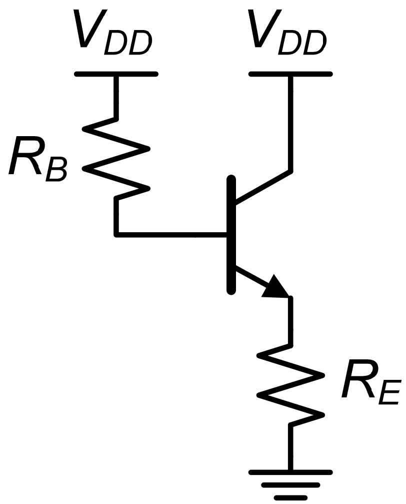
NPN Large Signal (Assume FAR)



VDD = 10V
Beta = 100
VA = infinity
RB=1k
RE=1k
VBEon=0.7V
VCEsat=0.5V

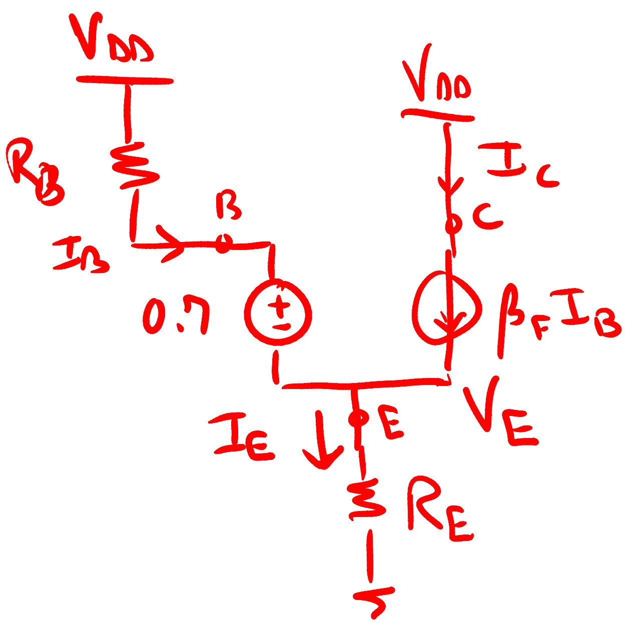
Solve for IC

1. Substitute large-signal FAR model
2. Solve for IC
3. Check assumption

$V_E \cong 9.2V$

$V_{CE} = V_{DD} - V_E = 0.8V$

Large-Sig model



$$I_E = I_B + I_C = \frac{I_C}{\beta} + I_C = \frac{\beta+1}{\beta} I_C$$

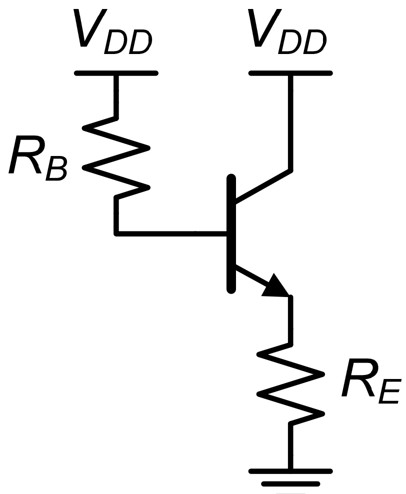
$$V_E = I_E R_E = \frac{\beta+1}{\beta} I_C R_E$$

$$V_B = V_E + 0.7V$$

$$\frac{V_{DD} - V_B}{R_B} = I_B = \frac{I_C}{\beta} = \frac{V_{DD} - \overbrace{\frac{\beta+1}{\beta} I_C R_E - 0.7}^{V_B}}{R_B}$$

$$I_C = \frac{V_{DD} - 0.7}{R_B/\beta + R_E \frac{\beta+1}{\beta}} = \frac{9.3}{10 + 1000 \cdot \frac{101}{100}} \approx 9.2mA$$

