ECE 511 - Lecture 24

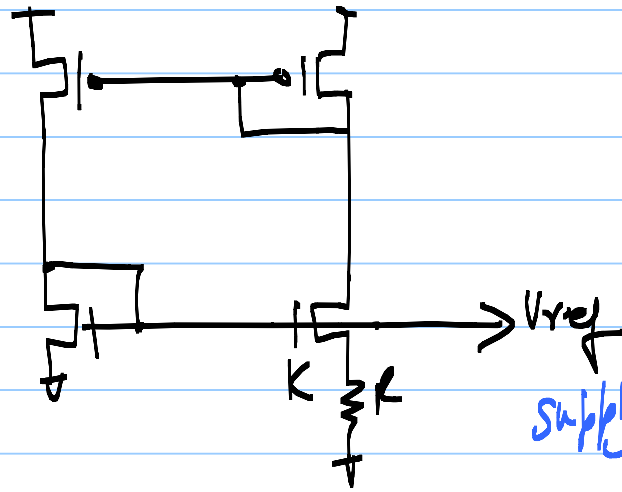
Note Title 4/30/2012

Bandgap References (chapter 25)

BMR

Spectre $\Rightarrow$ DC sweep

↳ Temperature



$T \uparrow$

$-25^\circ C \rightarrow 100^\circ C$

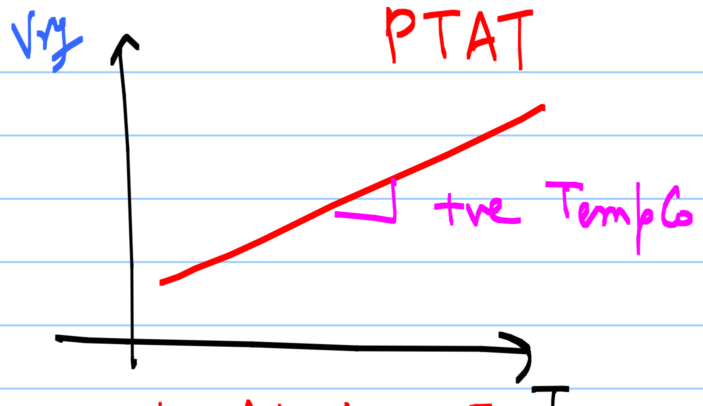
supply independent reference voltage

$$I_{ref} = \frac{2}{\beta R^2}\left(1 - \frac{1}{\sqrt{K}}\right)^2, \quad V_{ref} = \frac{2}{\beta R}\left(1 - \frac{1}{\sqrt{K}}\right) + V_{THN}$$

