Huazhong University of Science and Technology
The Department of Electronics and Information Engineering

Electronic Circuit Analysis and Design

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Integrated Circuit Biasing and Active Loads

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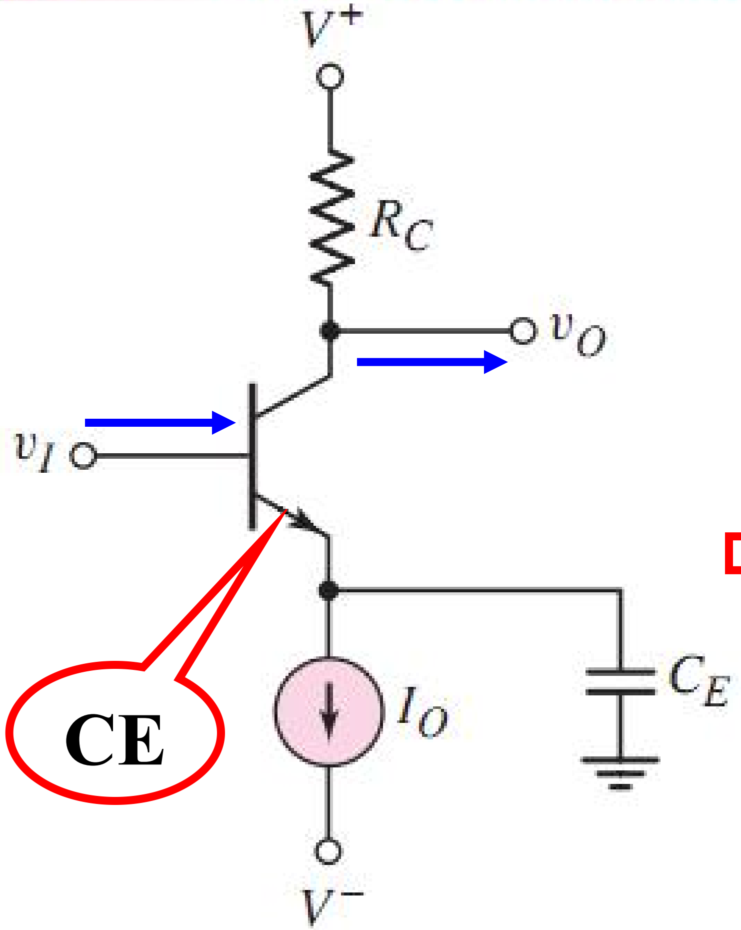
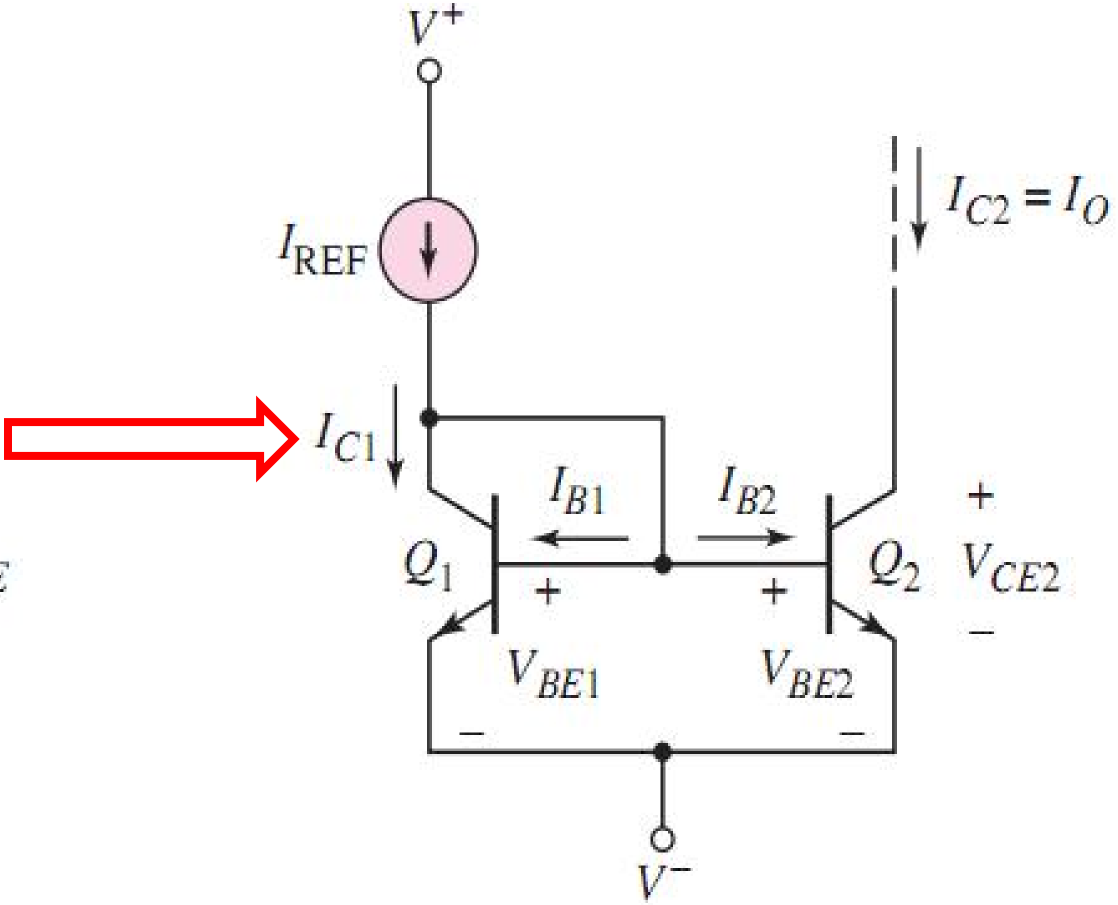
10.1.1 Two-Transistor Current Source





Which Region?

Forward active region

10.1 Bipolar Transistor Current Sources

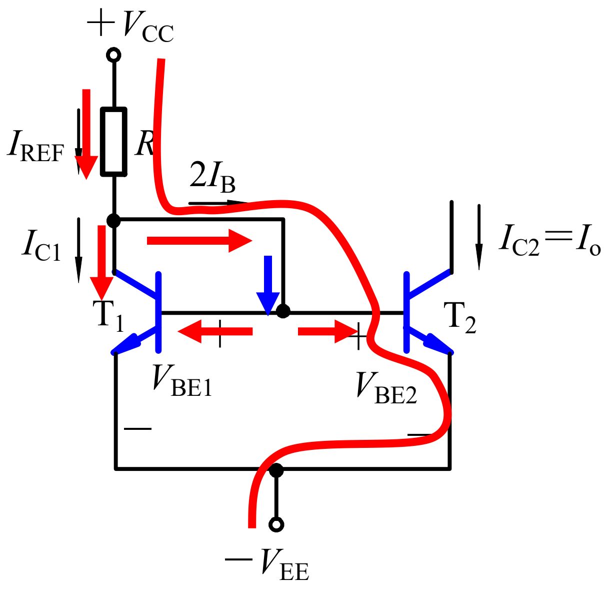
10.1.1 Basic Current Source (Current Mirror)

- T_1 ,T_2 are identical transistors.

$$\boldsymbol{V}_{BE2} = \boldsymbol{V}_{BE1} \qquad I_{E2} = I_{E1}$$

$$I_{REF} = I_{C1} + 2I_{B1} = I_{C1} + 2I_{C1} / \beta$$

$$I_{C2} = I_{C1} = \frac{I_{REF}}{1+2/\beta} \qquad (1)$$

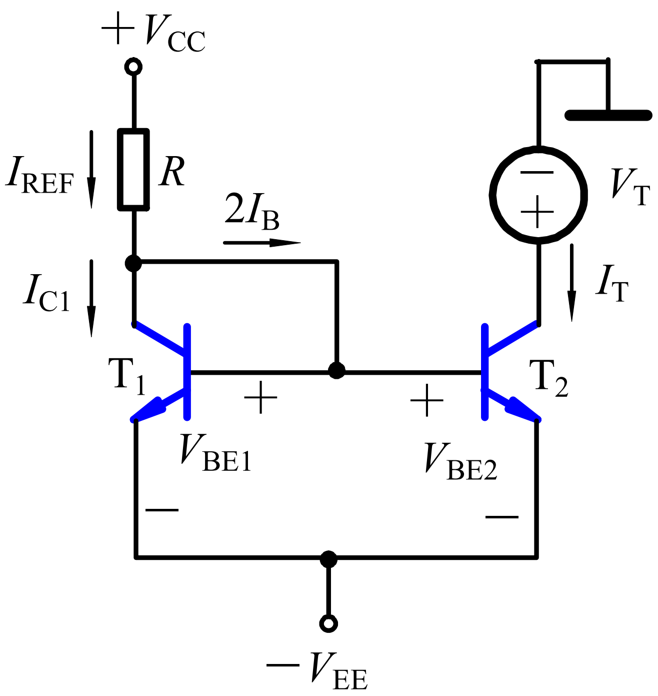


If $\beta >> 2$ $\quad I_{C2} = I_{C1} \approx I_{REF} = \frac{V_{CC} - V_{BE} + V_{EE}}{R} \approx \frac{V_{CC} + V_{EE}}{R}$

- I_{C2} is the mirror image of I_{C1}.
- I_{C2} is almost constant, no matter the value of R_C.