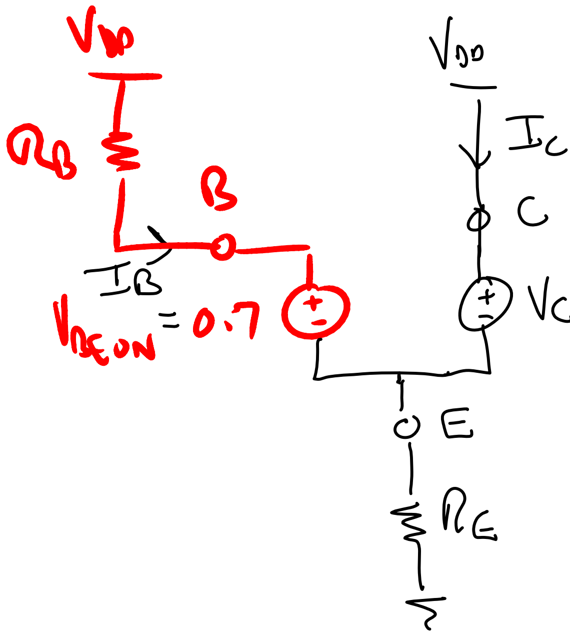
NPN Large Signal (Assume SAT)



VDD = 10V
Beta = 100
VA = infinity
RB=1k
RE=1k
VBEon=0.7V
VCEsat=0.5V

Solve for IC

1. Substitute large-signal SAT model
2. Solve for IC
3. Check assumption



$$V_E = V_{DD} - V_{CEsat} = 9.5V$$

$$V_B = V_E + V_{BE(ON)} = 10.2V$$

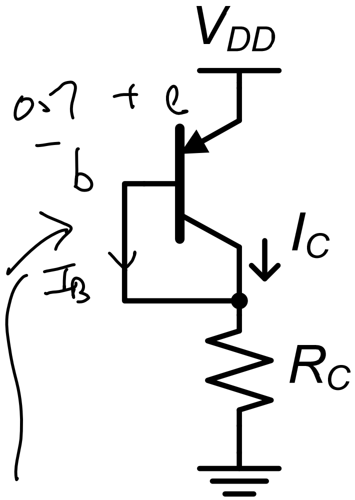
$$I_B = \frac{V_{DD} - V_B}{R_B} = \frac{-0.2}{R_B} = -200\mu A$$

$$I_E = I_B + I_C = ~~\frac{I_C}{\beta} + I_C = \frac{\beta+1}{\beta} I_C~~$$

$$I_E = \frac{V_E}{R_E} = 9.5\ mA$$

$$I_C = I_E - I_B$$

PNP Large Signal (1)



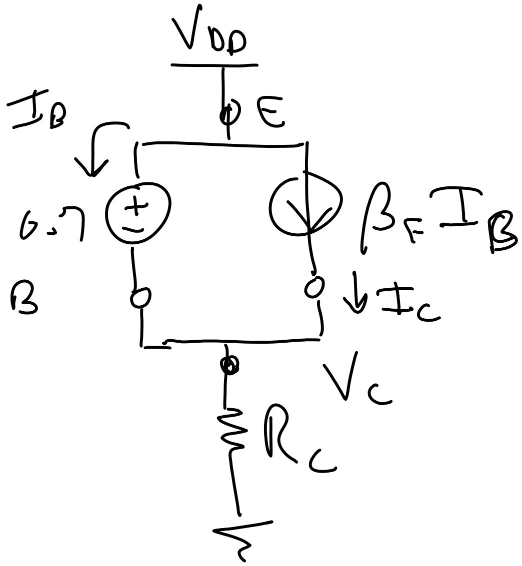
VDD = 10V
Beta = 100
VA = infinity
RC=1k
VBEon=-0.7V
VCEsat=-0.5V

Solve for IC

1. Choose region of operation
2. Substitute model
3. Solve for IC
4. Check assumption

"Diode Connected"