↳ Not constant with T

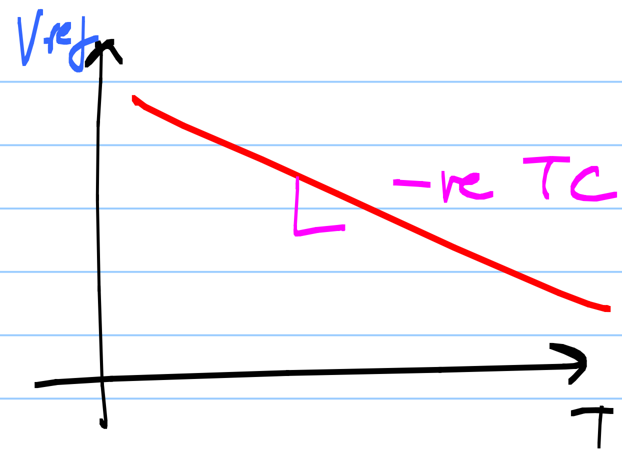
Voltage Reference

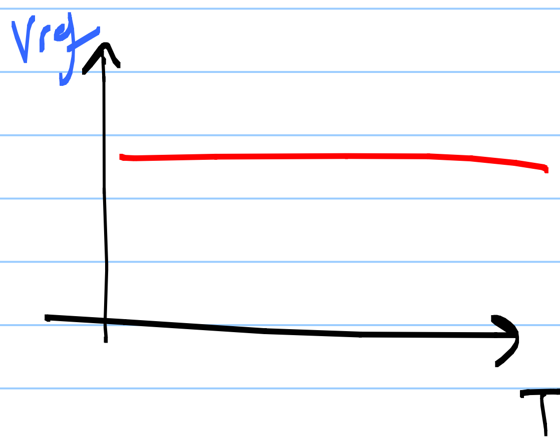
PTAT



prop. to Absolute Temperature

CTAT





ZTC

zero Temp Co $\Rightarrow \dfrac{\partial V_{ref}}{\partial T} = 0$

$$V_{ref} = \alpha_1 V_1 + \alpha_2 V_2$$

V_1: PTAT

V_2: CTAT

$\leftarrow$ ZTC

Temp. indep Ref

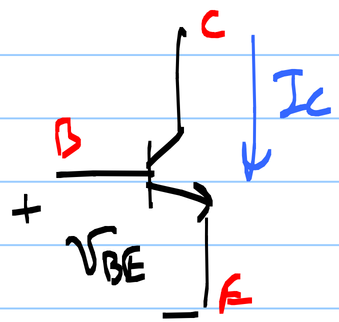
Goal: $\dfrac{\partial V_{ref}}{\partial T} = 0 \Rightarrow \alpha_1 \underbrace{\dfrac{\partial V_1}{\partial T}} + \alpha_2 \underbrace{\dfrac{\partial V_2}{\partial T}} = 0$

ZTC

$\alpha_1, \alpha_2 = ?$

$\dfrac{\partial V_1}{\partial T}, \dfrac{\partial V_2}{\partial T} \Leftarrow$ may not be constant

① CTAT $\Leftarrow$ −ve Tc Voltage



npn BJT

$$I_c \simeq I_s e^{\frac{V_{BE}}{nV_T}} \longrightarrow ①$$

$V_T \Leftarrow \frac{KT}{q}$

26 mV @ T=300K

$n=1$

$$I_s \propto \mu k T n_i^2$$

$$n_i^2 \propto T^3 e^{-E_g/kT}$$

Bandgap Energy of Si

$$\mu = \mu_0 T^m, \quad m = -\frac{3}{2}$$

$$\boxed{I_s = b\, T^{(4+m)} e^{-E_g/kT}} \longrightarrow ②$$

@ I_c

$$v_{BE} = V_T \ln\left(\frac{I_c}{I_s}\right)$$

$$\frac{\partial v_{BE}}{\partial T} = \frac{\partial V_T}{\partial T} \ln\left(\frac{I_c}{I_s}\right) - \boxed{\frac{V_T}{I_s} \cdot \boxed{\frac{\partial I_s}{\partial T}}} \longrightarrow 3$$

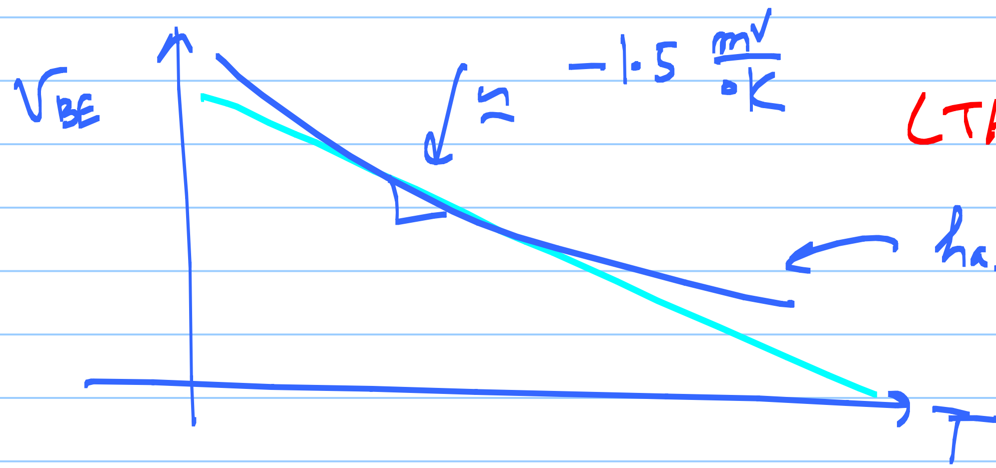
$$\frac{\partial I_s}{\partial T} = \frac{(4+m)}{T} \cdot I_s + I_s \cdot \frac{E_g}{kT^2}$$

$$\Rightarrow \boxed{\frac{V_T}{I_s} \cdot \frac{\partial I_s}{\partial T}} = (4+m)\frac{V_T}{T} + \frac{E_g}{kT^2} \cdot V_T \longrightarrow 4$$

$$\frac{\partial V_{BE}}{\partial T} = \frac{V_T}{T}\ln\left(\frac{I_c}{I_s}\right) - (4+m)\frac{V_T}{T} - \frac{E_g}{kT^2}\cdot V_T$$