10.1.1 Basic Current Source (Current Mirror)

- **Because I_{C2} is almost constant, ac value I_T of I_{C2} is**



Output Resistance

$$I_T \approx 0$$

$$r_o = \frac{V_T}{I_T} \approx \infty$$

- In general, r_o is in order of 100 kΩ.

$$r_o = r_{ce}$$

10.1.2 Improved Current Source

$$I_{E3} = I_{B1} + I_{B2} = \frac{2}{\beta} I_{C2}$$

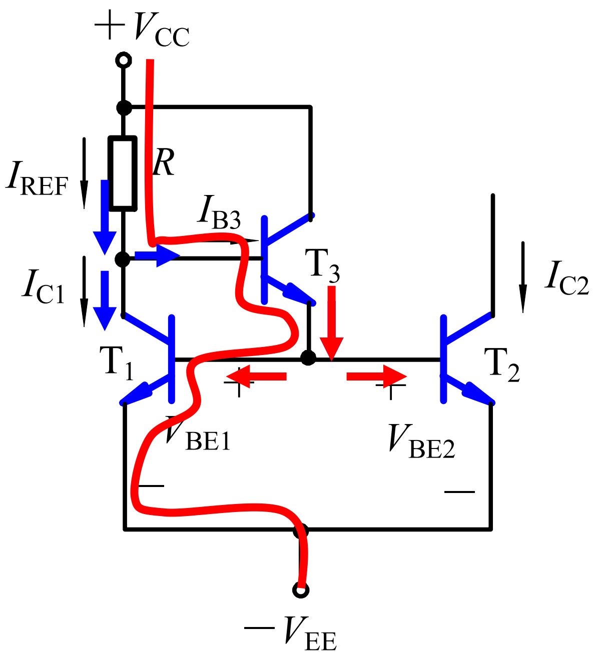
$$I_{B3} = \frac{I_{E3}}{1+\beta} = \frac{2}{\beta(1+\beta)} I_{C2}$$

$$I_{REF} = I_{C1} + I_{B3} = I_{C1} + \frac{2}{\beta(1+\beta)} I_{C2}$$

$$I_{C2} = I_{C1}$$

$$I_{C2} = \frac{I_{REF}}{1+2/(\beta^2+\beta)} \qquad (2)$$

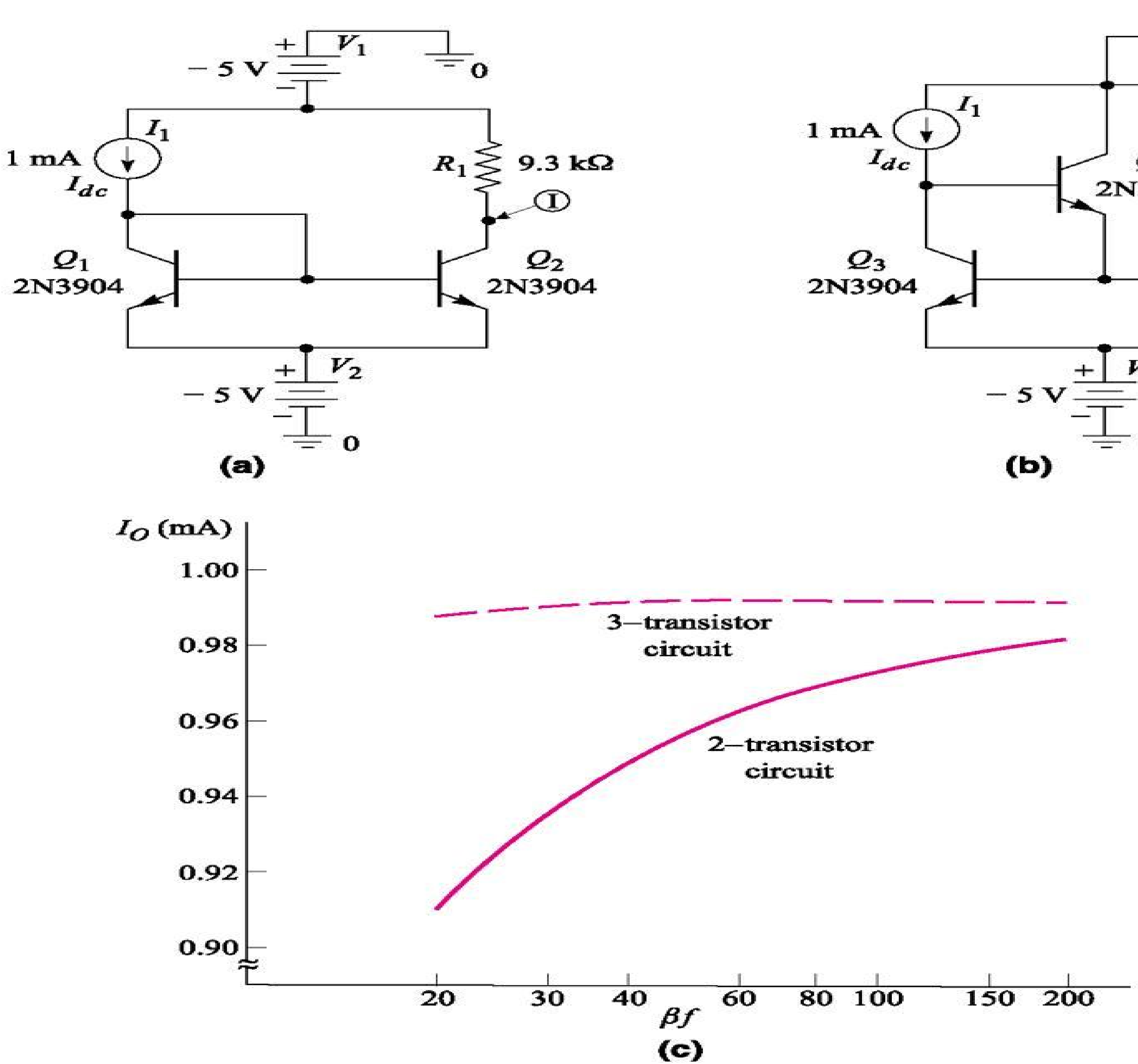
$$I_{REF} = \frac{V_{CC} - V_{BE1} - V_{BE3} + V_{EE}}{R}$$



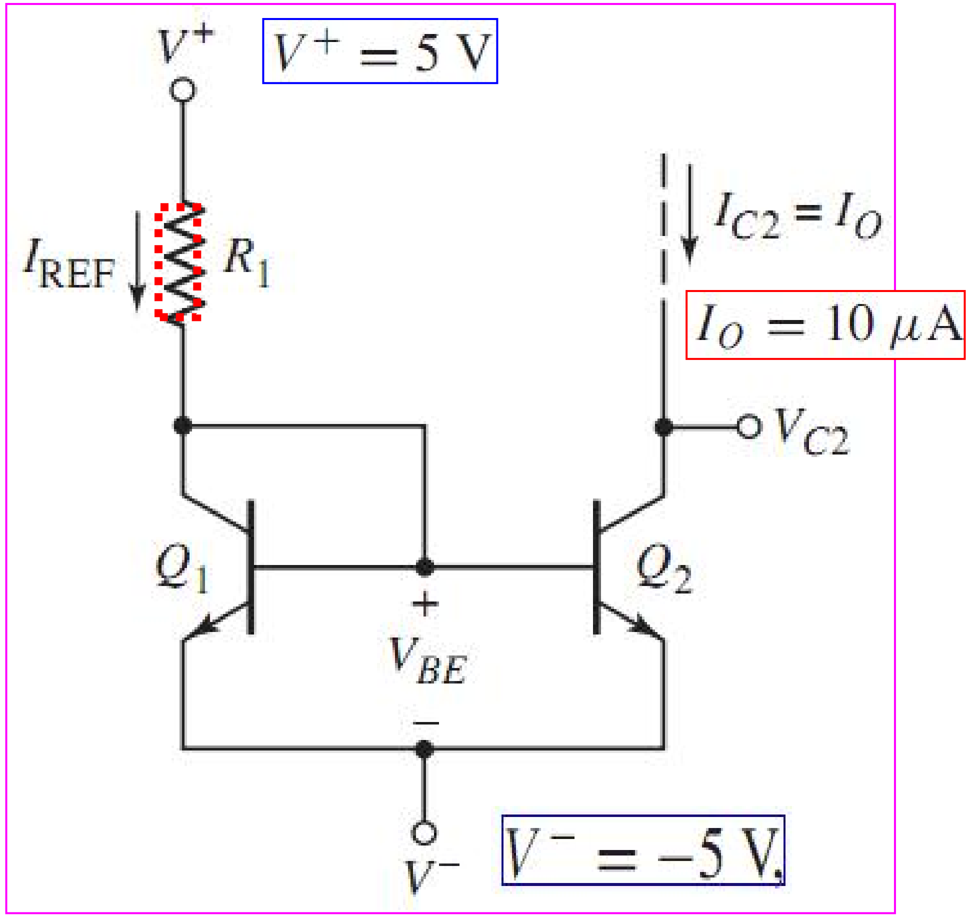
$$I_{C2} = I_{C1} = \frac{I_{REF}}{1+2/\beta} \qquad (1)$$

- Comparing Expressions (1) and (2), when $I_{C2} \approx I_{REF}$, the error of (2) can be reduced by adding transistor T_3.