Assume FAR



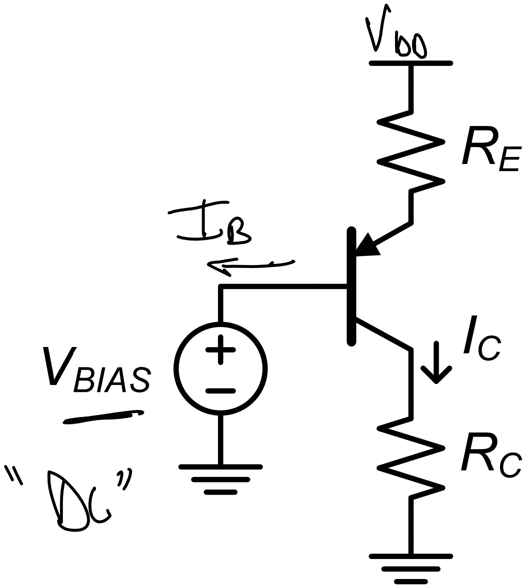
$$V_C = (I_B + \beta_F I_B) R_C = \left(\frac{I_C}{\beta_F} + I_C\right) R_C = \frac{\beta_F + 1}{\beta_F} I_C R_C$$

$$V_C = V_{DD} - 0.7 = \frac{\beta_F + 1}{\beta_F} I_C R_C$$

$$I_C = \frac{V_{DD} - 0.7}{\frac{\beta+1}{\beta} R_C} \quad \star \quad = \frac{9.3}{1.01 \cdot 1k} \simeq 9.2mA$$

$$V_{CE} = ? = -0.7 \qquad |V_{CE}| > |V_{CE(sat)}| \quad \text{FAR} \checkmark$$

PNP Large Signal (2)



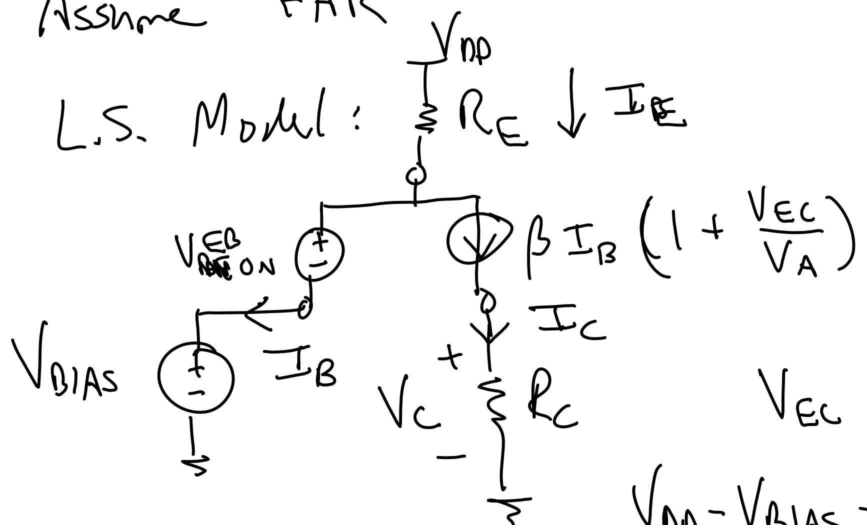
Find expression for IC

1. Choose region of operation
2. Substitute model
3. Find expression for IC

$V_{BIAS} \ll V_{DD}$ PNP = ON FAR/SAT ?

Assume FAR

L.S. Model:



$$V_E = V_{BIAS} + V_{EB(ON)}$$

$$I_E = \frac{V_{DD} - V_E}{R_E} = \frac{V_{DD} - V_{BIAS} - V_{EB(ON)}}{R_E}$$

$$I_E = I_B + \underbrace{\beta I_B \left(1 + \frac{V_{EC}}{V_A}\right)}_{I_C}$$

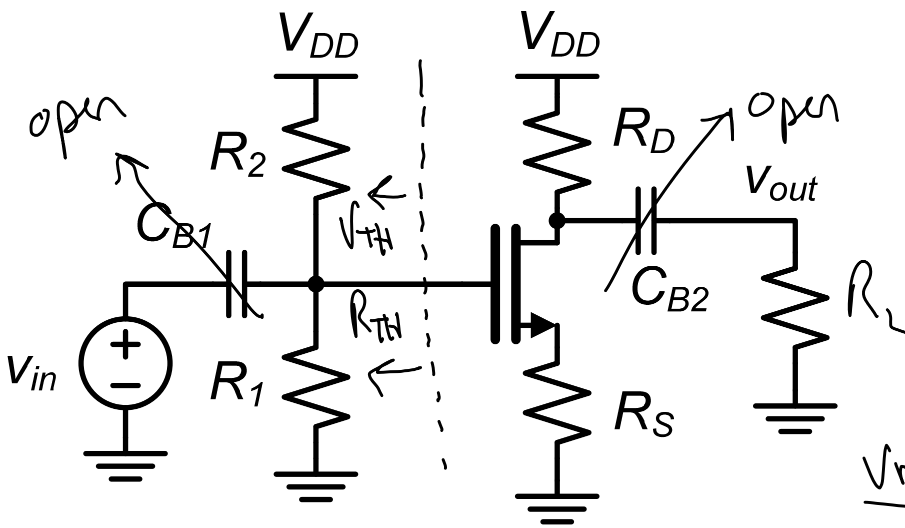
$$I_E = \frac{I_C}{\beta\left(1 + \frac{V_{EC}}{V_A}\right)} + I_C$$