V_{BE}

$$\boxed{\frac{\partial V_{BE}}{\partial T} = \frac{V_{BE} - (4+m)V_T - \frac{E_g}{q}}{T}} \rightarrow (5)$$

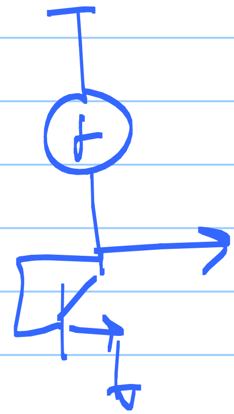


CTAT

has a curvature

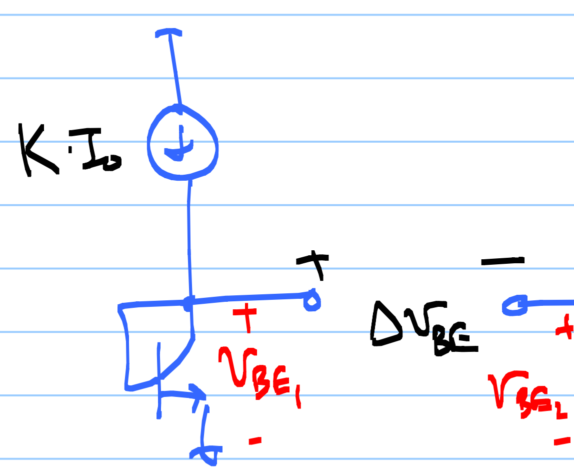
$V_{BE} \Rightarrow$ not a linear CTAT

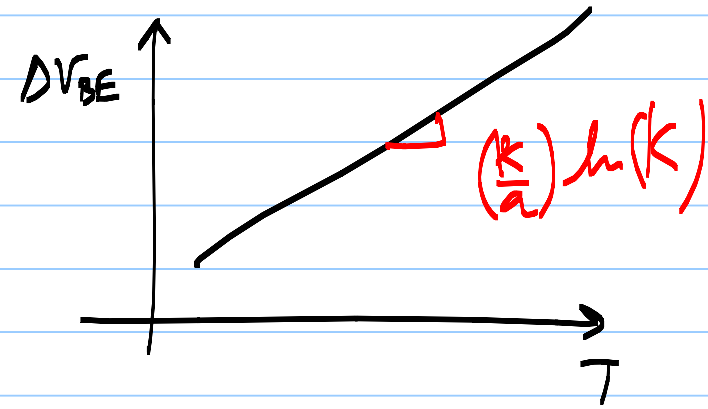
↳ can't make a perfect ZTC at all Temp.



$V_{BE} \leftarrow$ CTAT

② PTAT ⇒ +ve TC





$$\Delta V_{BE} = V_{BE_1} - V_{BE_2}$$

$$= V_T \ln\left(\frac{K I_0}{I_S}\right) - V_T \ln\left(\frac{I_0}{I_S}\right)$$

$$= V_T \ln\left(\frac{K \cancel{I_0}}{\cancel{I_0}}\right) = \boxed{V_T \ln(K)} = \left(\frac{k}{q}\ln K\right) T$$

"Bandgap Reference" (BGR)

$$\underline{\underline{V_{ref}}} = \alpha_1 \underbrace{V_{BE}}_{CTAT} + \alpha_2 \underbrace{(V_T \ln K)}_{PTAT}$$

$$\frac{\partial V_{BE}}{\partial T} = -1.5 \frac{mV}{°K} \qquad \frac{\partial V_T}{\partial T} = \frac{k}{q} = +0.087 \frac{mV}{°K}$$

