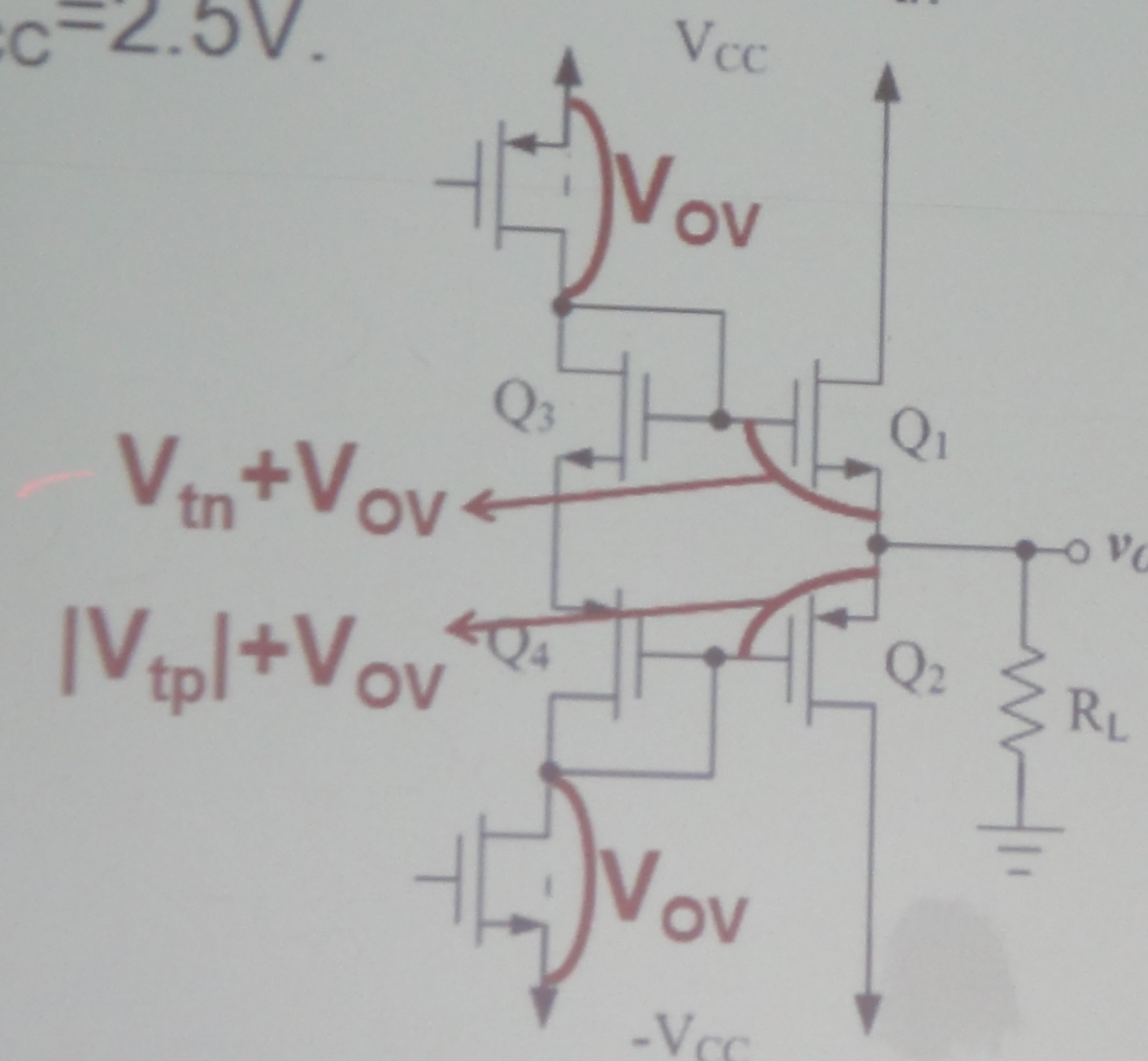
$$\begin{aligned}-V_{cc} + 2V_{ov} + V_{tp} &\leq v_O \\ \Rightarrow -1.3V &\leq v_O \leq 1.3V\end{aligned}$$