$$V_{EC} = V_E - V_C = \left(V_{BIAS} + V_{EB(ON)}\right) - I_C R_C$$

$$\frac{V_{DD} - V_{BIAS} - V_{EB(ON)}}{R_E} = \frac{I_C}{\beta\left[1 + \frac{(V_{BIAS} + V_{EB(ON)} - I_C R_C)}{V_A}\right]} + I_C$$

Solve for I_C . . .

NMOS DC Model



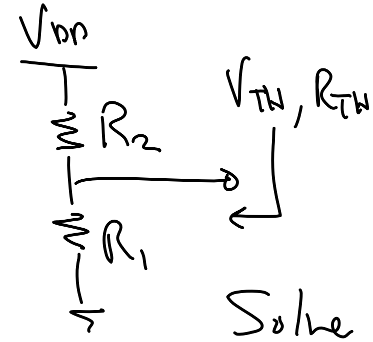
Find expression for ID

1. Choose region of operation
2. Substitute model
3. Find expression for ID

$C_{Bi} = C_{BIG}$

@ DC $C_{BIG} \Rightarrow$ open

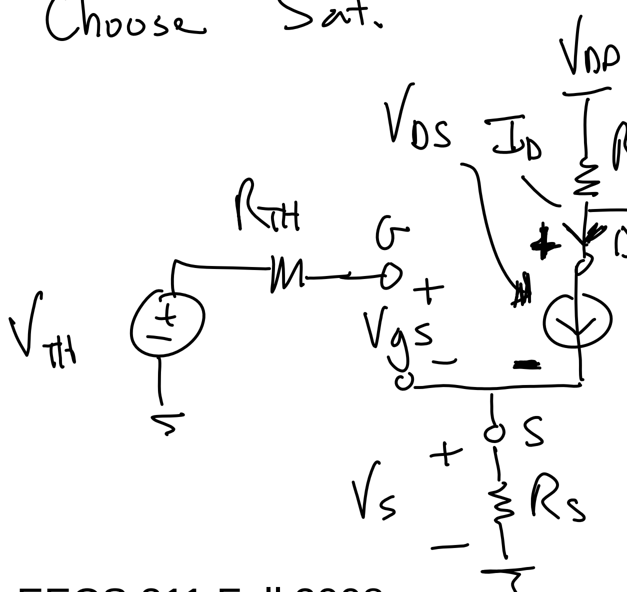
Choose Sat.



$$V_{TH} = V_{DD}\frac{R_1}{R_1+R_2}$$

$$R_{TH} = R_1 \| R_2 = \frac{R_1R_2}{R_1+R_2}$$

Solve for I_D



$I_S = I_D$

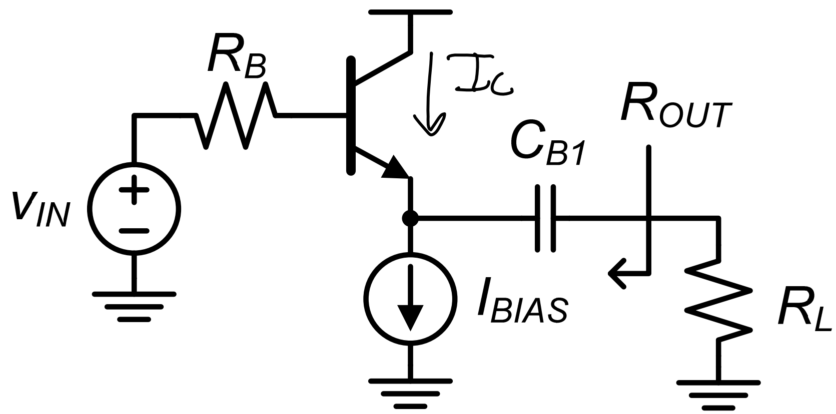
$V_S = I_D R_S$ $\quad V_D = V_{DD} - I_D R_D$ $\quad V_G = V_{TH}$