10.1.2 Improved Current Source



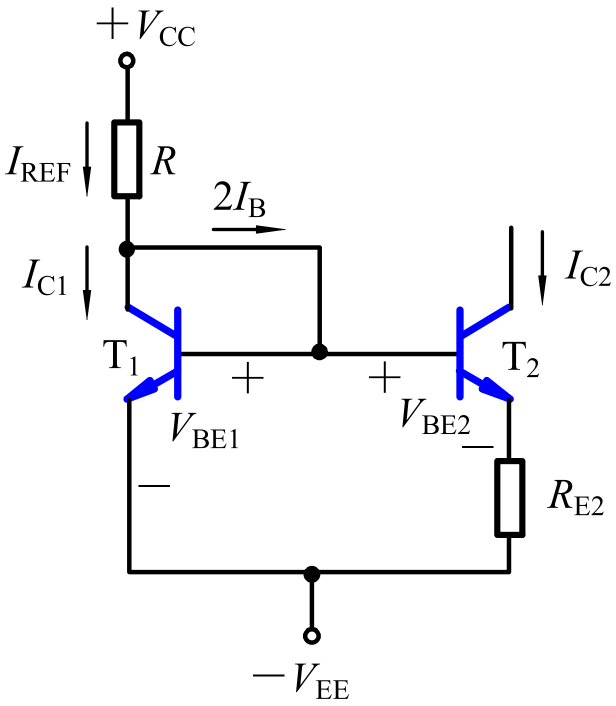
10.1.3 Widlar Current Source



$$R_1 = \frac{V^+ - V_{BE} - V^-}{I_{REF}} \cong \frac{5 - 0.7 - (-5)}{10 \times 10^{-6}} = 930\ \text{k}\Omega$$

10.1.3 Widlar Current Source

$$I_{C2} \approx I_{E2} = \frac{V_{BE1} - V_{BE2}}{R_{E2}} = \frac{\Delta V_{BE}}{R_{E2}}$$



- Because ΔV_{BE} is very small, I_{C2} is very small.

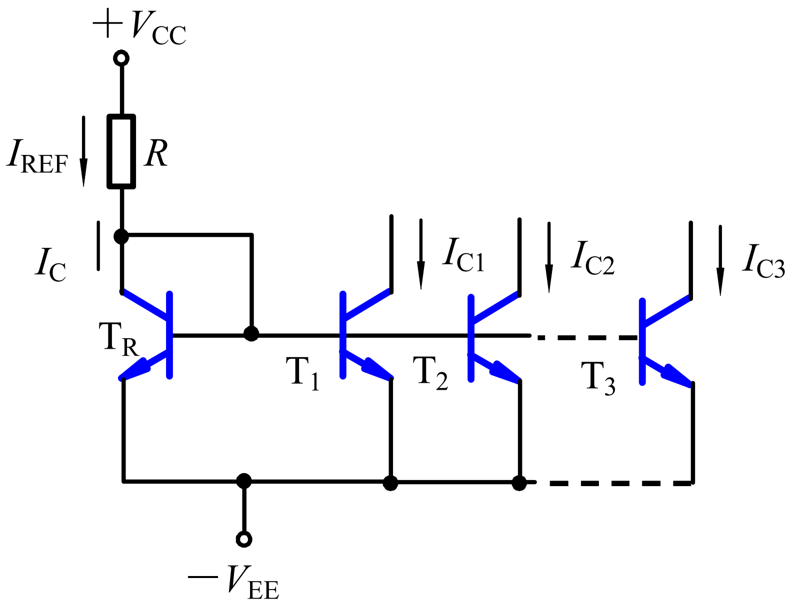
and $$I_{C2} R_{E2} = V_T \ln\left(\frac{I_{REF}}{I_{C2}}\right)$$

(The process of derivation on page 81).

$$r_o \approx r_{ce2}\left(1 + \frac{\beta R_{e2}}{r_{\pi 2} + R_{e2}}\right)$$

10.1.4 Multi-transistor Current Source

- **T and *R* serve as the reference for all output transistors.**
- **T_R supplies the total base currents.**
- **T_R makes $I_{REF} \approx I_C$.**

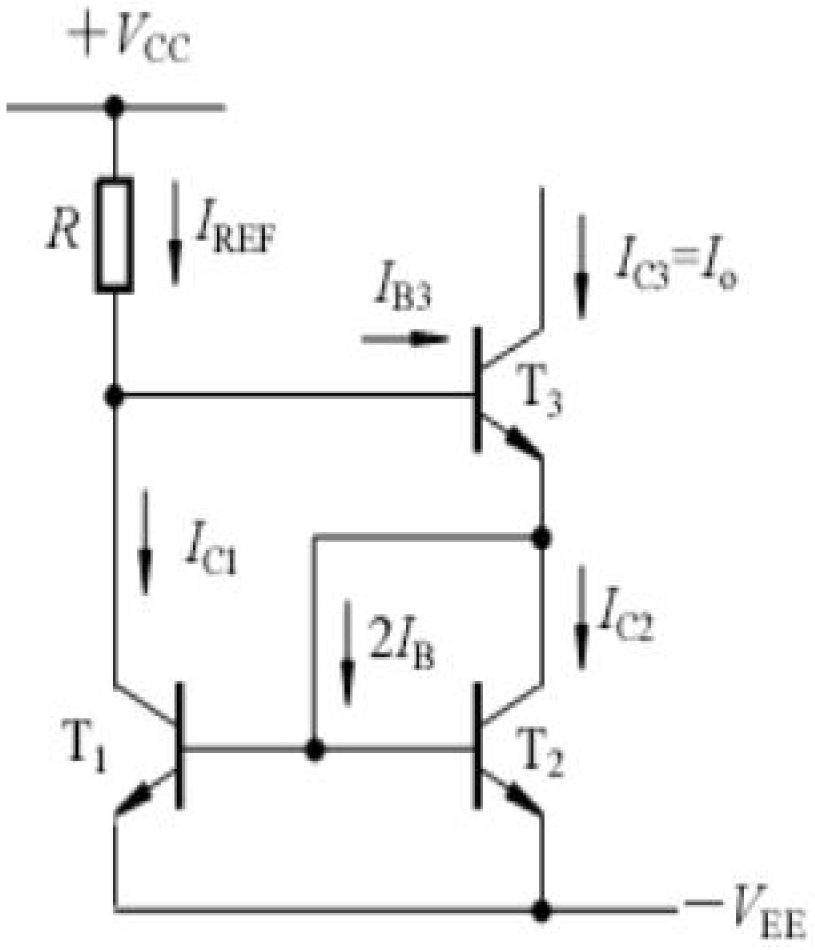


$$\boldsymbol{I}_{C1} = \boldsymbol{I}_{C2} = \boldsymbol{I}_{C3} = \ldots = \boldsymbol{I}_{REF}$$

- **There are N output transistors.**

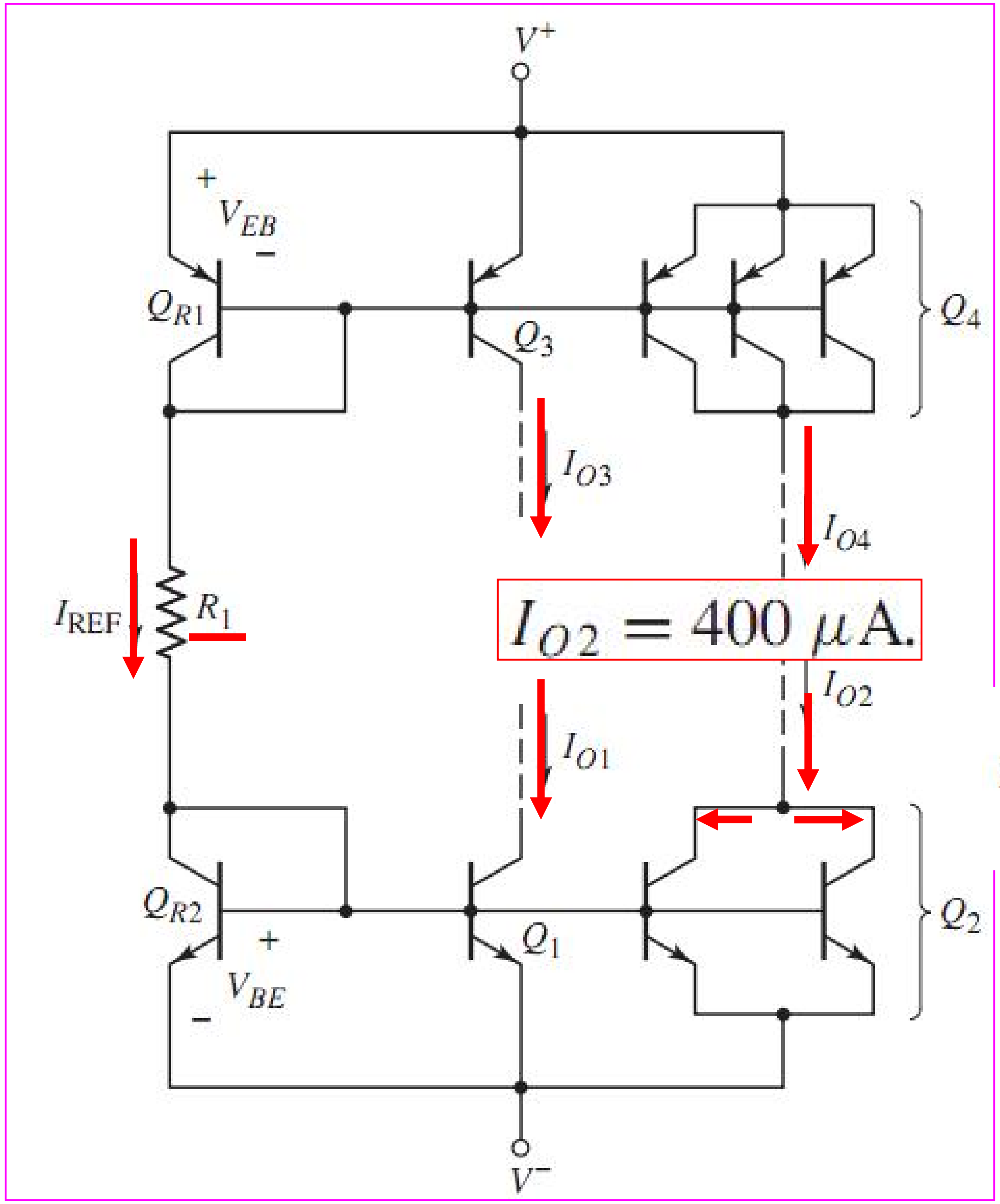
10.1 Bipolar Transistor Current Sources

I_{REF}=?



$$I_{REF} = \frac{V_{CC} - V_{BE3} - V_{BE2} + V_{EE}}{R}$$

10.1.4 Multi-transistor Current Source



$V^+ = +5$ V

$V^- = -5$ V.