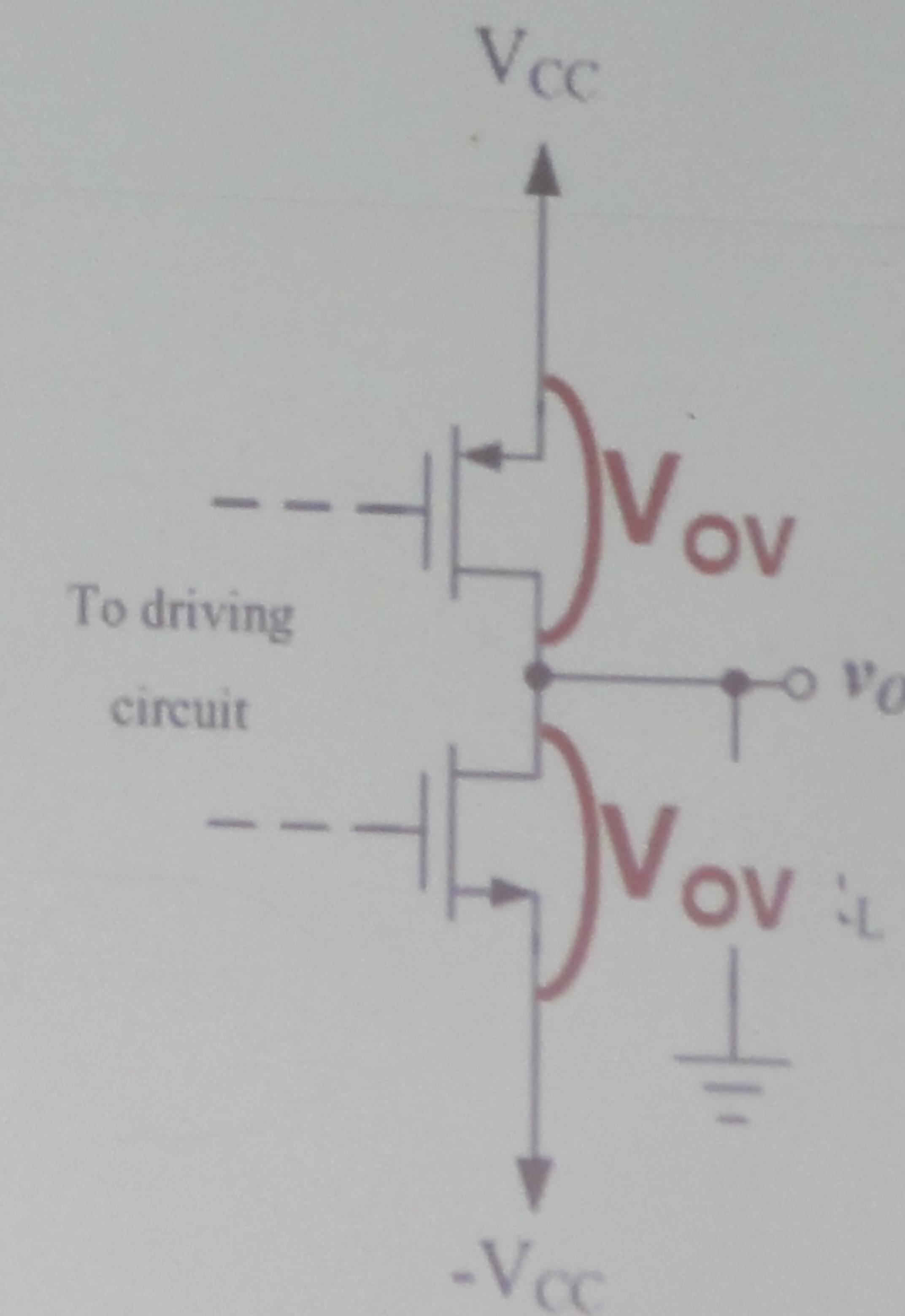
$$\begin{aligned}-V_{cc} + V_{ov} &\leq v_O \leq V_{cc} - V_{ov} \\ \Rightarrow -2.3V &\leq v_O \leq 2.3V\end{aligned}$$

## Question 5

- Figs. 5(a) and 5(b) show two different types of CMOS class AB output stage, respectively. Assume  $|V_{ov}|=0.2V$  for all transistors,  $|V_{tp}|=0.8V$ ,  $V_{tn}=0.7V$ , and dual-supply voltage  $V_{cc}=2.5V$ .



$$\begin{aligned}-V_{cc} + 2V_{ov} + V_{tp} &\leq v_O \leq V_{cc} - 2V_{ov} + V_{tn} \\ \Rightarrow -1.3V &\leq v_O \leq 1.4V\end{aligned}$$

