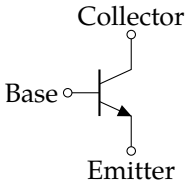
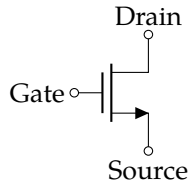
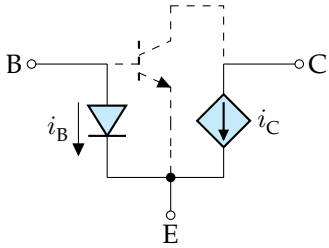
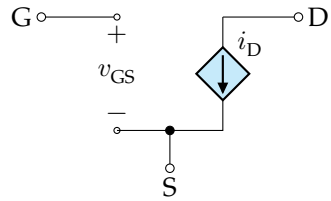
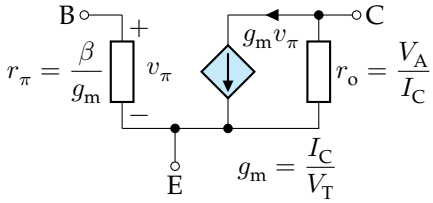
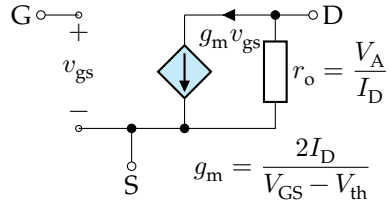
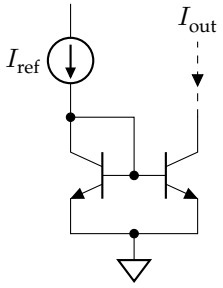
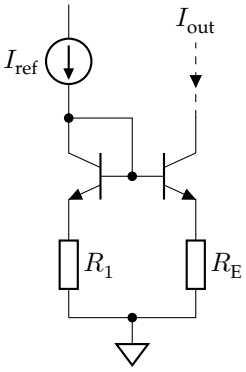
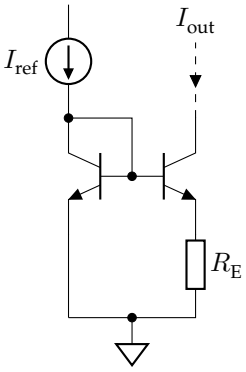
# 模拟电路知识点小结

最新版：https://github.com/chenshuo/nuedc

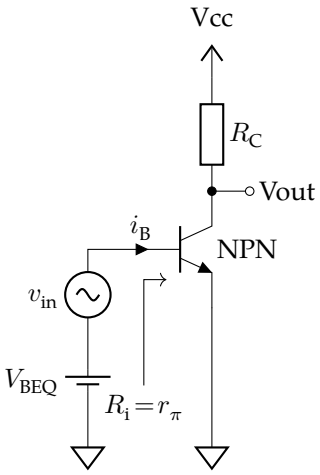
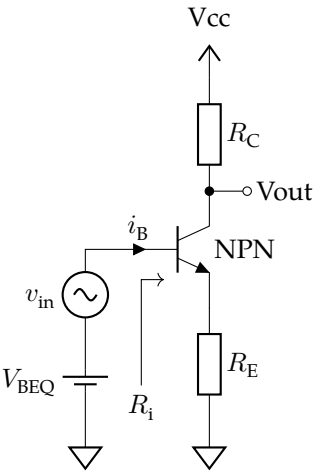
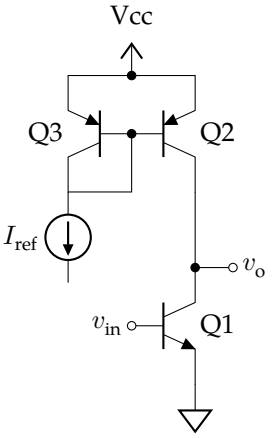
## Transistor