Neglect base currents

$V_{BE} = V_{EB} = 0.6$ V.

$\boxed{I_{O2} = 400\ \mu A.}$

$I_{REF} = I_{O1} = I_{O3} = 200\ \mu A$

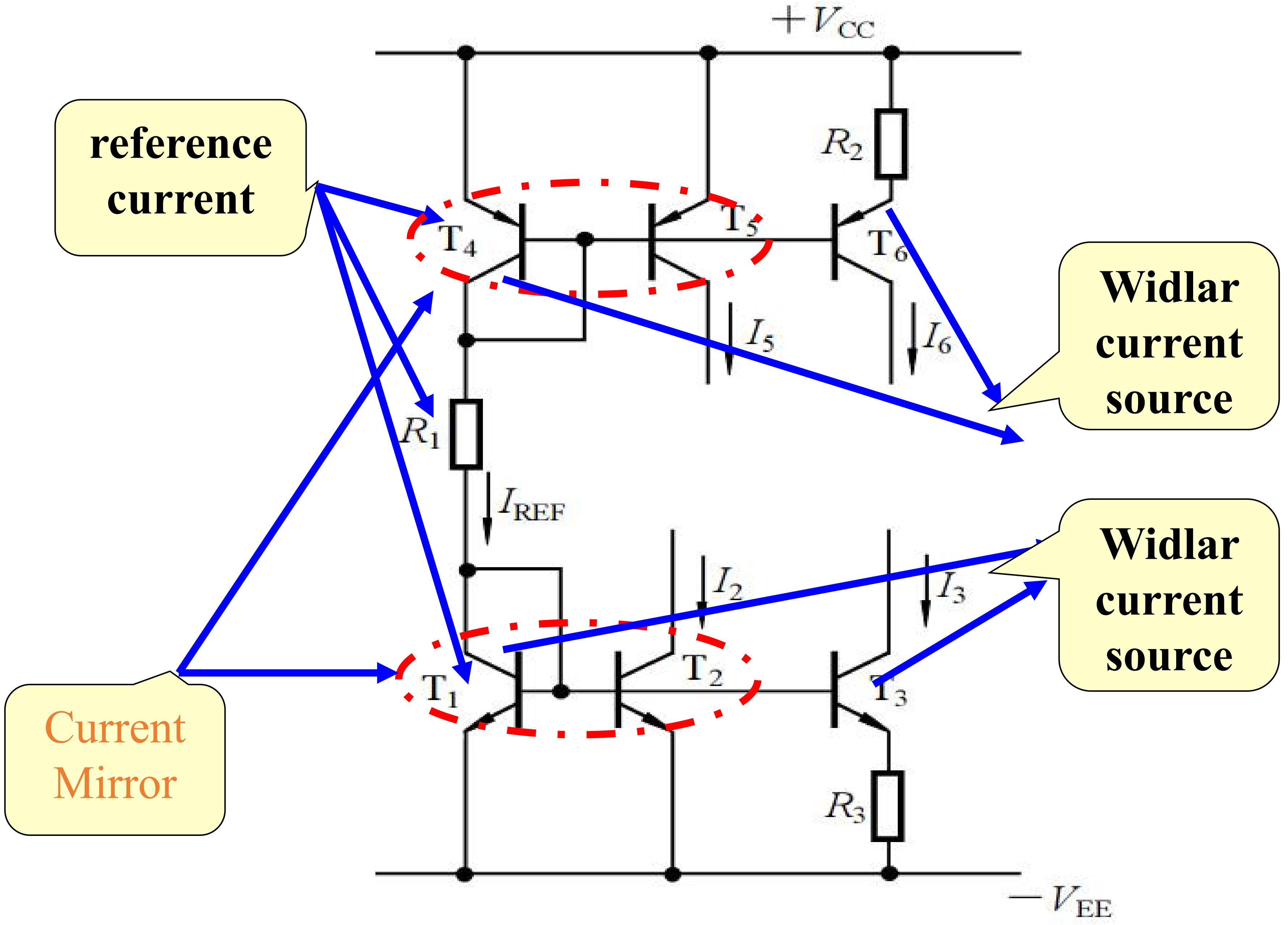
$I_{O4} = 600\ \mu A$

$$R_1 = \frac{V^+ - V_{EB}(Q_{R1}) - V_{BE}(Q_{R2}) - V^-}{I_{REF}}$$

$$= \frac{5 - 0.6 - 0.6 - (-5)}{0.2}$$

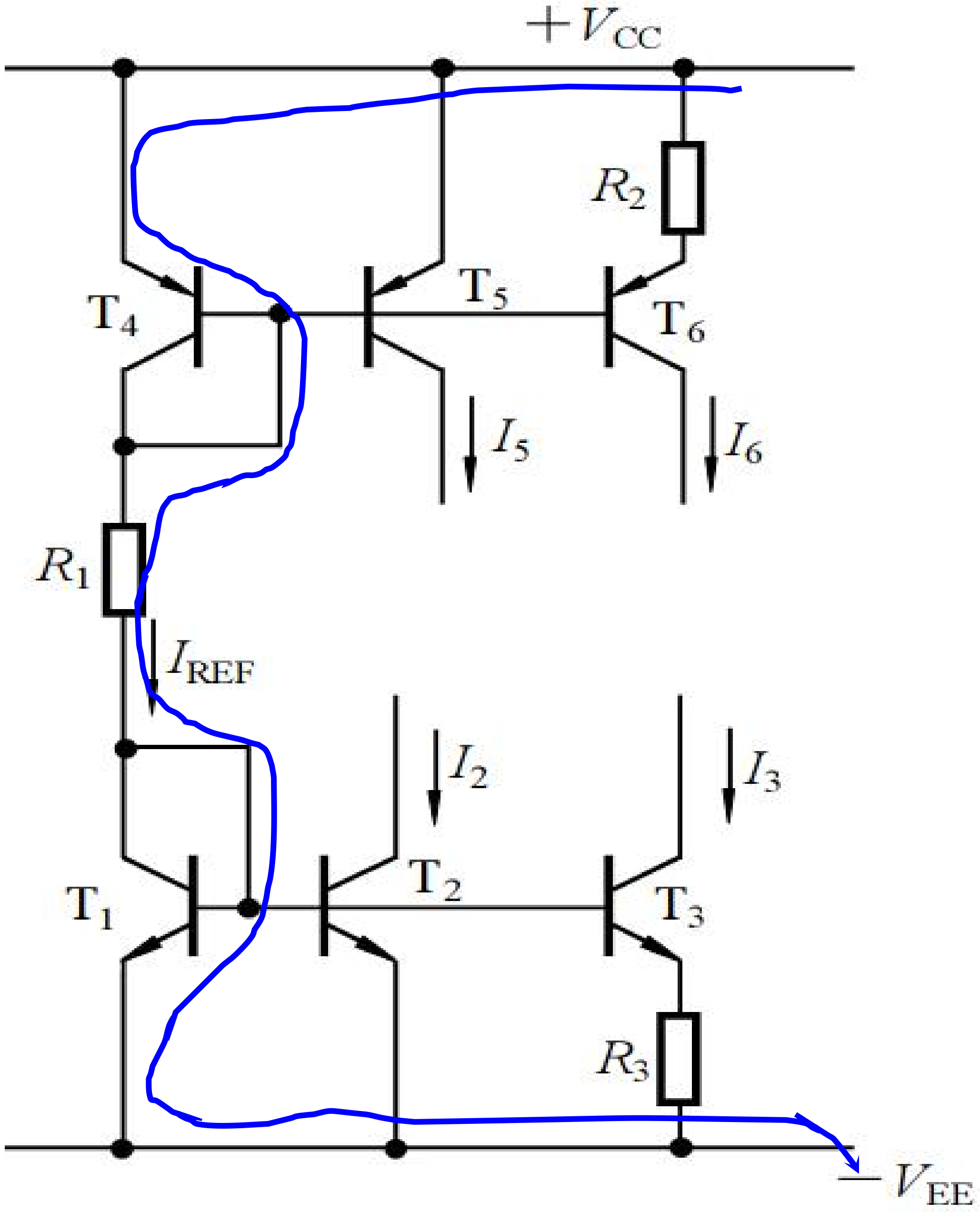
$$R_1 = 44\ k\Omega$$

10.1 Bipolar Transistor Current Sources

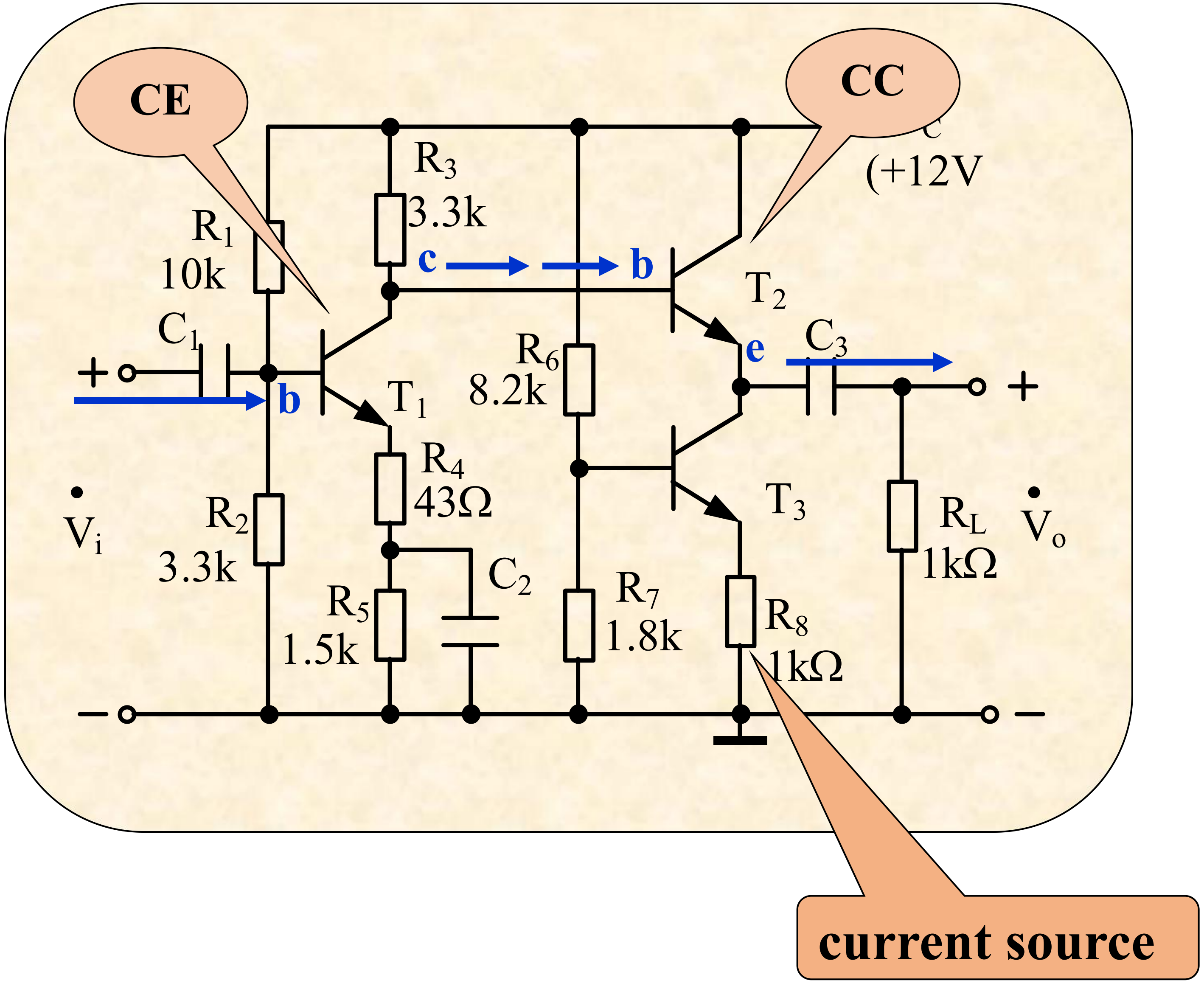


I_{REF}=?

$$I_{REF} = \frac{V_{CC} + V_{EE} - V_{BE1} - V_{EB4}}{R_1}$$



Example



CE
CC
(+12V
R1
10k
R2