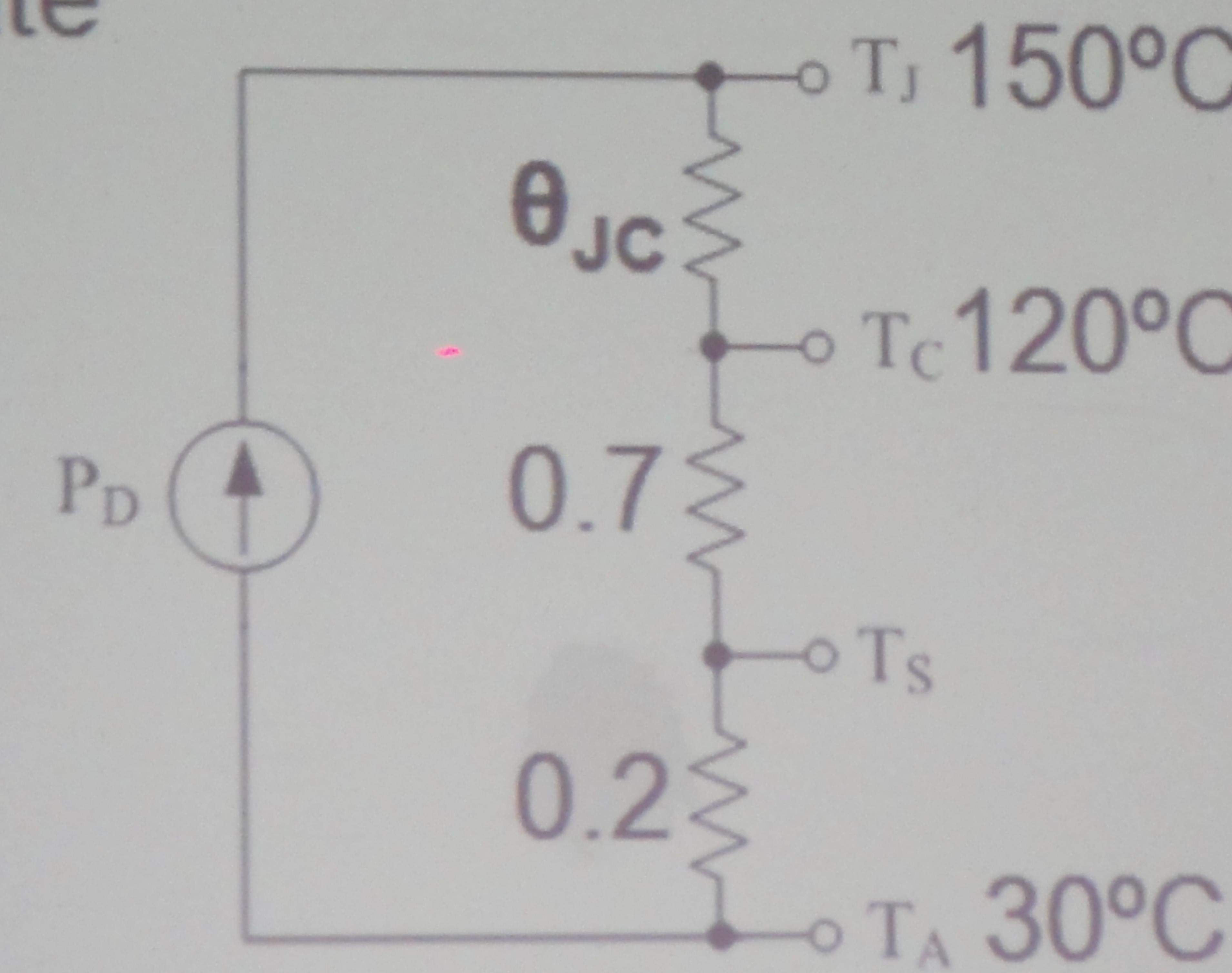


$$\begin{aligned}-V_{cc} + V_{ov} &\leq v_O \leq V_{cc} - V_{ov} \\ \Rightarrow -0.3V &\leq v_O \leq 2.3V\end{aligned}$$

## Question 6

- When a power transistor is operated at junction temperature  $T_J$  of  $150^\circ\text{C}$  with a heat sink, the case temperature  $T_C$  is found to be  $120^\circ\text{C}$ . The case is attached to the heat sink with a bond having a thermal resistance  $\theta_{CS}=0.7^\circ\text{C/W}$  and the thermal resistance of the heat sink  $\theta_{SA}=0.2^\circ\text{C/W}$ , as shown in Fig. 6. If the ambient temperature  $T_A$  is  $30^\circ\text{C}$ , please calculate

- $T_S$ . (5%)
- $P_D$ . (5%)
- $\theta_{JC}$ . (5%)



$T_S = 50^\circ\text{C}$
$P_D = 100\text{W}$
$\theta_{JC} = 0.3^\circ\text{C}/\text{W}$

Fig. 6