第八章

模拟集成电路中的单元电路

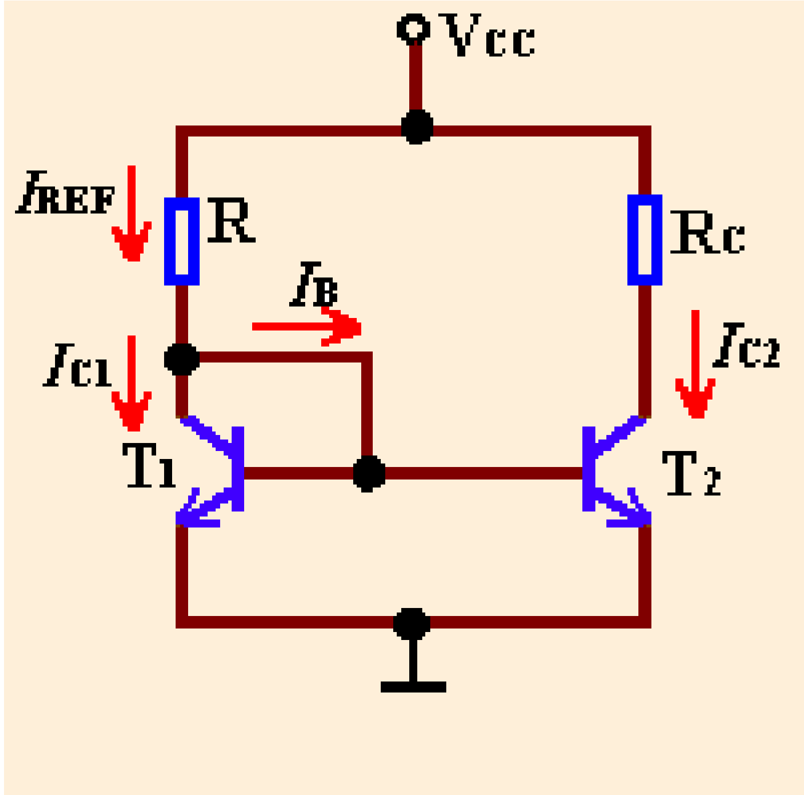
8.1 电流源和电流镜

8.2 差动放大级

8.3 集成运放

8.1 电流源和电流镜

一. 镜像电流源



基准电流：

$$I_{\text{REF}} = \frac{V_{\text{CC}} - V_{\text{BE}}}{R}$$

因为： $V_{\text{BE2}} = V_{\text{BE1}}$

所以： $I_{\text{B2}} = I_{\text{B1}} \quad I_{\text{C2}} = I_{\text{C1}}$

$$I_{REF} = I_{C1} + I_{B1} + I_{B2} = I_{C1}(1 + 2/\beta)$$

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

无论R_c的值如何，I_{C2}的电流值将保持不变。

因为

$$I_c = I_s e^{\frac{V_{BE}}{V_t}} \left(1 + \frac{V_{CE}}{V_A} \right)$$

若V_A=100V，V_{CE2}=20V

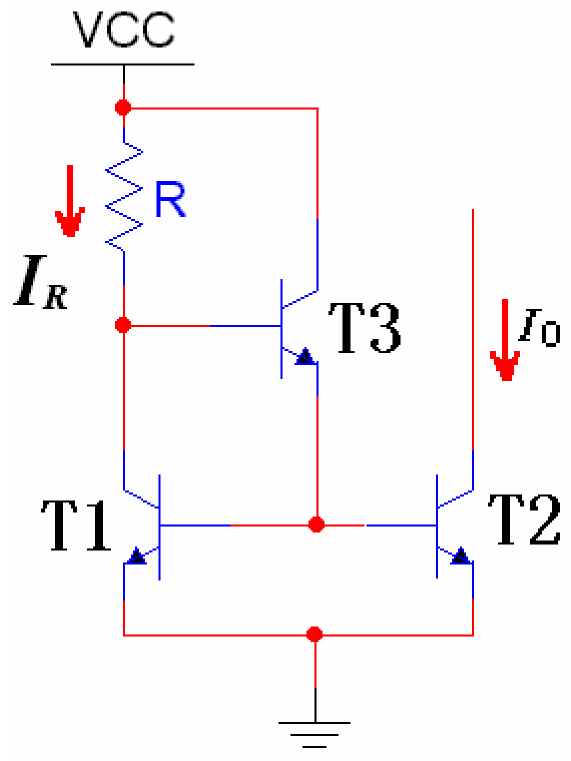
所以由基区调变效应引起的失配为

$$\frac{I_{c2}}{I_R} = \frac{1 + V_{CE2}/V_A}{1 + V_{CE1}/V_A} = \frac{1 + 20/100}{1 + 0.6/100} \approx 1.2$$

$$I_O = I_{C2} = I_{C1} = I_R - I_{B3}$$

$$I_{E3} = \frac{I_{C1}}{\beta} + \frac{I_{C2}}{\beta} = \frac{2I_O}{\beta}$$

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



$$\therefore \quad I_O = I_R \Big/ \left[1 + \frac{2}{\beta(1+\beta)}\right] \approx I_R \Big/ \left(1 + \frac{2}{\beta^2}\right)$$