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{gs}-V_{tn})^2(1+\lambda V_{DS}) = I_D$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\Big[\underbrace{(V_{TH} - I_D R_S)}_{V_{gs}} - V_{TN}\Big]^2\Big[1+\lambda\underbrace{(V_{DD} - I_D R_D - I_D R_S)}_{V_{DS}}\Big]$$

Solve for I_D . . .

NPN Small Signal Rout

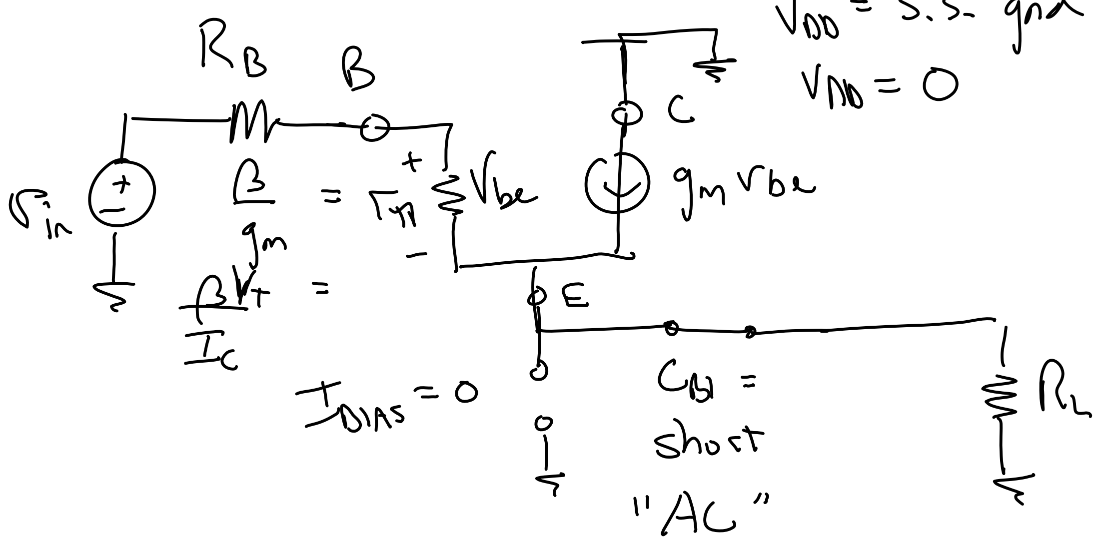


Neglect r_o in BJT model

1. Find small signal AC model
2. Apply test source to measure Rout
3. Rout = vt/it

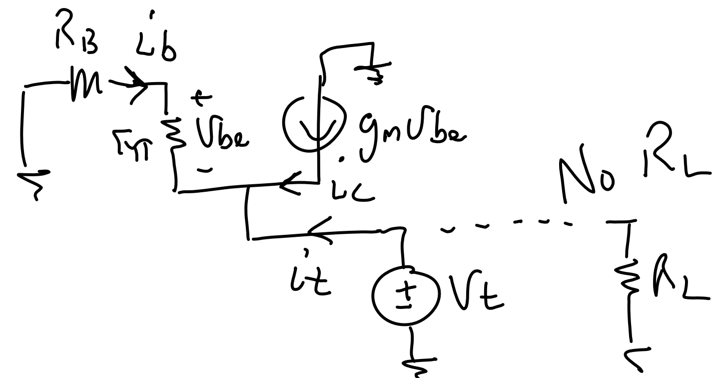
V_{DD} = s.s. gnd

$V_{DD} = 0$



Find R_{OUT}

zero indep. sources (v_{in})



$$v_{be} = -v_t \frac{r_\pi}{r_\pi + R_B} \qquad i_c = g_m\left(-v_t \frac{r_\pi}{r_\pi + R_B}\right)$$

