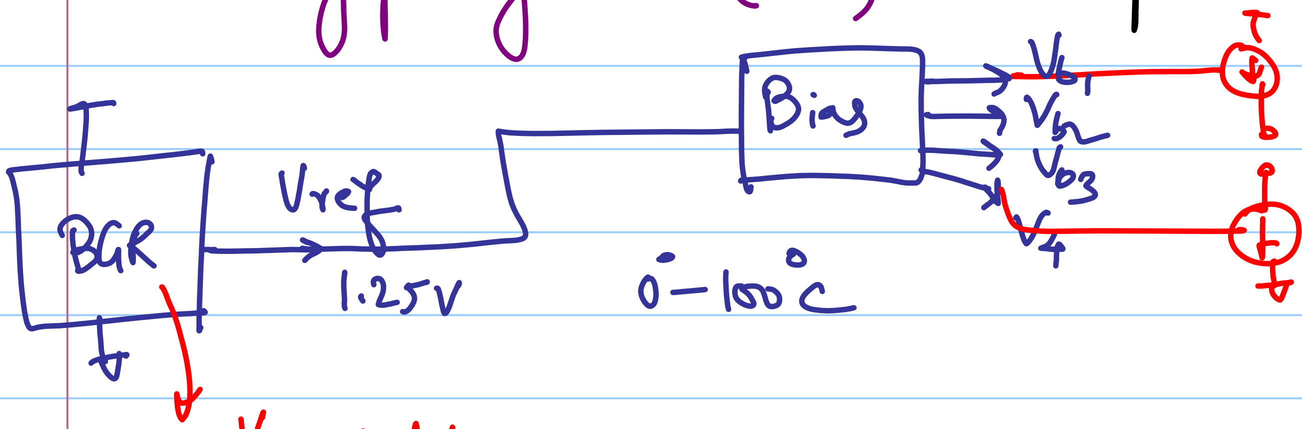
ECE 511 - Lecture 27

Note Title 5/6/2014

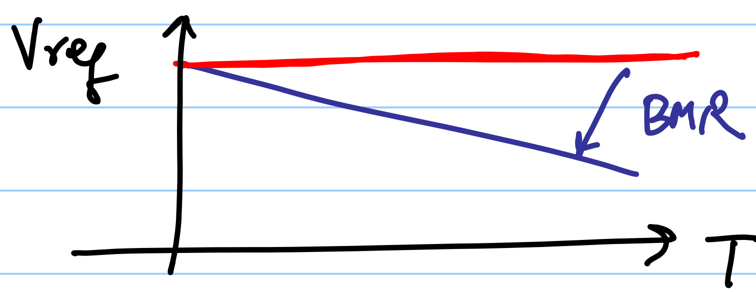
Bandgap Reference (BGR) → Temp Independent reference



V_{DD} indep

Temp indep

Temperature Coefficient (TempCo)

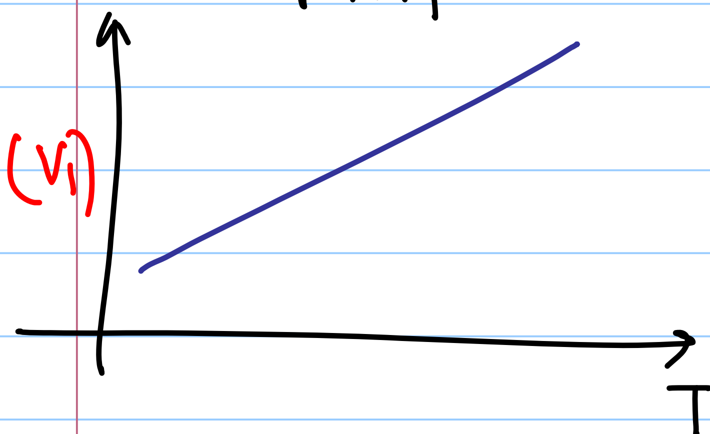


$$\text{TempCo} = \left(\frac{\partial V_{ref}}{\partial T}\right) \cdot \frac{1}{V_{ref}}$$