$\alpha_1, \alpha_2 = ??$

$$\frac{\partial V_{ref}}{\partial T} = 0$$

$$\alpha_1 \cdot \frac{\partial V_{BE}}{\partial T} + \alpha_2 \frac{\partial}{\partial T}\left(V_T \ln K\right) = 0$$

$$\Rightarrow \qquad \alpha_2 \ln(K) = \frac{-\alpha_1 \cdot \frac{\partial V_{BE}}{\partial T}}{k/q}$$

$$= \frac{\alpha_1 \cdot 1.5 \frac{mV}{^\circ K}}{0.087 \frac{mV}{^\circ K}}$$

$$\boxed{\alpha_2 \ln(K) = 17.2\ \alpha_1}$$

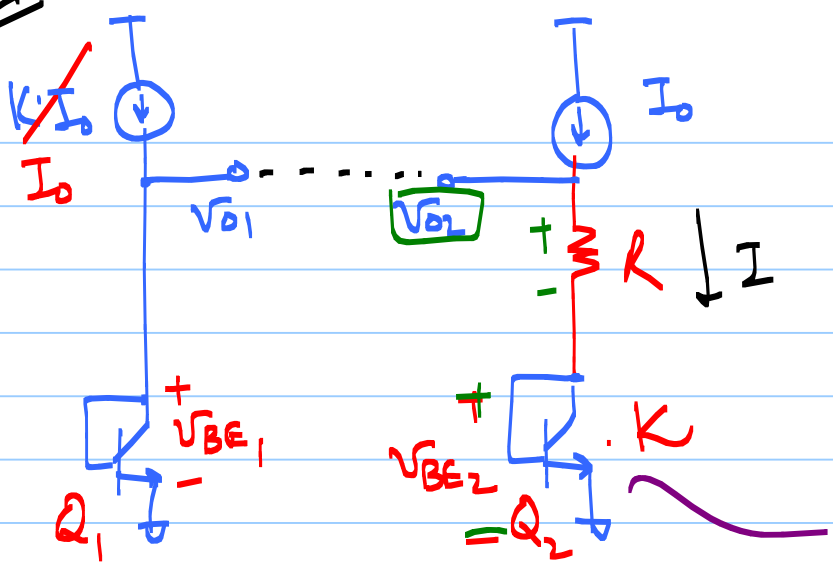
choose $\underline{\alpha_1 = 1}$

$\Rightarrow$ $\boxed{\alpha_2 \ln(K) \simeq 17.2}$

$$V_{ref} = \alpha_1 V_{BE} + \alpha_2 (V_T \ln K)$$

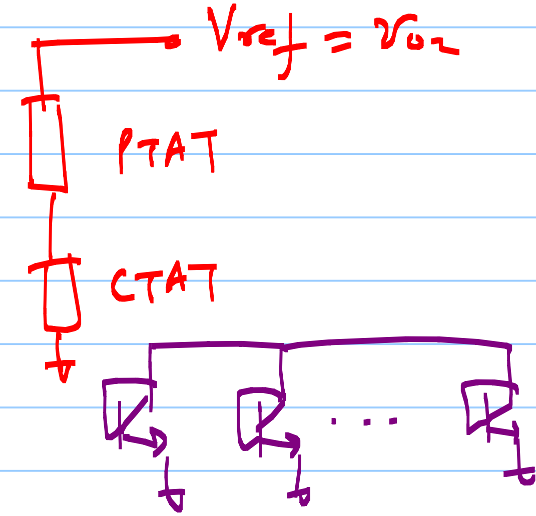
$$\boxed{V_{ref} = V_{BE} + 17.2 \times V_T} \Rightarrow \frac{\partial V_{ref}}{\partial T} = 0$$

Example#1



PTAT

$v_{o1} - v_{o2}$



K devices "in parallel"

Somehow force $v_{o1} = v_{o2}$

$$v_{BE_1} = IR + v_{BE_2}$$

$$IR = v_{BE_1} - v_{BE_2} = \underline{v_T \ln(K)}$$

$$V_{o2} = V_{BE_2} + IR$$

$$= \underbrace{V_{BE_2}}_{\text{CTAT}} + \underbrace{V_T \ln(K)}_{\text{PTAT}}$$