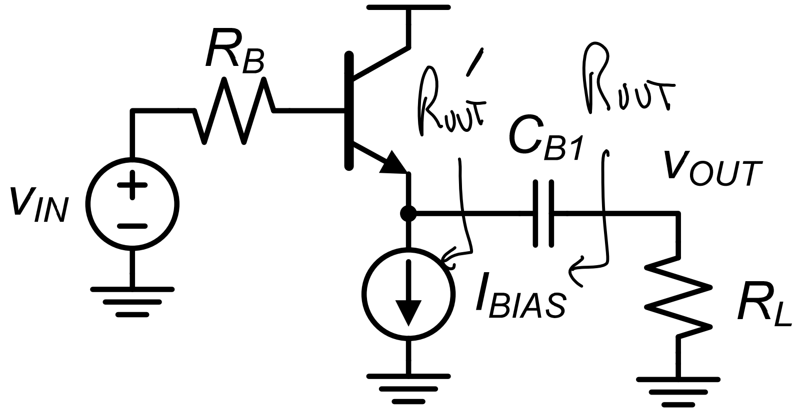
$$i_b = -\frac{v_t}{r_\pi + R_B}$$

$$i_t = -i_b - i_c = +v_t \frac{1}{r_\pi + R_B} + v_t \frac{g_m r_\pi}{r_\pi + R_B}$$

$$R_{OUT} = \frac{v_t}{i_t} = \frac{r_\pi + R_B}{1 + g_m r_\pi} = \frac{r_\pi + R_B}{1 + \beta_F}$$

$$= \frac{r_\pi}{1+\beta_F} + \frac{R_B}{1+\beta_F} \simeq \frac{1}{g_m} + \frac{R_B}{\beta}$$

OCTC to Find f_L



$$R_{OUT}' = \frac{1}{g_m} + \frac{R_B}{\beta} \simeq R_{OUT}$$

OCTC

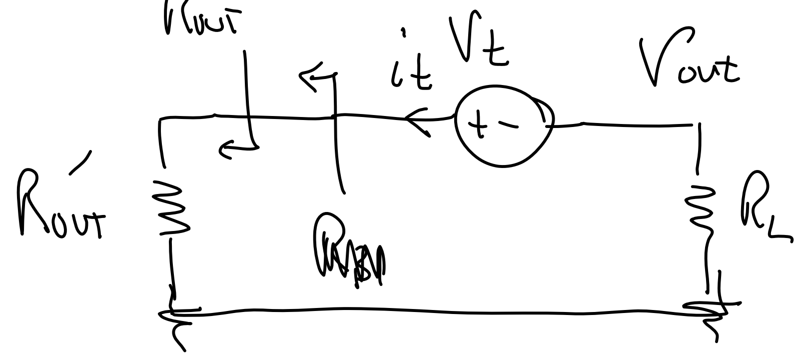
Find R_{B1} for C_{B1}

→ Replace C_{B1} w/ V_t

Neglect r_o in BJT model

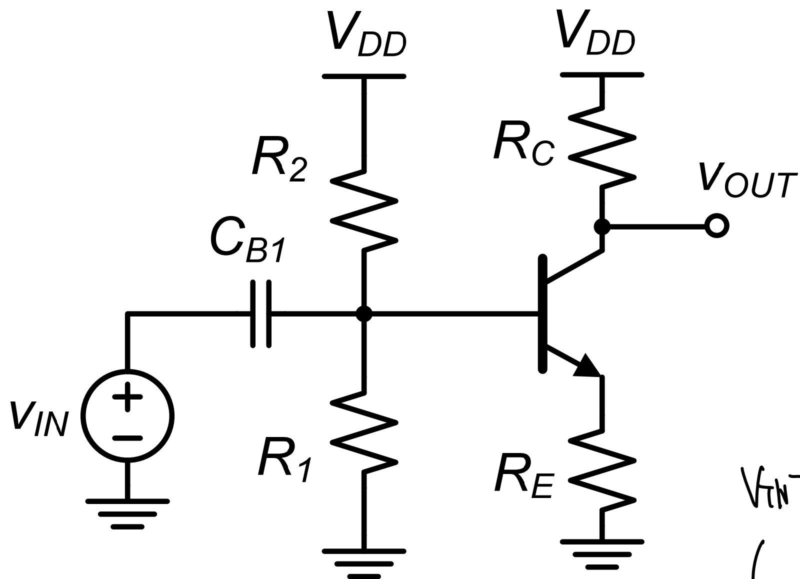
1. Find small signal low-freq model
2. Apply OCTC