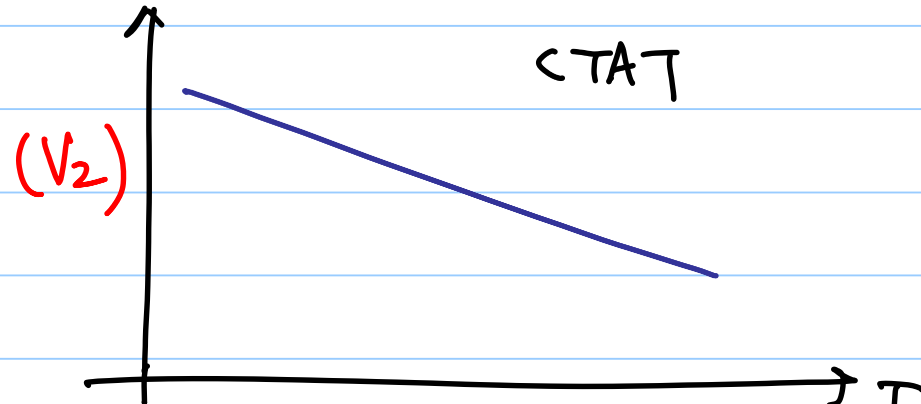
zero

Zero Temp Coeff (ZTC)

PTAT

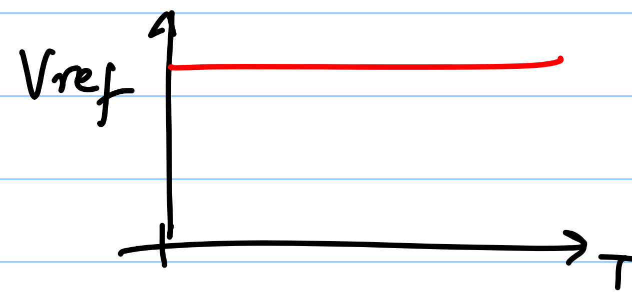


proportional to absolute Temp.



Complementary to the 'T'

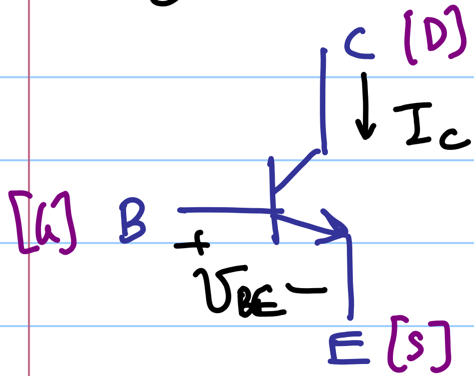
Combine PTAT & CTAT



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

$$\frac{\partial V_{ref}}{\partial T} = \alpha_1 \left(\frac{\partial V_1}{\partial T} \right) + \alpha_2 \left(\frac{\partial V_2}{\partial T} \right) = 0 \qquad \text{"ZTC"}$$

① Negative TempCo (CTAT)



$$I_C = \underbrace{I_S}\, e^{\frac{\eta V_{BE}}{V_T}} \to ①$$

$$V_T = \frac{kT}{q} \to 26\,mV \ @ \ 27\,°C$$

$$I_S \propto \mu k T \cdot n_i^2$$

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

E_g is the Bandgap energy

Si → 1.12 eV

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

$$I_S = b \cdot T^{(4+m)} \cdot e^{-E_g/kT} \to ②$$

from ①:

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right).$$

Compute TempCo V_{BE} for fixed I_C

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

from (2)

$$\frac{\partial I_s}{\partial T} = b(4+m)\,T^{3+m}\,e^{-E_g/kT} + bT^{4+m} \cdot e^{-E_g/kT} \cdot \frac{E_g}{kT^2}$$