3.3k
R3
3.3k
R4
43Ω
R5
1.5k
R6
8.2k
R7
1.8k
R8
1kΩ
RL
1kΩ
C1
C2
C3
T1
T2
T3
b
c
b
e
Vi
Vo
+
+
–
–
current source

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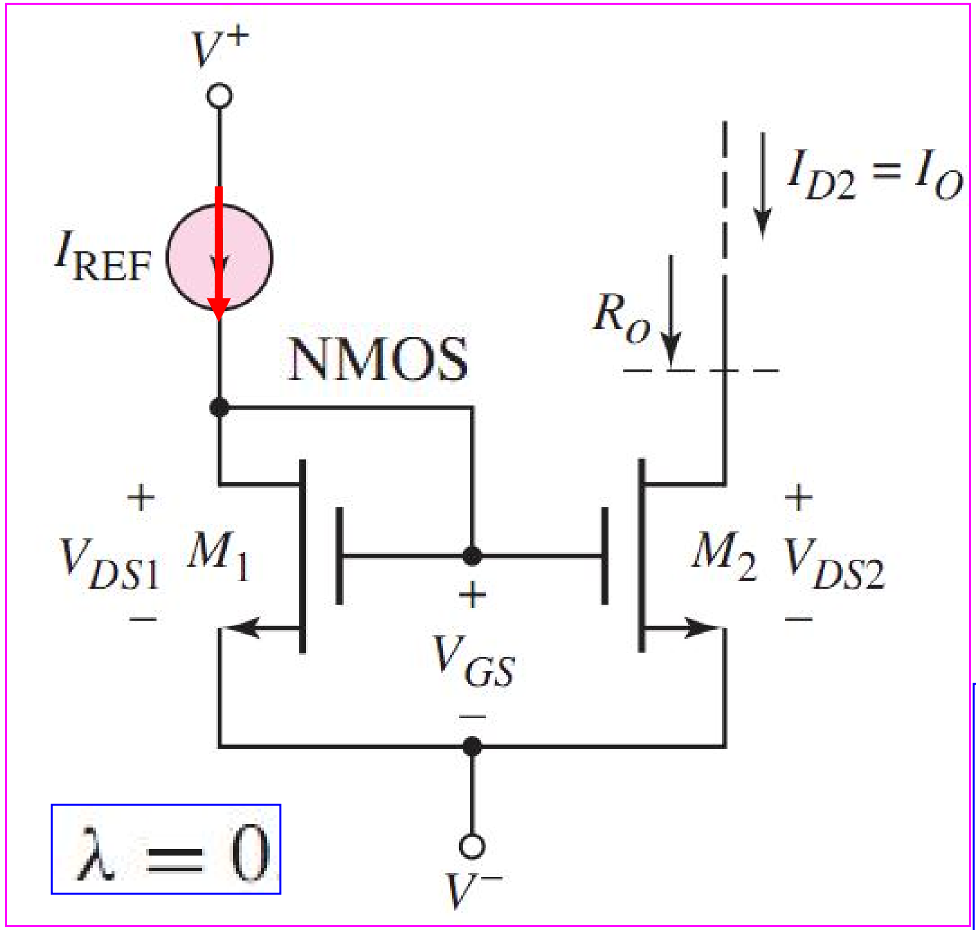
10.2 FET Current Sources

10.2.1 Basic Current Source



M_1

$$I_{REF} = K_{n1}(V_{GS} - V_{TN1})^2$$

$$\Downarrow$$

$$V_{GS} = V_{TN1} + \sqrt{\frac{I_{REF}}{K_{n1}}}$$

M_2

$$I_O = K_{n2}(V_{GS} - V_{TN2})^2$$

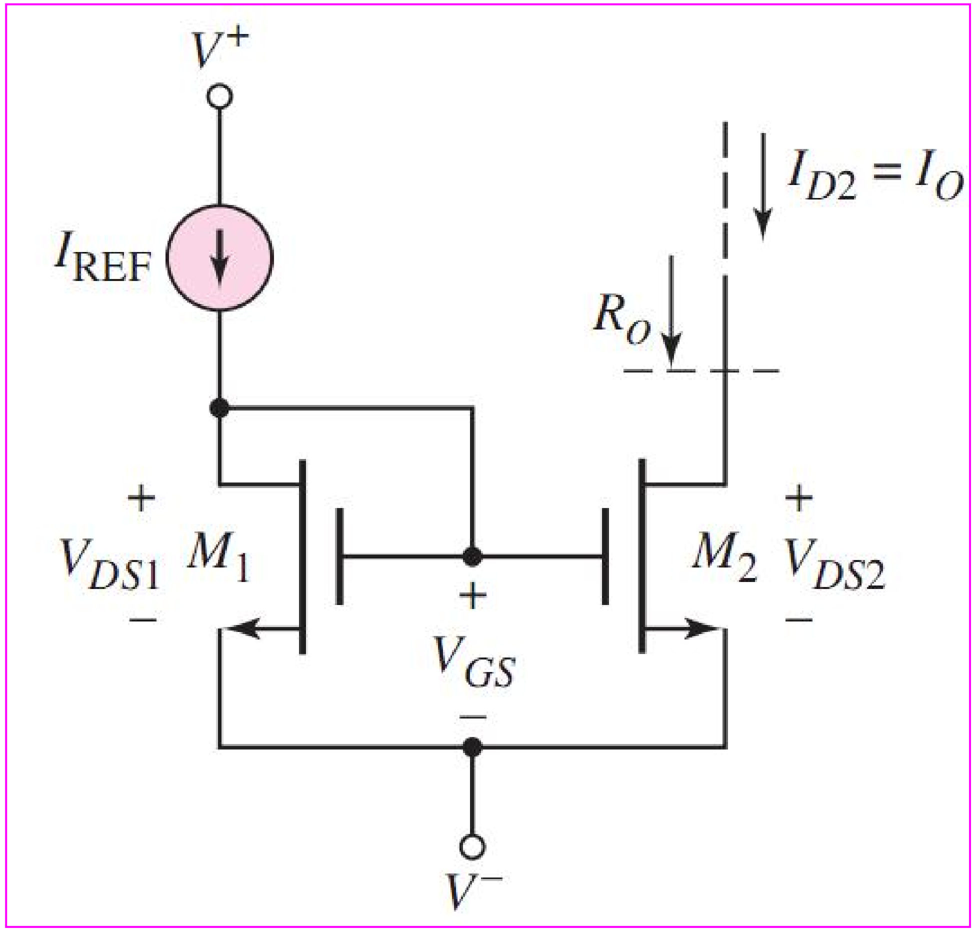
$$\boxed{I_O = K_{n2}\left[\sqrt{\frac{I_{REF}}{K_{n1}}} + V_{TN1} - V_{TN2}\right]^2}$$