二. 微电流源

$$\because V_{BE1} = V_{BE2} + I_{E2}R_{e2}$$

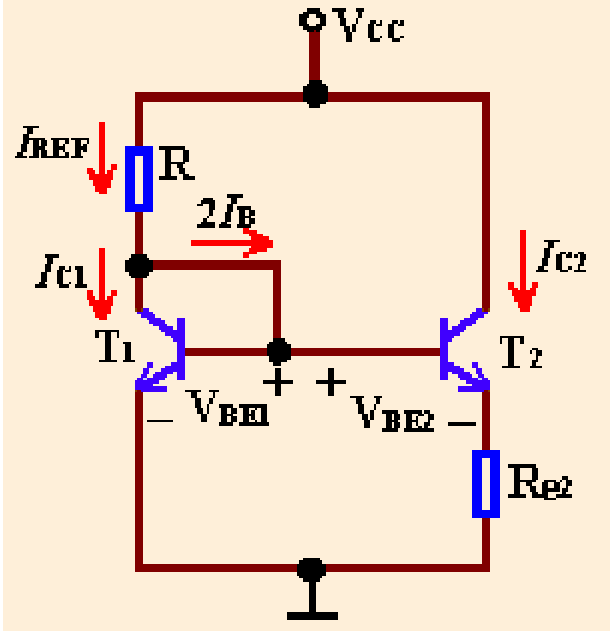
$$I_{C2} \approx I_{E2} = \frac{V_{BE1} - V_{BE2}}{R_{e2}} = \frac{\Delta V_{BE}}{R_{e2}}$$

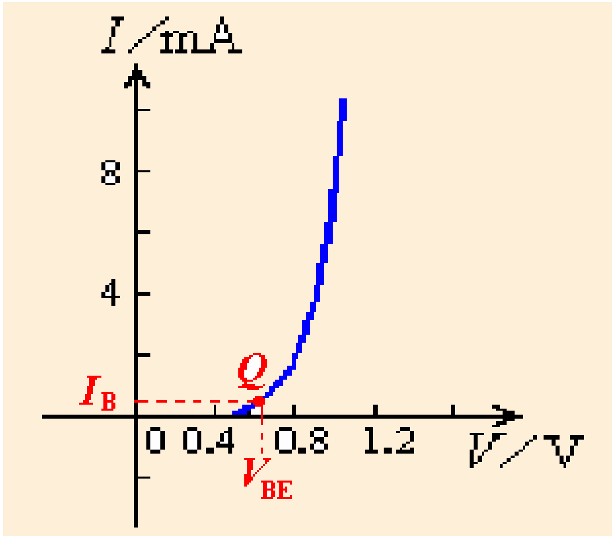
由于 ΔV_{BE} 很小， 所以I_{C2}也很小。

$$\because I_C = I_S e^{V_{BE}/V_t} \quad I_{S1} = I_{S2}$$

$$\therefore V_t \ln\frac{I_{C1}}{I_{S1}} - V_t \ln\frac{I_{C2}}{I_{S2}} = I_{E2}R_{e2}$$

$$\therefore I_{C2}R_{e2} = V_t \ln\frac{I_{REF}}{I_{C2}}$$





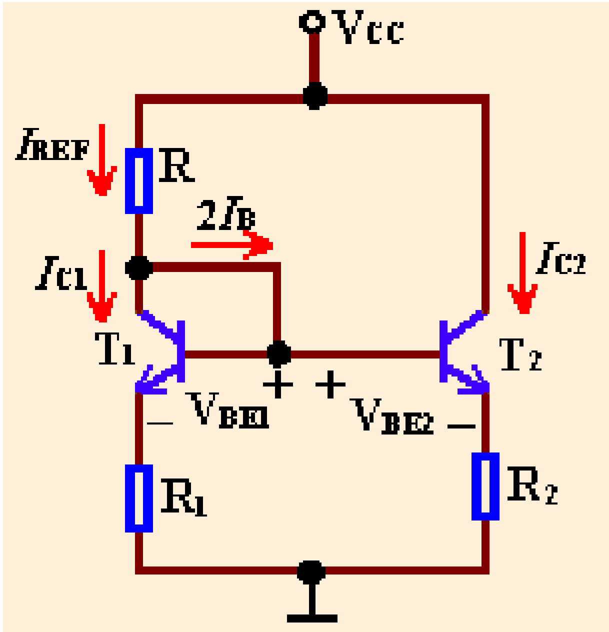
三. 比例电流源

$$U_{BE1} + I_{E1}R_1 = U_{BE2} + I_{E2}R_2$$

$$U_{BE1} \approx U_{BE2}$$

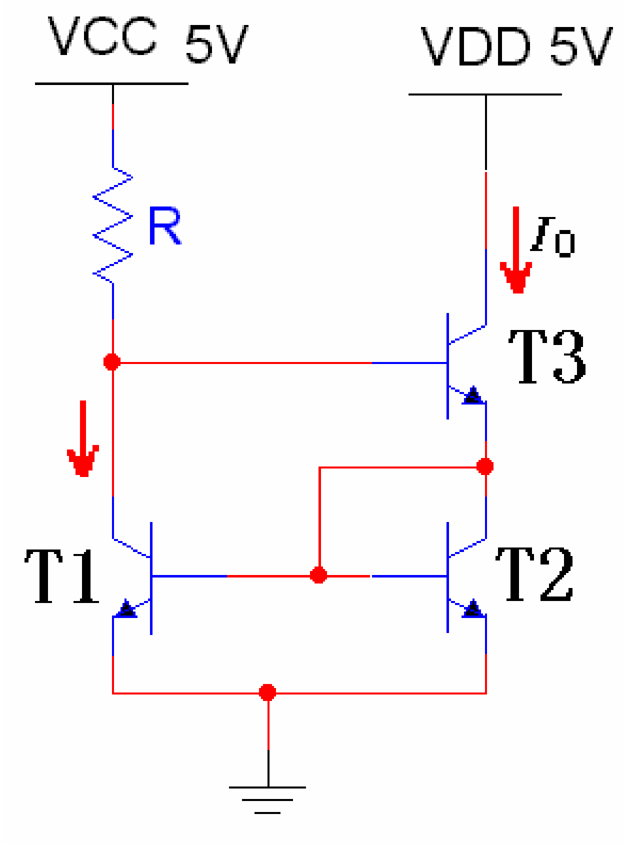
$$\therefore I_{E1}R_1 \approx I_{E2}R_2$$