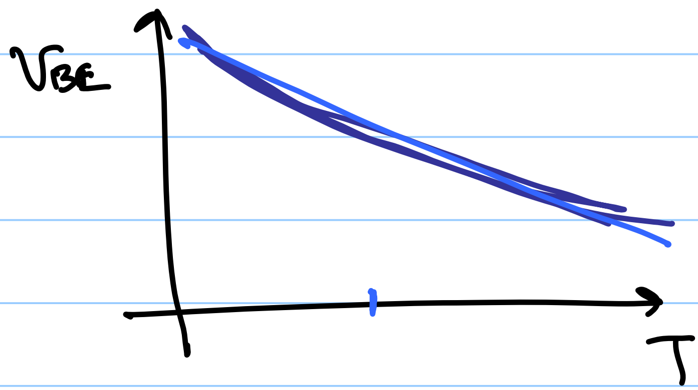
$$= \frac{(4+m)}{T} \underbrace{bT^{4+m}\,e^{-E_g/kT}}_{I_s} + \underbrace{bT^{4+m}\,e^{-E_g/kT}}_{I_s} \cdot \frac{E_g}{kT^2}$$

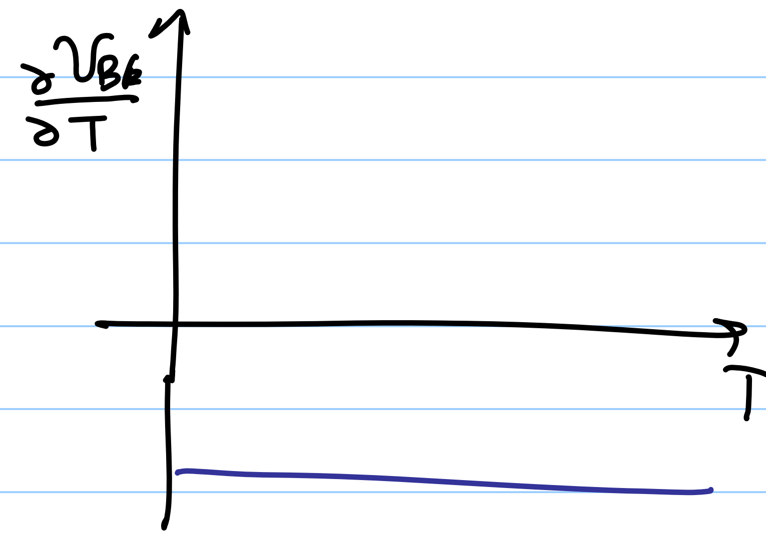
$$= \frac{(4+m)}{T} I_s + I_s \cdot \frac{E_g}{kT^2}$$

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

plug (4) into (3)