If M_1 and M_2 are identical transistors $V_{TN1} = V_{TN2}$ and $K_{n1} = K_{n2}$

$$I_O = I_{REF}$$

10.2 FET Current Sources

10.2.1 Basic Current Source



aspect ratios

width-to-length ratios

$$I_O = \frac{(W/L)_2}{(W/L)_1} \cdot I_{REF}$$

If the transistors are matched except for the aspect ratios,

10.2 FET Current Sources

10.2.1 Basic Current Source

- Load current

$$I_O = \frac{W_2 / L_2}{W_1 / L_1} I_{REF}$$

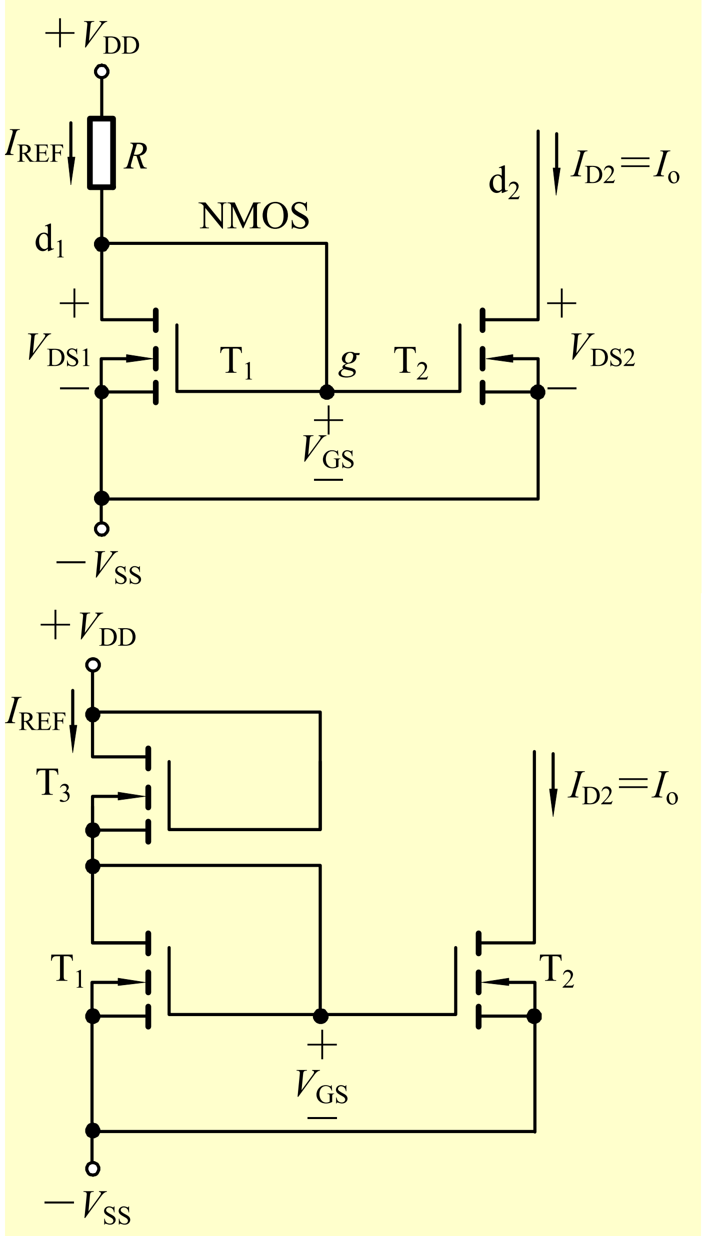
$$I_O = I_{D2} = K_{n2}(V_{GS2} - V_{T2})^2$$