| 器件 | NPN | NMOS |
|---|---|---|
| 符号 |  |  |
| 大信号模型 | Ebers–Moll | Shichman–Hodges |
| BJT 放大区<br>MOS 管恒流区 |  |  |
| | $i_C = I_S \exp \frac{v_{BE}}{V_T}$<br>$i_B = \frac{i_C}{\beta}$<br>$i_E = i_B + i_C = (1+\beta) i_B$ | $0 < v_{GS} - V_{th} \le v_{DS}$ :<br>$i_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(v_{GS} - V_{th})^2$<br>$0 < v_{DS} < v_{GS} - V_{th}$ :<br>$i_D = \mu_n C_{ox} \frac{W}{L}[(v_{GS} - V_{th}) v_{DS} - \frac{{v_{DS}}^2}{2}]$ |
| Early 效应 | $i_C = i_{C0}\left(1 + \frac{v_{CE}}{V_A}\right)$ | $i_D = i_{D0}\left(1 + \frac{v_{DS}}{V_A}\right) = i_{D0}(1 + \lambda v_{DS})$ |
| 低频小信号模型<br>hybrid-pi |  |  |
| 跨导 $g_m$ | $g_m = \frac{I_C}{V_T}$ | $g_m = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{th}) = \sqrt{2\mu_n C_{ox} \frac{W}{L} I_D}$ |
| 输入阻抗 $r_{be}$, $r_\pi$ | $r_\pi = \frac{V_T}{I_B} \approx \frac{\beta}{g_m}$ | $r_i = \infty$ |
| 输出阻抗 $r_{ce}$, $r_o$ | $r_o = \frac{V_A + V_{CE}}{I_C} \approx \frac{V_A}{I_C}$ | $r_o = \frac{V_A}{I_D} = \frac{1}{\lambda I_D}$ |
| 本征增益 $A_0 \equiv g_m r_o$ | $A_0 = \frac{V_A}{V_T}$ | $A_0 = \frac{2V_A}{V_{GS} - V_{th}}$ |

# BJT 电流源

| Type | Mirror | Emitter degeneration | Widlar |
|---|---|---|---|
| |  |  |  |
| 输出电流 $I_{out}$ | $I_{out}=\frac{I_{ref}}{1+2/\beta}\approx I_{ref}$ | $I_{out}\approx\frac{R_1}{R_E}I_{ref}$ | $I_{out}R_E=V_T\ln\frac{I_{ref}}{I_{out}}$ |
| 输出阻抗 $R_o$ | $R_o=r_o\approx\frac{V_A}{I_C}$ | $R_o\approx r_o[1+g_m(R_E//r_\pi)]$ | 同左，但通常 $R_E\ll r_\pi$ |

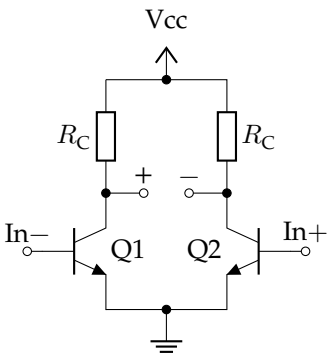
# 单管 Common-Emitter 放大电路

| Type | Basic | Emitter degeneration | Active load |
|---|---|---|---|
| |  |  |  |
| 输入阻抗 $R_i$ | $R_i=r_\pi=\frac{V_T}{I_B}\approx\frac{\beta}{g_m}$ | $R_i=r_\pi+(1+\beta)R_E$ | $R_i=r_\pi$ |
| 输出阻抗 $R_o$ | $R_o=R_C//r_o\approx R_C$ | $R_o\approx R_C$ | $R_o=r_{o1}//r_{o2}$ |
| 空载增益 $A_{v0}$ | $g_m(R_C//r_o)\approx g_mR_C$ | $\frac{R_C}{1/g_m+R_E}\approx\frac{R_C}{R_E}$ | $g_m(r_{o1}//r_{o2})$ |
| max $A_{v0}$ | $A_{v0}=\frac{I_CR_C}{V_T}<\frac{V_{CC}}{V_T}$ | | $A_{v0}=\frac{V_{A1}V_{A2}}{V_T(V_{A1}+V_{A2})}$ |

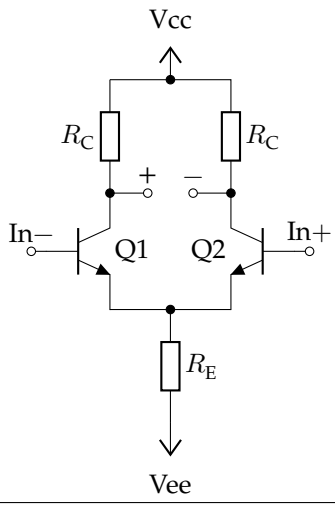
# Diffential-Pair

电路

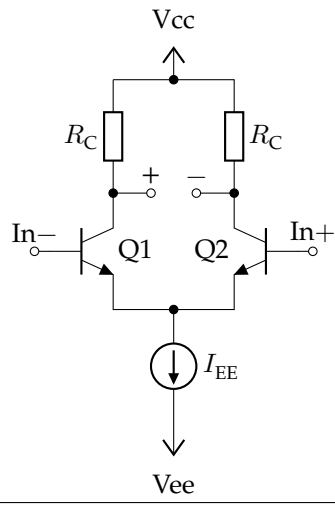
Basic




Long tail




电流源偏置




有源负载
五管 OTA