For V_{o2} to ZTC reference

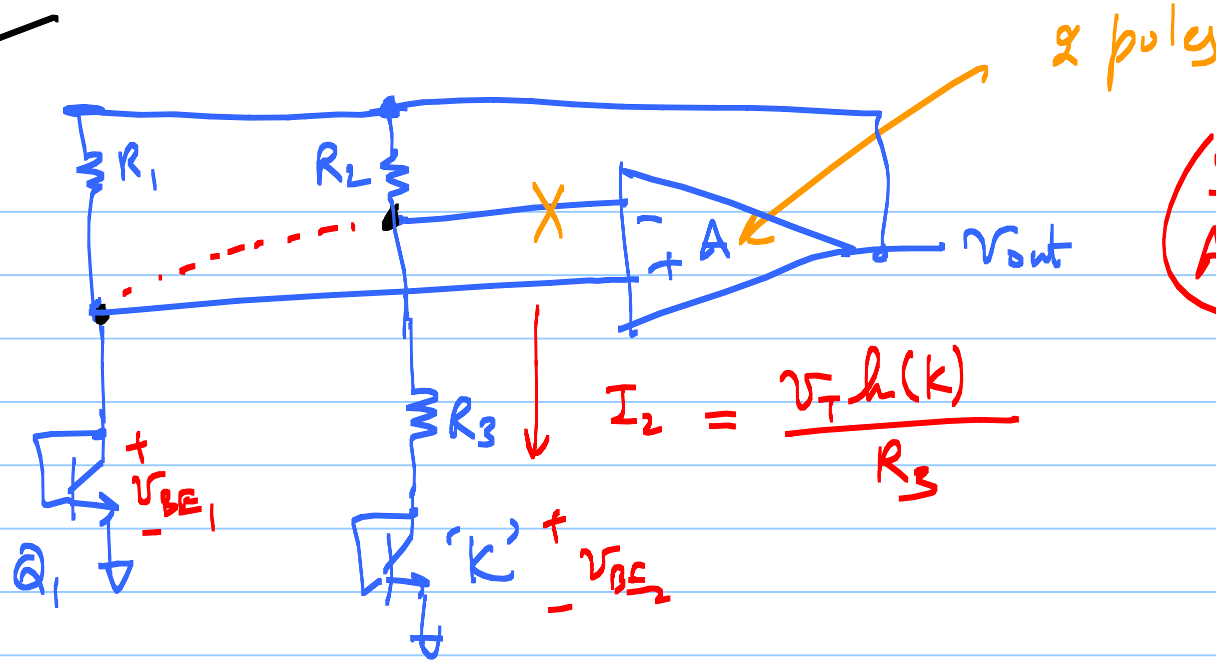
$$\ln(K) = 17.2$$

$$K = e^{17.2} = (2.78)^{17.2}$$

"Impractical"

$$\boxed{K_2 = 1}$$

Example #2



$$I_2 = \frac{v_T \ln(K)}{R_3}$$

(STB Analysis)

$$v_{out} = v_{BE_2} + I_2 \cdot (R_2 + R_3)$$

$$= v_{BE_2} + v_T \ln(K) \left[1 + \frac{R_2}{R_3}\right]$$

$\alpha_2 > 1$

for $\frac{\partial V_{out}}{\partial T} = 0 \Rightarrow$

$$\alpha_2 \cdot \ln(K) = 17.2$$

$$\left(1 + \frac{R_2}{R_3}\right) \ln(K) = 17.2$$

$$\frac{R_2}{R_3} = 4 \Rightarrow K = 31$$

* Why Bandgap Reference ??

$$V_{REF} = V_{BE} + \boxed{V_T \ln(K)}$$

$$\Rightarrow \frac{\partial V_{REF}}{\partial T} = \frac{\partial V_{BE}}{\partial T} + \frac{V_T}{T}\ln(K) = 0$$

$$\Rightarrow \frac{V_{BE} - (4+m)V_T - E_g/q}{T} = -\frac{V_T}{T}\ln(K)$$

$$\Rightarrow V_{Ref} = \cancel{V_{BE}} - \cancel{V_{BE}} + (4+m)V_T + E_g/q$$

$$\boxed{V_{REF} = \frac{E_g}{q} + (4+m)V_T}$$

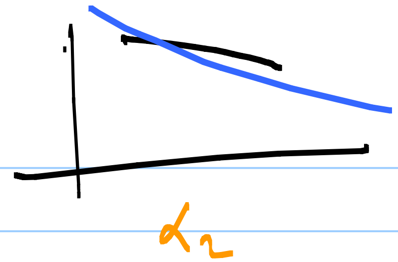
ZTC voltage $\Rightarrow$ Bandgap voltage of the Si $\left(\frac{E_g}{q}\right)$