$$\boldsymbol{I_O = I_{D2} = I_{REF} = \frac{V_{DD} + V_{SS} - V_{GS}}{R}}$$

- Output Resistance

$$r_o = r_{ds2} \approx \infty$$

- T_3 substitute R



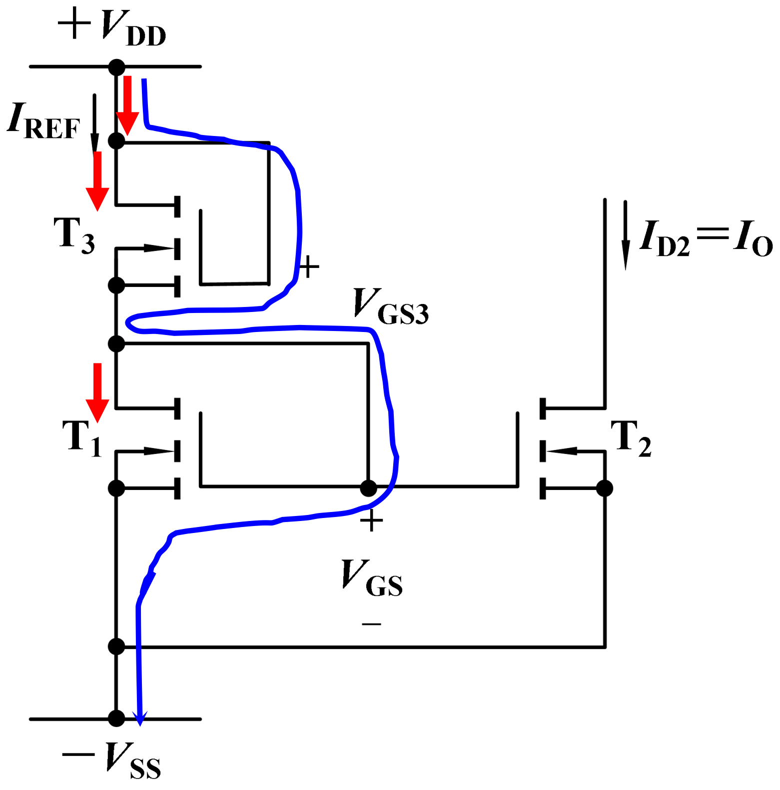
10.2 FET Current Sources

$$I_{D1} = I_{D3} = I_{REF} = K_n(V_{GS} - V_{TN})^2$$

$$V_{GS3} = V_{GS} = \frac{1}{2}(V_{DD} + V_{SS})$$

$$V_{DD} + V_{SS} > 2V_{TN}$$

$$I_{D2} = K_n(V_{GS} - V_{TN})^2$$



10.2.2 Multi-MOSFET Current Source

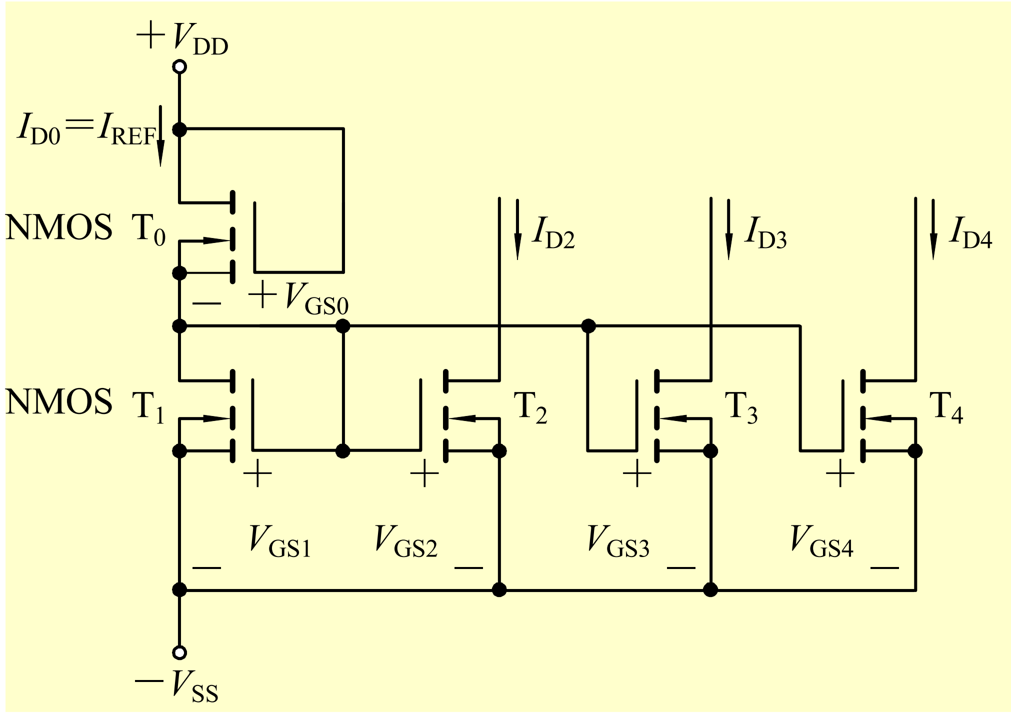
- Currents

$$I_{D2} = \frac{W_2 / L_2}{W_1 / L_1} I_{REF}$$

$$I_{D3} = \frac{W_3 / L_3}{W_1 / L_1} I_{REF}$$

$$I_{D4} = \frac{W_4 / L_4}{W_1 / L_1} I_{REF}$$

$$I_{REF} = I_{D0} = K_{n0}(V_{GS0} - V_{T0})^2$$



10.3 circuit with active loads

- T_2, T_3 , R **form active load in amplifier** T_1 **circuit.**

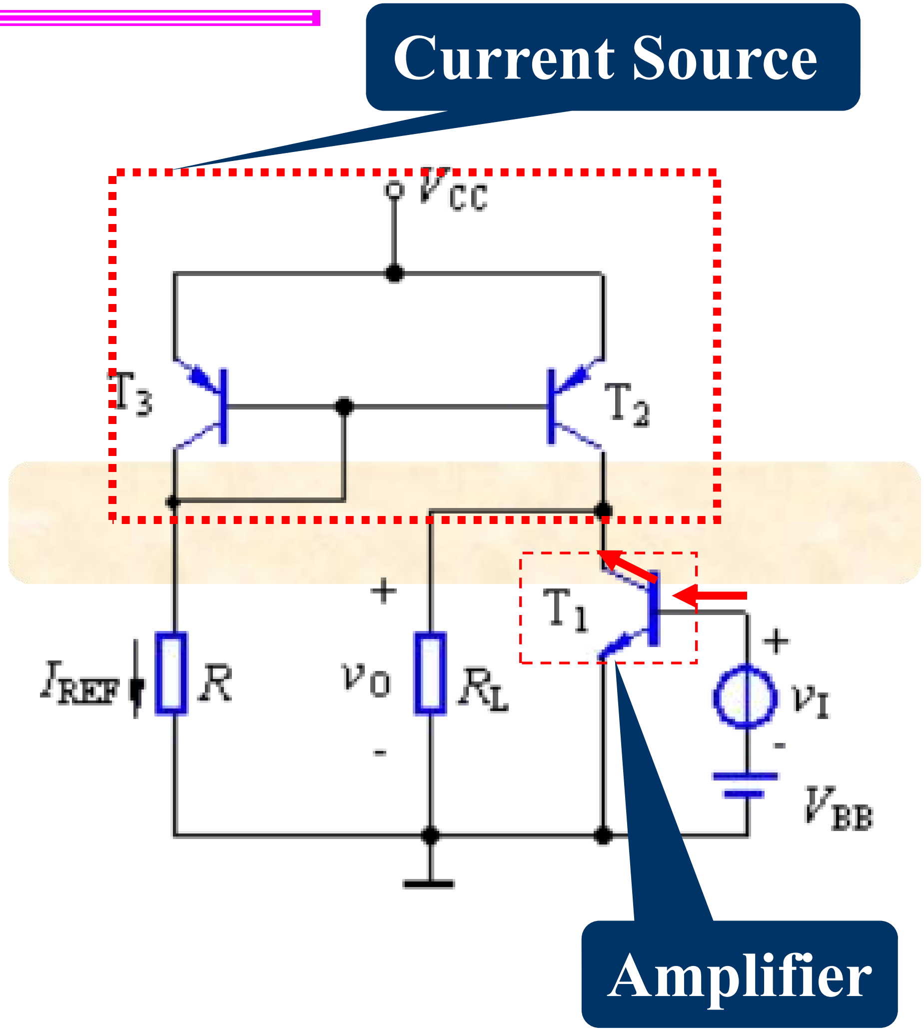
- **Voltage gain of CE:**

$$\dot{A}_V = \frac{\dot{V}_o}{\dot{V}_i} = -\frac{\beta(R_C // R_L)}{r_\pi}$$

- **Equivalent ac output resistance of current source is the load for** T_1 **, and v** $R_C = r_o$

$$\dot{A}_V = -\frac{\beta R_L}{r_\pi}$$

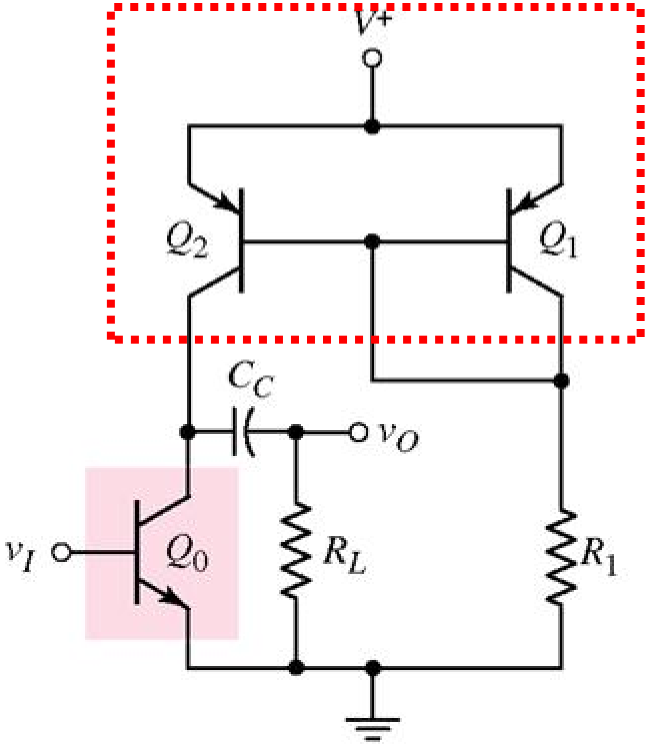
Voltage gain with active load is greater than that of no active load.



common-emitter

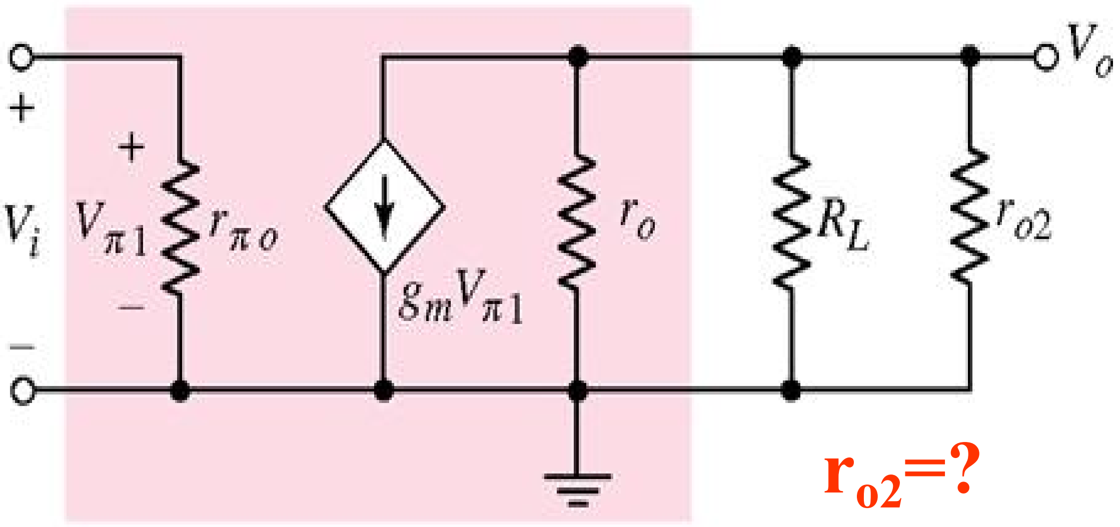
10.4 Small-Signal Analysis: Active Load Circuits