$$I_{C2} \approx \frac{R_1}{R_2} I_{C1} \approx \frac{R_1}{R_2} I_{REF}$$



四. Wilson电流源

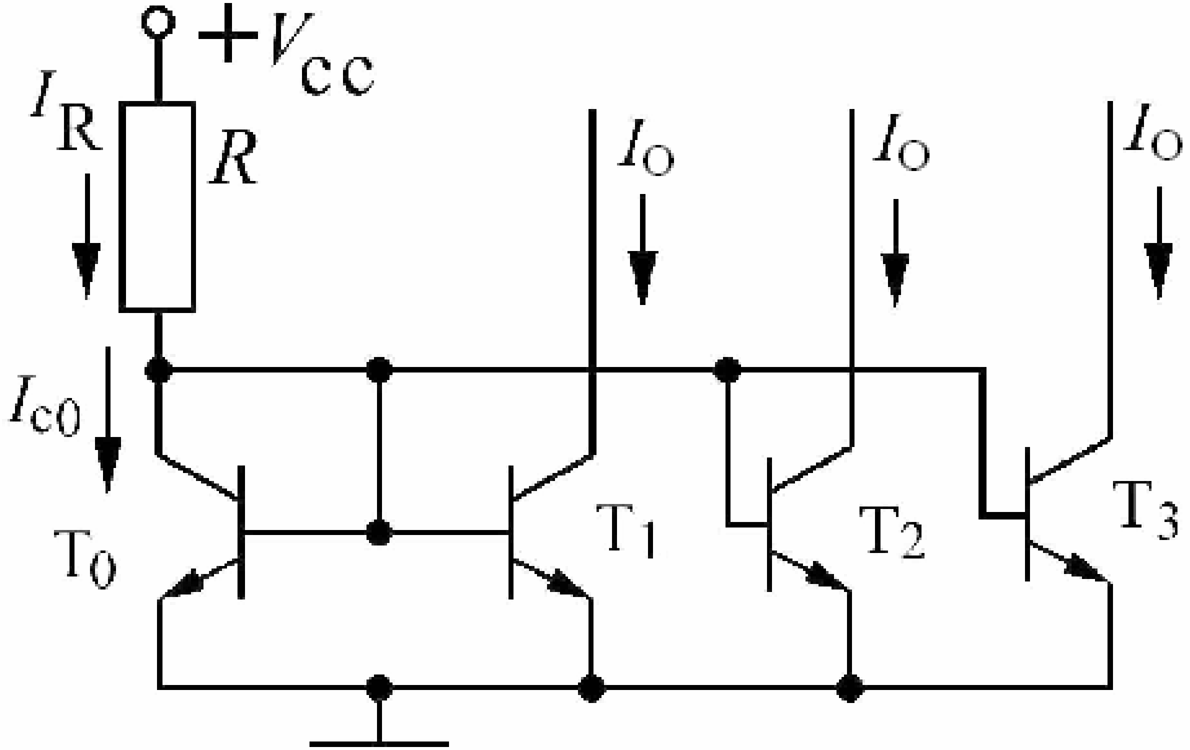
$$I_R = I_{C1} + I_{B3} = I_{C1} + \frac{I_O}{\beta}$$