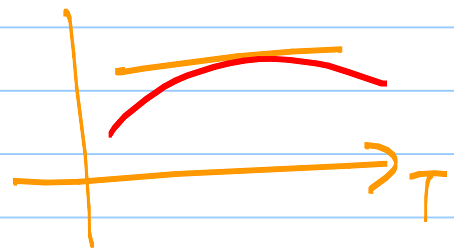
$\Rightarrow$ m & V_T

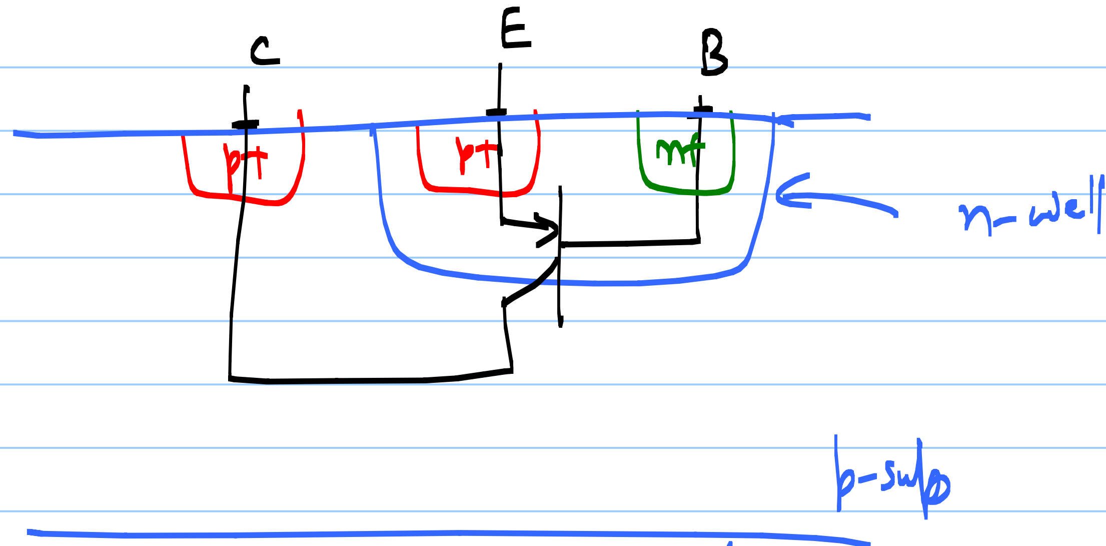
If $T \rightarrow 0 \Rightarrow V_{REF} \longrightarrow \frac{E_g}{q} \Rightarrow 1.12\ V$

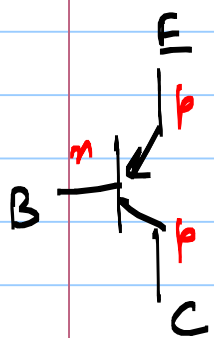
"Bandgap Reference"