Active Load



Simple BJT amplifier with active load

small-signal equivalent circuit



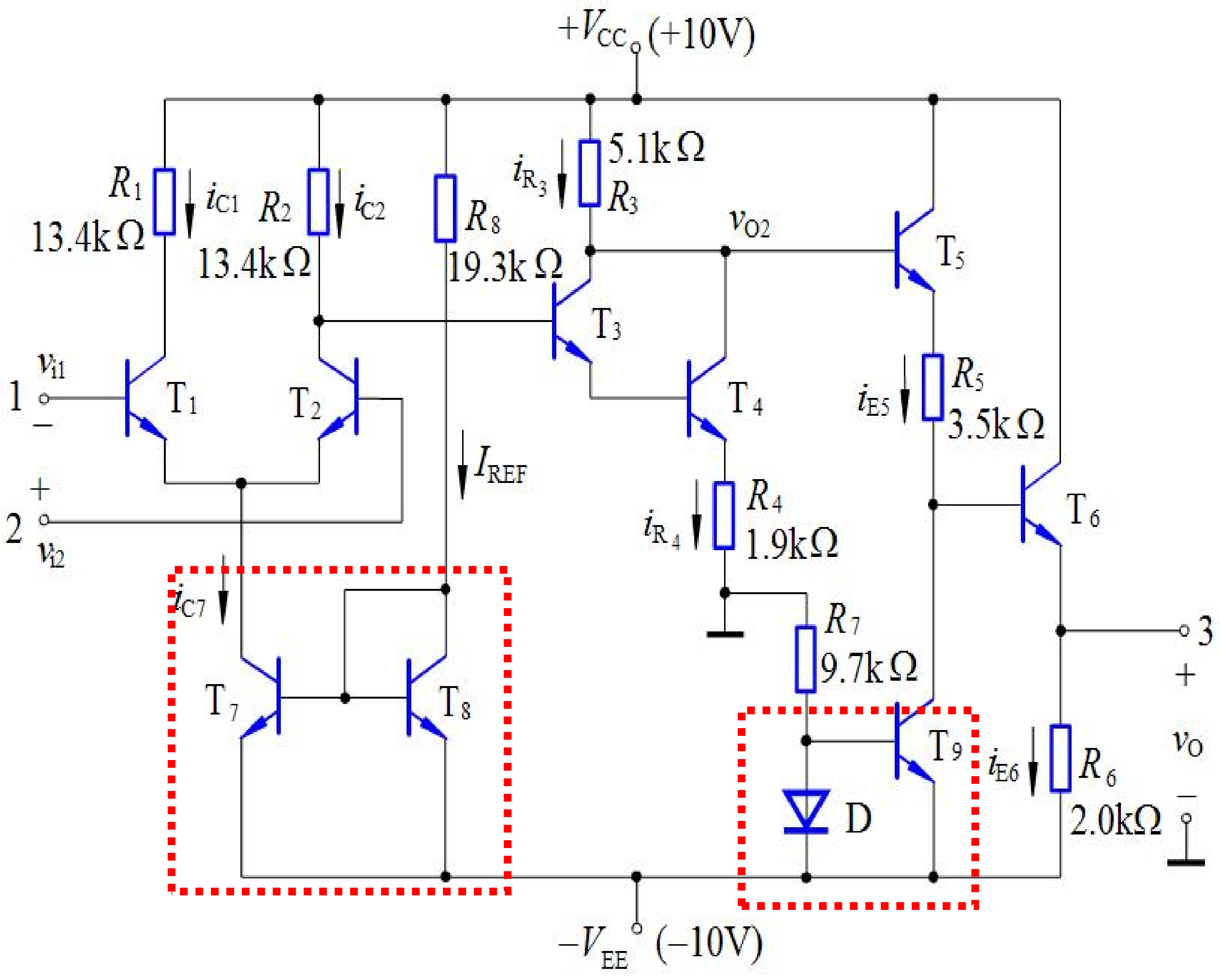
r_{o2}=?

$r_{o2}=r_{ce2}$

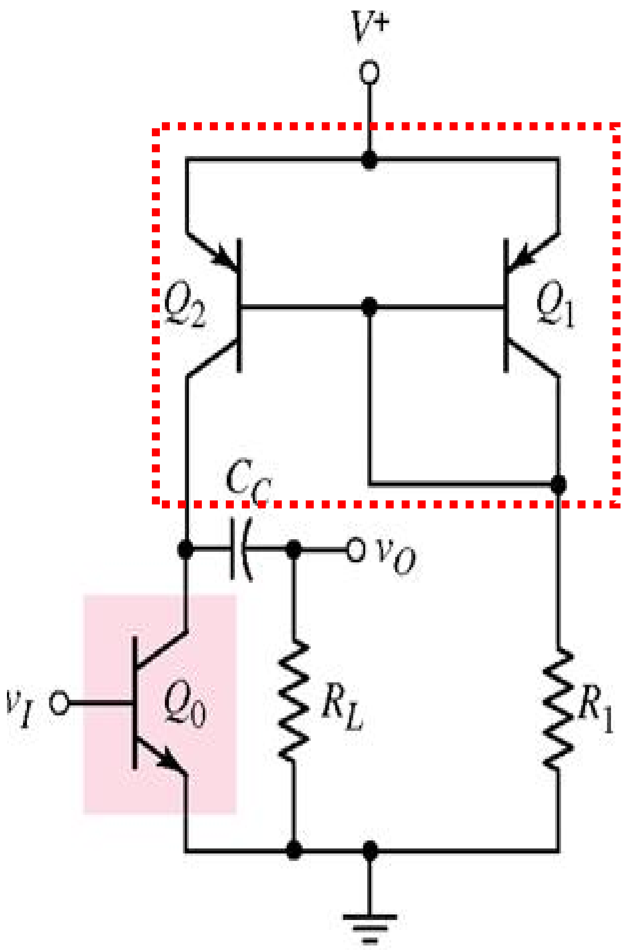
$$A_v = \frac{V_o}{V_i} = -g_m(r_o \| R_L \| r_{o2})$$

current source

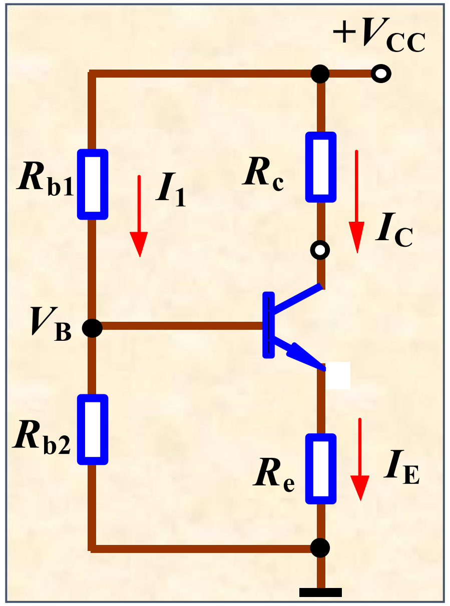
Integrated Circuit Biasing

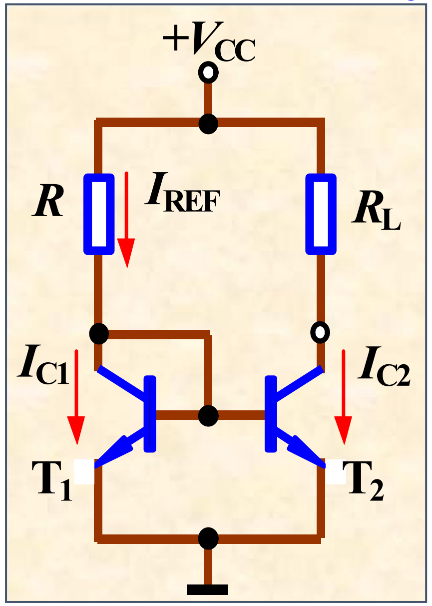


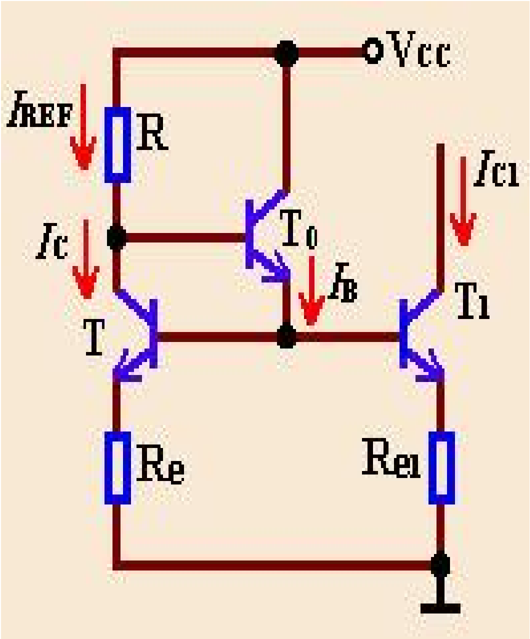
Active Loads

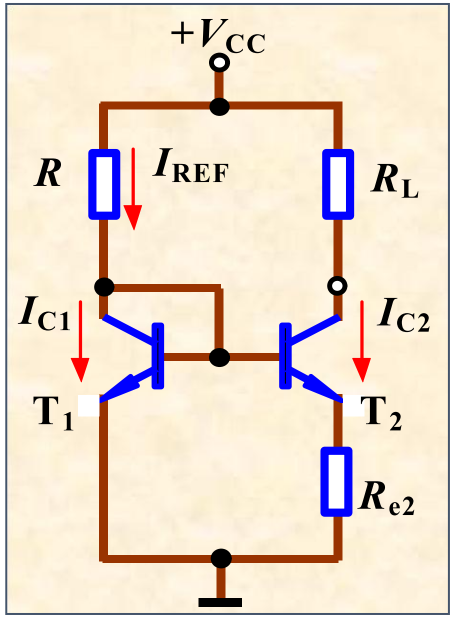


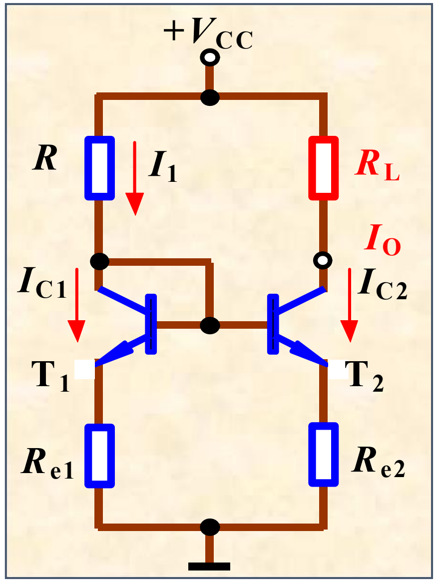
Summary











$$I_o = I_1 \frac{R_{e1}}{R_{e2}}$$