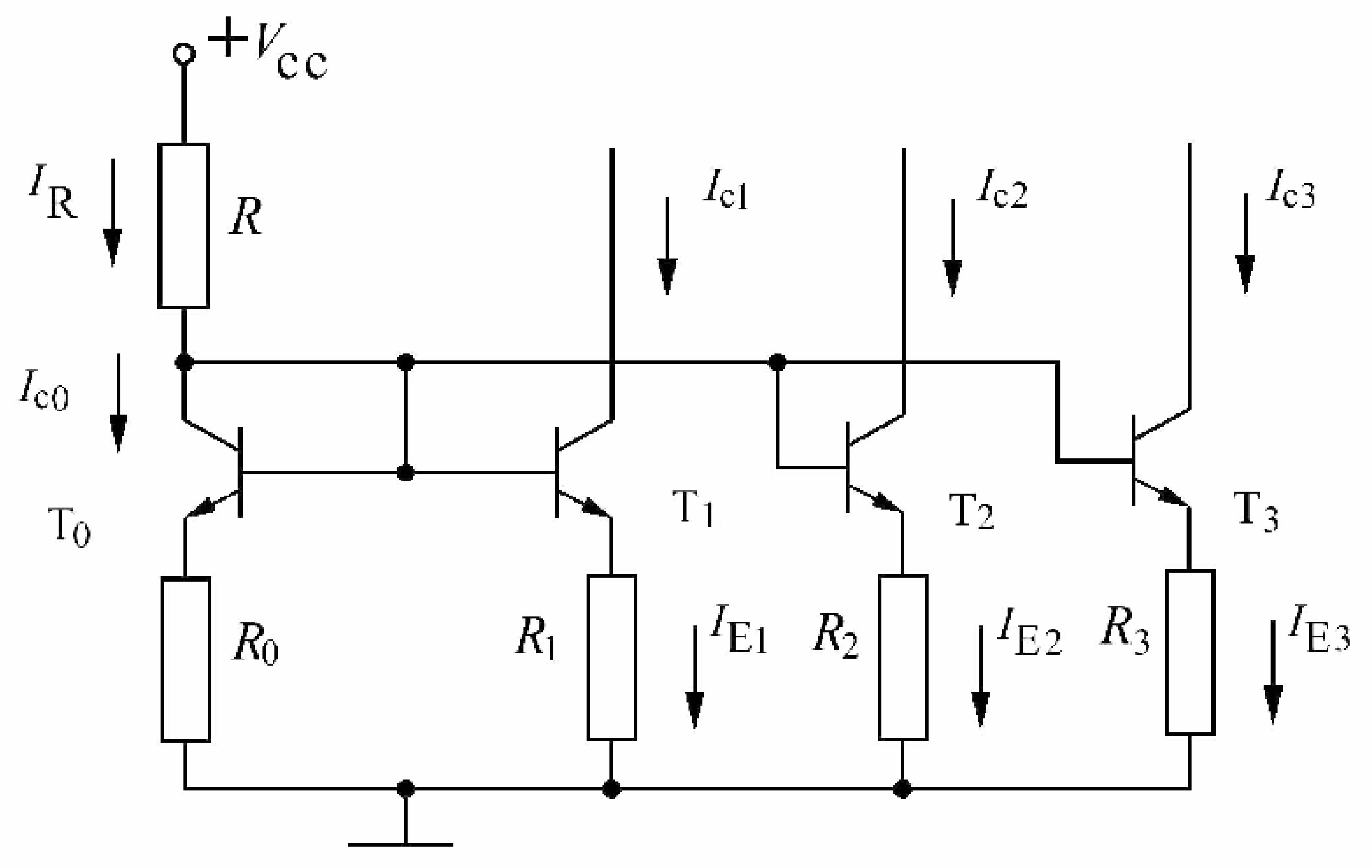


$$\begin{cases} I_{E3} = I_{C2} + I_{B1} + I_{B2} = I_{C2}\left(1 + \dfrac{2}{\beta}\right) \\ I_{C1} = I_{C2} \\ I_{E3} = \dfrac{1+\beta}{\beta} I_O \end{cases}$$

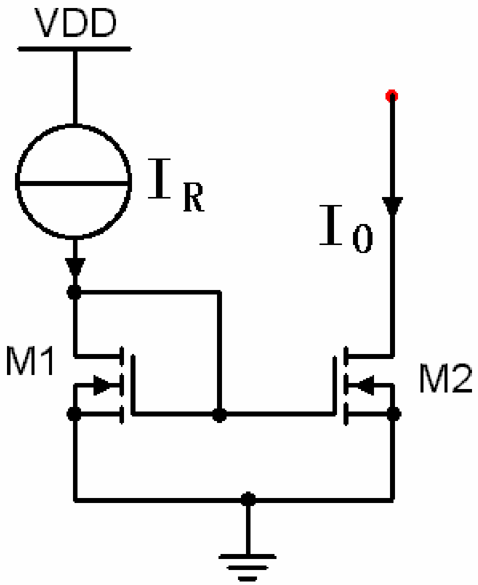
所以 $$I_O = I_R\left(1 - \frac{2}{\beta^2 + 2\beta + 2}\right)$$

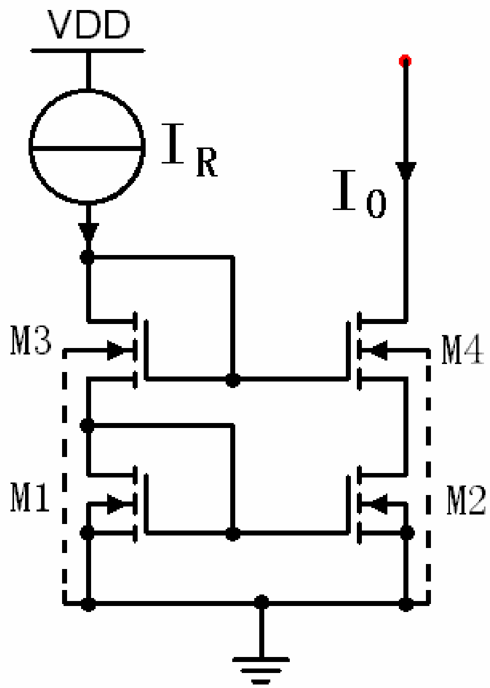
五. 多路电流源




+V_{CC}
I_R
R
I_{c1}
I_{c2}
I_{c3}
I_{c0}
T_0
T_1
T_2
T_3
R_0
R_1
I_{E1}
R_2
I_{E2}
R_3
I_{E3}

六. MOS型电流源





$$\frac{I_O}{I_R}=\frac{K_2^{'}W_2L_1\left(V_{GS2}-V_{T2}\right)^2\left(1+\left|\lambda_2V_{DS2}\right|\right)}{K_1^{'}W_1L_2\left(V_{GS1}-V_{T1}\right)^2\left(1+\left|\lambda_1V_{DS1}\right|\right)}$$

$$\frac{I_O}{I_R}=\frac{W_2L_1\left(1+\left|\lambda_2V_{DS2}\right|\right)}{W_1L_2\left(1+\left|\lambda_1V_{DS1}\right|\right)}$$