Small Sig



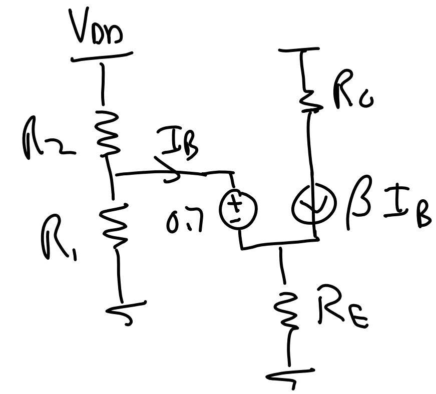
$$R_{B1} = \underbrace{\frac{1}{g_m}}_{\simeq R_{OUT}'} + R_L$$

NPN Design Example (1)



Find relationship between Power, DC bias stability, and gain

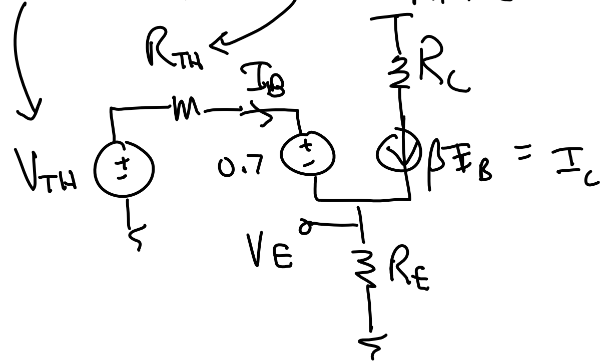
① DC Bias



Assume FAR,

C_{B1} = open

$V_{TH} = V_{DD}\frac{R_1}{R_1+R_2}$ $\quad R_{TH} = \frac{R_1 R_2}{R_1+R_2}$



$$V_E = (I_B+I_C)R_E = \frac{\beta+1}{\beta}I_C R_E$$

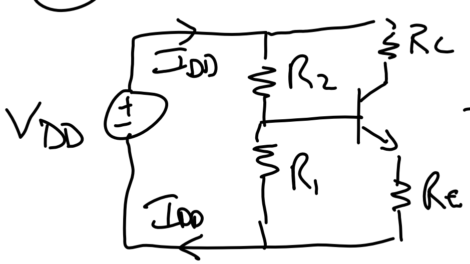
$$I_B = \frac{I_C}{\beta} = \frac{V_{TH}-0.7-V_E}{R_{TH}} = \frac{V_{TH}-0.7-\frac{\beta+1}{\beta}I_C R_E}{R_{TH}}$$

$$I_C = \frac{V_{TH}-0.7}{\frac{R_{TH}}{\beta}+\frac{\beta+1}{\beta}R_E} \simeq \frac{V_{TH}-0.7}{\frac{R_{TH}}{\beta}+R_E}$$