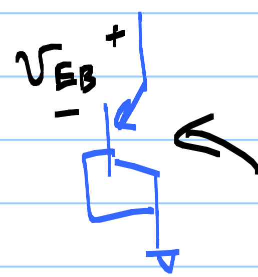

α_1


α_2


T

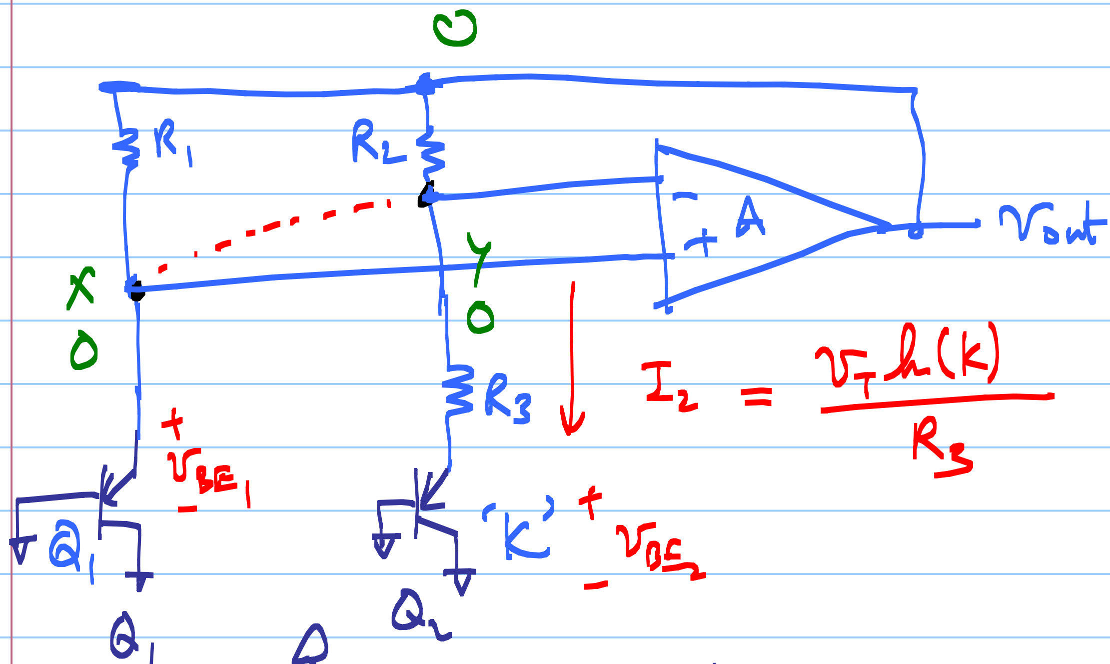






Diode connected pnp BJT

"β"

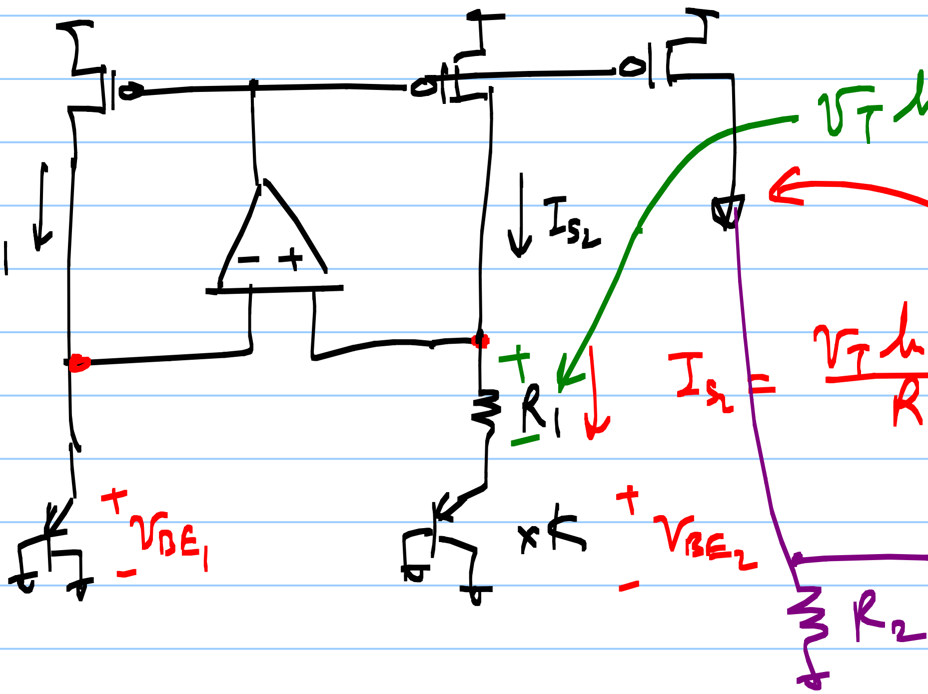


$$I_2 = \frac{v_T \ln(K)}{R_3}$$

need a startup circuit

parasitic npn diodes

Practical BGR Circuits



$V_T \ln(K) \in$ PTAT

$I_{S_2} = \frac{V_T \ln K}{R_1}$

$\frac{PTAT}{R}$ current

$\frac{PTAT}{R_1} \times R_2 = \frac{R_2}{R_1} \cdot V_T (\ln K)$