8.2 差动放大电路

一. 结构：对称性结构

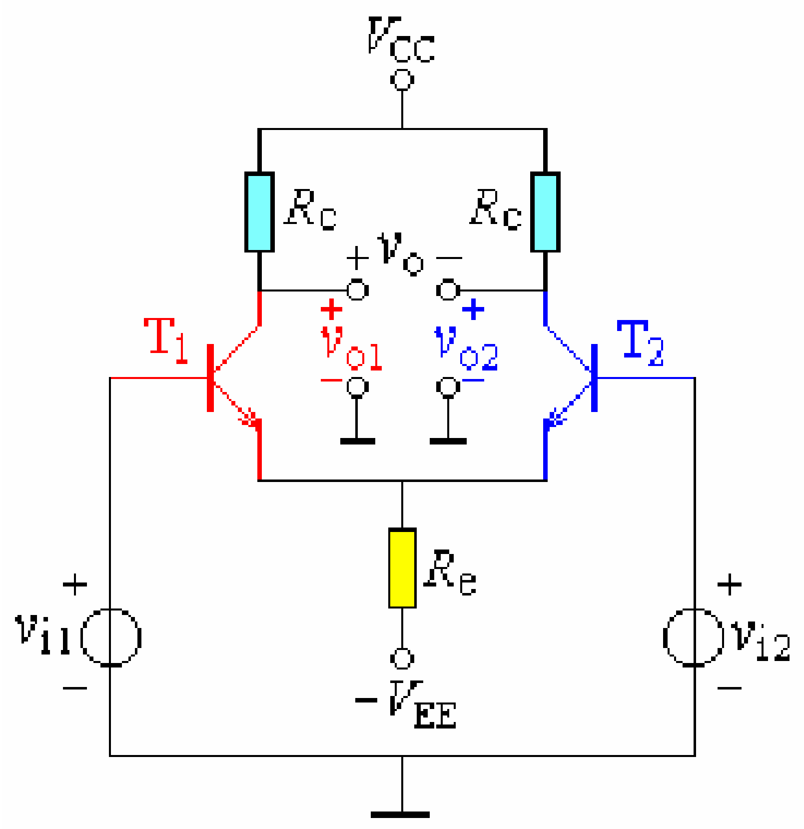
即：$\beta_1=\beta_2=\beta$

$V_{BE1}=V_{BE2}=V_{BE}$

$I_{CBO1}=I_{CBO2}=I_{CBO}$

$r_{be1}=r_{be2}=r_{be}$

$R_{C1}=R_{C2}=R_C$

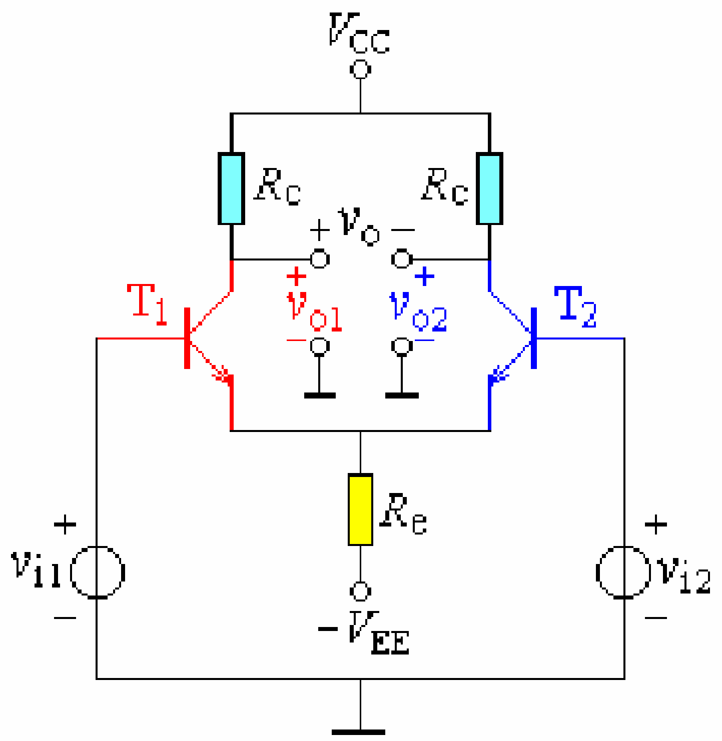


二. 几个基本概念

1. 差动放大电路一般有两个输入端：

双端输入——从两输入端同时加信号。

单端输入——仅从一个输入端对地加信号。



2. 差分放大电路可以有两个输出端，一个是集电极C_1，另一个是集电极C_2。

双端输出——从C_1 和C_2输出。

单端输出——从C_1或C_2 对地输出。

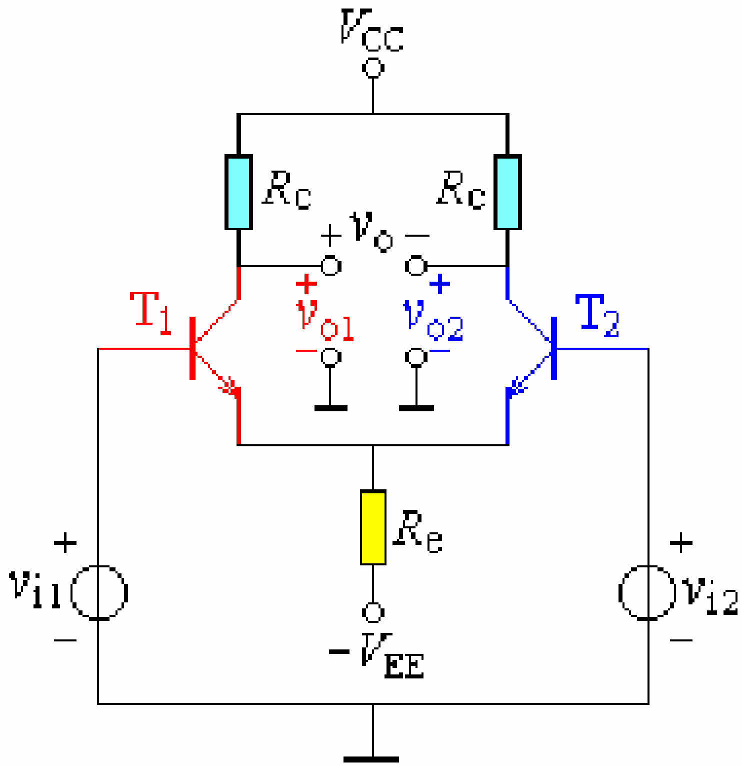
3. 差模信号与共模信号

差模信号：$\boldsymbol{v}_{\mathbf{id}} = \boldsymbol{v}_{\mathbf{i1}} - \boldsymbol{v}_{\mathbf{i2}}$

共模信号：$\boldsymbol{v}_{\mathbf{ic}} = \dfrac{1}{2}(\boldsymbol{v}_{\mathbf{i1}} + \boldsymbol{v}_{\mathbf{i2}})$

差模电压增益 $A_{\mathrm{VD}} = \dfrac{v_{\mathrm{od}}}{v_{\mathrm{id}}}$

共模电压增益 $A_{\mathrm{VC}} = \dfrac{v_{\mathrm{oc}}}{v_{\mathrm{ic}}}$



总输出电压

$$v_{\mathrm{o}} = v_{\mathrm{od}} + v_{\mathrm{oc}} = A_{\mathrm{VD}} v_{\mathrm{id}} + A_{\mathrm{VC}} v_{\mathrm{ic}}$$