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



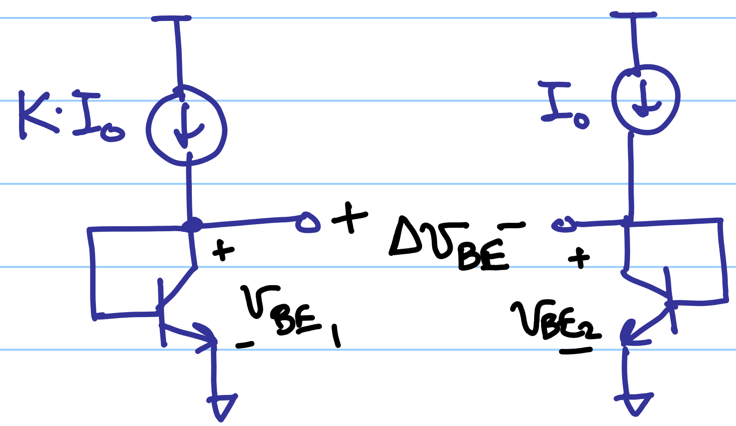


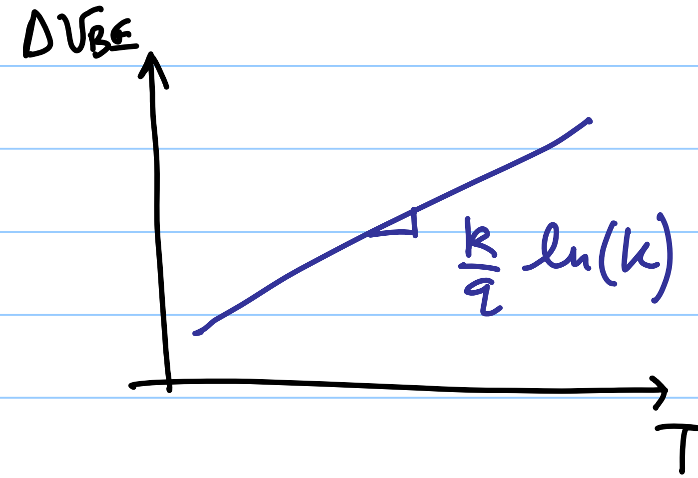
'V_{BE} itself is a CTAT'

* Since $\frac{\partial V_{BE}}{\partial T}$ itself depends on V_{BE} & T

↳ not a linear CTAT

② Positive TempCo (PTAT)





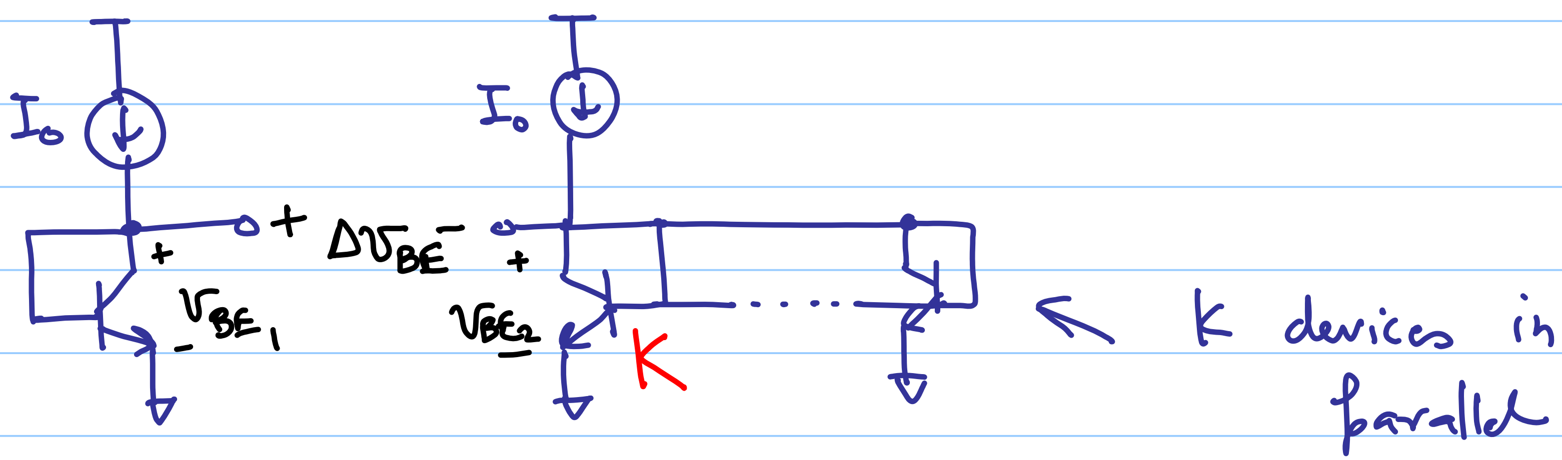
$$\Delta V_{BE} = V_{BE_1} - V_{BE_2}$$

$$= V_T \ln\left(\frac{K I_0}{I_S}\right) - V_T \ln\left(\frac{I_0}{I_S}\right) \quad , \underbrace{I_{S_1} = I_{S_2}}$$