⇒ $\frac{R_{TH}}{\beta} \ll R_E$ ⇒ I_C indep of β

But, small R_{TH} = high power

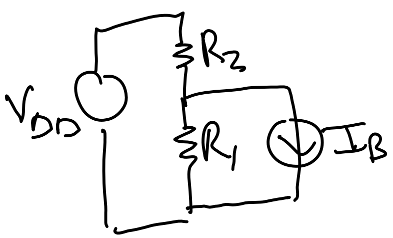
② Power



$P = V_{DD} I_{DD}$

$I_{DD} = I_{R2} + I_C$

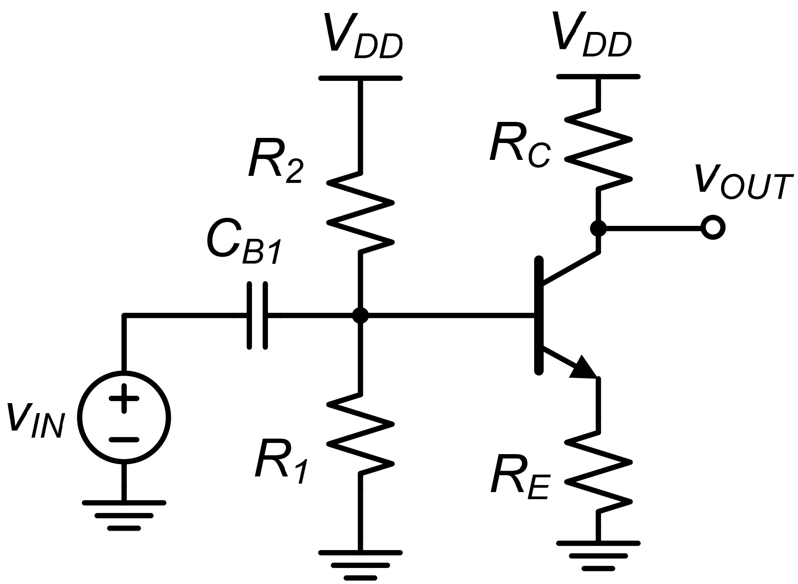
Find I_{R2}:



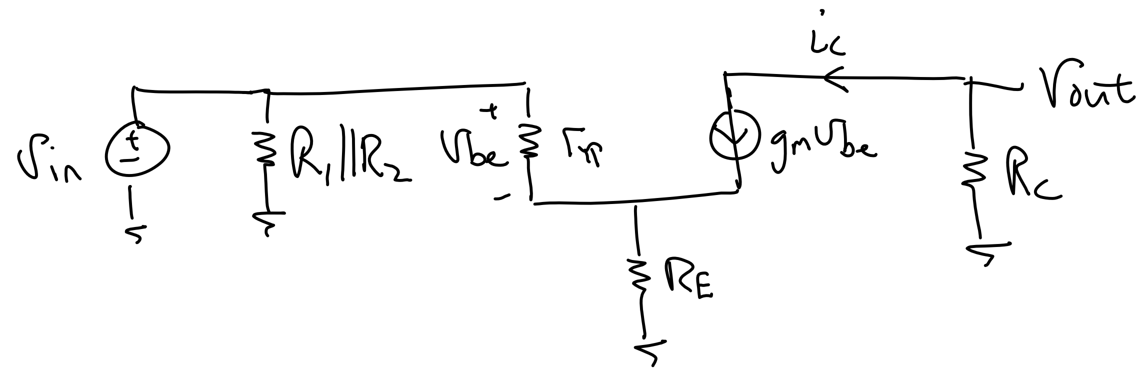
$$I_{R2} = \frac{V_{DD}}{R_1+R_2} + I_B\frac{R_1}{R_1+R_2} = \frac{V_{DD}}{R_1+R_2} + \frac{I_C}{\beta}\frac{R_1}{R_1+R_2}$$

$$P = \frac{V_{DD}^2}{R_1+R_2} + V_{DD}I_C\left[1+\frac{1}{\beta}\frac{R_1}{R_1+R_2}\right]$$

NPN Design Example (2)



S.S. AC model: C_{B1} = short



$$v_e = i_e R_E = \left(\frac{v_{be}}{r_\pi} + g_m v_{be}\right) R_E \qquad v_{be} = v_{in} - v_e$$

$$v_{be} = v_{in} - v_{be} R_E\left(\frac{1}{r_\pi} + g_m\right) \qquad v_{be} = \frac{v_{in}}{1 + R_E\left(\frac{1}{r_\pi} + g_m\right)}$$

$$i_c = g_m v_{be} = v_{in} \frac{g_m}{1 + g_m R_E + \underbrace{\frac{R_E}{r_\pi}}_{\frac{R_E g_m}{\beta}}} \simeq v_{in} \frac{g_m}{1 + g_m R_E}$$

$$v_{out} = -i_c R_C = v_{in} \frac{g_m R_C}{1 + g_m R_E}$$

For $I_C \simeq I_E$

$$\frac{v_{out}}{v_{in}} = -\frac{g_m R_C}{1 + g_m R_E} \simeq -\frac{V_{RC}/V_T}{1 + V_{RE}/V_T}$$

<u>Gain independent of power!</u>