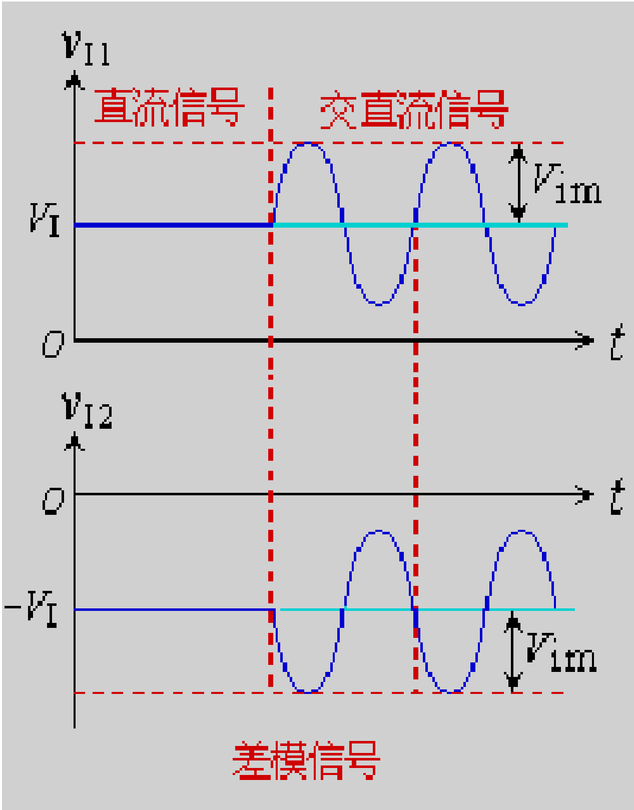
4. 共模抑制比

$$K_{\mathrm{CMRR}} = \left| \frac{A_{\mathrm{VD}}}{A_{\mathrm{VC}}} \right|$$

纯差模信号

大小相等，极性相反

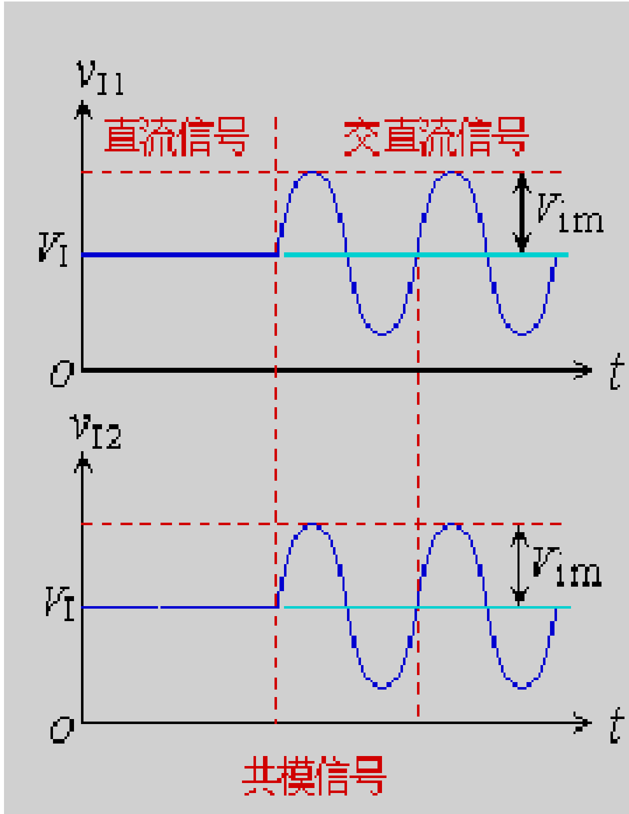
$u_{sd1} = - u_{sd2}$



纯共模信号

大小相等，极性相同

$u_{sc1} = u_{sc2}$

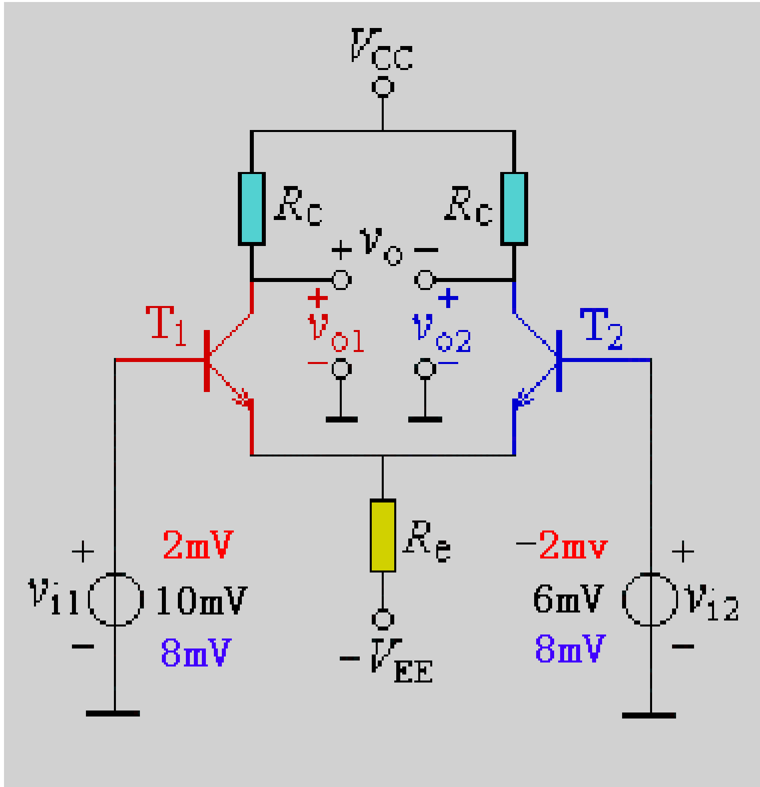


任意信号分解为共模信号和差模信号

$$\because \begin{cases} V_{i1} = V_{sd1} + V_{sc1} \\ V_{i2} = V_{sd2} + V_{sc2} \end{cases}$$

$$\begin{cases} V_{sd1} = -V_{sd2} \\ V_{sc1} = V_{sc2} \end{cases}$$

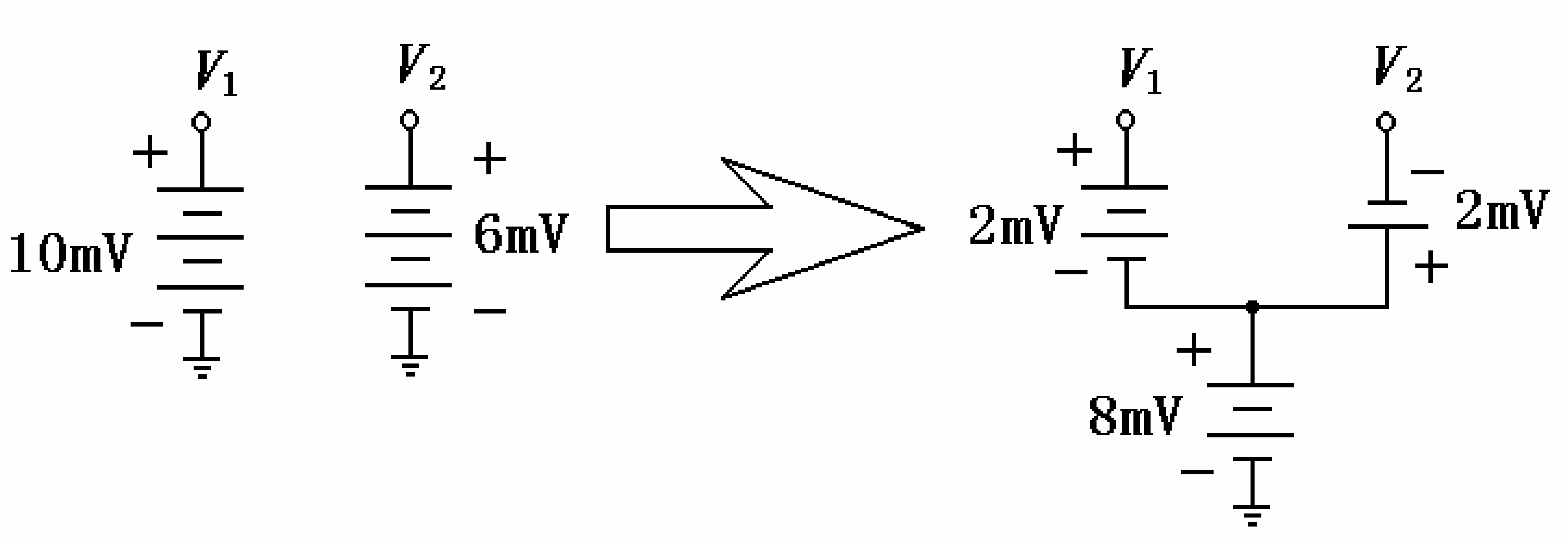
$$\therefore \begin{cases} V_{sd1} = -V_{sd2} = \dfrac{V_{i1} - V_{i2}}{2} \\ V_{ic1} = V_{ic2} = \dfrac{V_{i1} + V_{i2}}{2} \end{cases}$$



例：Vi1=10mV，Vi2=6mV

$$v_{sd1} = -v_{sd2} = \frac{v_{i1} - v_{i2}}{2} = 2\text{mV}$$

$$v_{ic1} = v_{ic2} = \frac{v_{i1} + v_{i2}}{2} = 8\text{mV}$$



三. 差动放大电路的基本工作原理

1. 静态工作点的计算：

$v_{i1} = v_{i2} = 0$

双端输入、双端输出

忽略I_b，有：

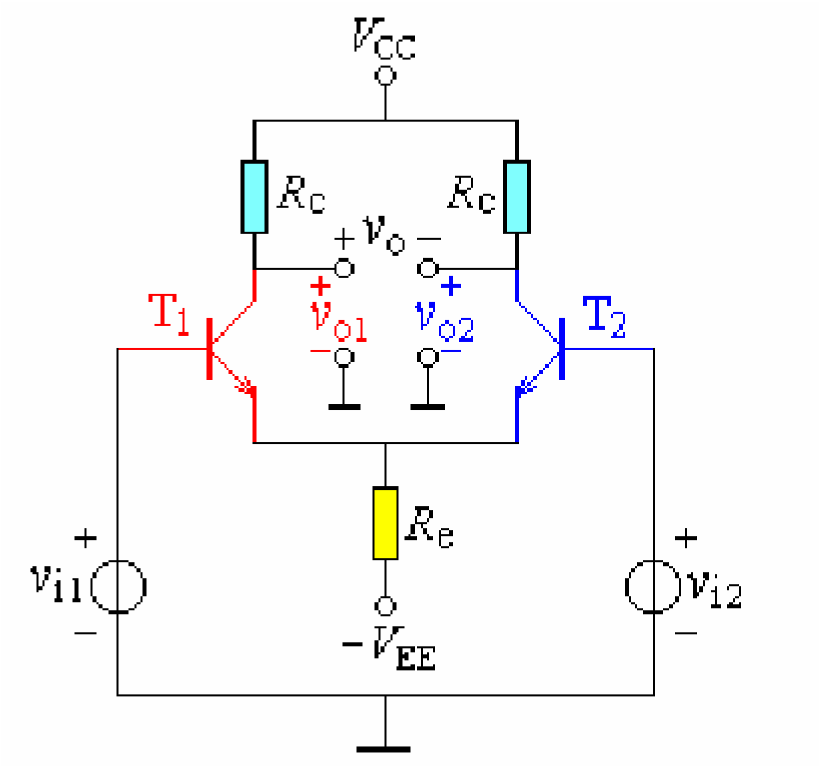
$$I_{Re} = \frac{-0.7V - (-V_{EE})}{R_e}$$

$$I_{C1} = I_{C2} = I_C = \frac{1}{2} I_{Re}$$

$$V_{CE1} = V_{CE2}$$

$$= V_{CC} - I_C R_C - (-0.7)$$

$$I_{B1} = I_{B2} = \frac{I_C}{\beta}$$



$$V_O = V_{C1} - V_{C2} = 0$$

2.抑制零漂的原理:

双端输入、双端输出

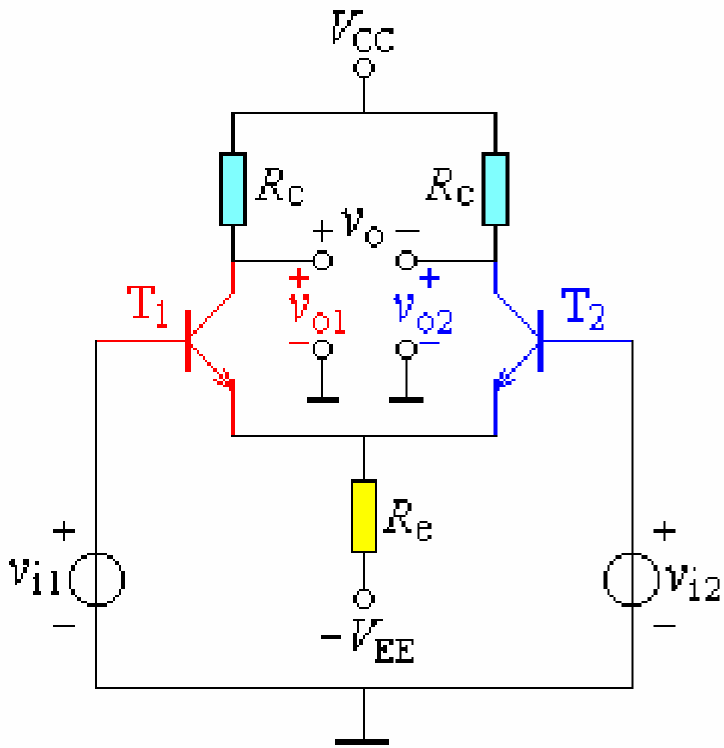
当$v_{i1} = v_{i2} = 0$ 时，

$$v_{C1} = v_{C2}$$

$$v_o = v_{C1} - v_{C2} = 0$$

当温度变化时:

$$\Delta v_{C1} = \Delta v_{C2}$$



$$v_o = (v_{C1} + \Delta v_{C1}) - (v_{C2} + \Delta v_{C2}) = 0$$

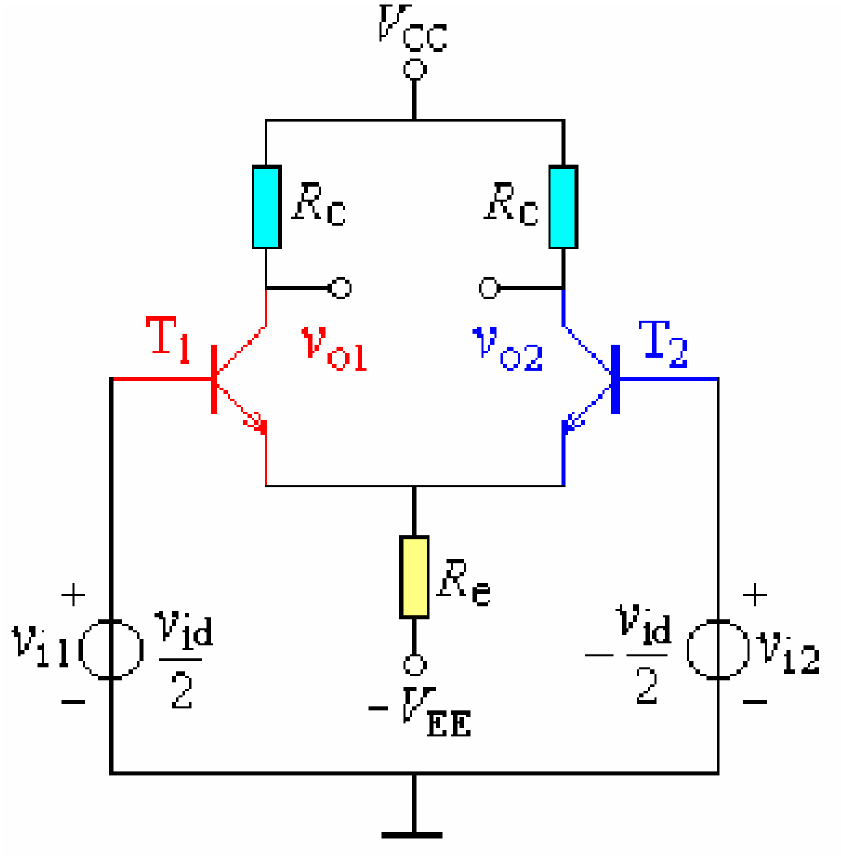
3. 电路的动态分析

双端输入、双端输出

(1) 加入纯差模信号

设： $v_{i1}=-v_{i2}=v_{id}/2$，$v_{ic}=0$。

R_e对差模信号相当于短路



因为：设$v_{i1}\uparrow$, $v_{i2}\downarrow\rightarrow i_{b1}\uparrow$, $i_{b2}\downarrow$

$\rightarrow i_{e1}\uparrow$, $i_{e2}\downarrow\rightarrow|\Delta i_{e1}| = -|\Delta i_{e2}|$

$\rightarrow I_{Re}$不变 $\rightarrow V_E$不变