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

$$= V_T \ln K$$

$$\frac{\partial \Delta v_{BE}}{\partial T} = \left(\frac{k}{q}\right) \ln(K) > 0$$



$$\Delta v_{BE} = v_T \ln\left(\frac{I_o}{I_s}\right) - v_T \ln\left(\frac{I_o/K}{I_s}\right)$$

$$= v_T \ln K$$

Need to design this

$$V_{ref} = \underbrace{\alpha_1 V_{BE}}_{CTAT} + \underbrace{\alpha_2 \Delta V_{BE}}_{PTAT} \qquad \Delta V_{BE} \rightarrow kT \ln(K)$$

$$\text{ZTC} \Rightarrow \frac{\partial V_{ref}}{\partial T} = 0$$

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

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

$\frac{\partial V_{BE}}{\partial T}$: $-1.5\ mV/°K$ CTAT

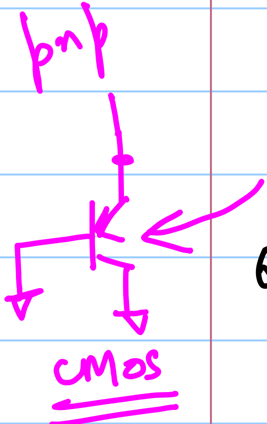
$\frac{k}{q} = +0.087\ mV/°K$ PTAT

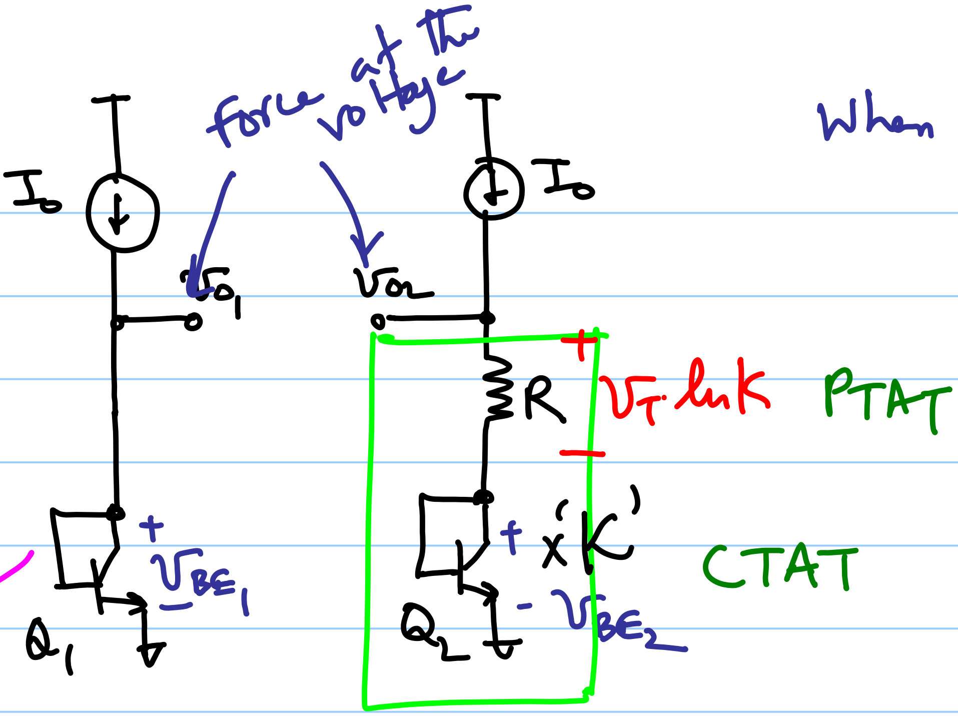
$$\alpha_2 \cdot \ln(K) = 17.2 \times \alpha_1$$

choose $\alpha_1 = 1$

$$\boxed{\alpha_2 \ln K = 17.2}$$

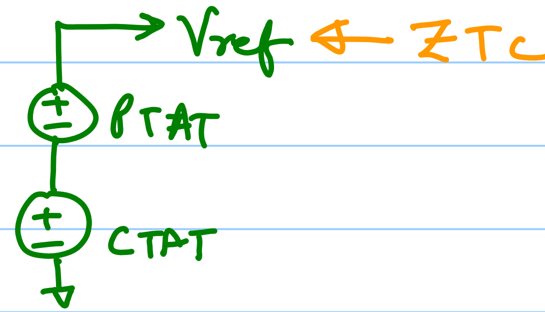
$$\boxed{V_{ref} = V_{BE} + 17.2 \times V_T} \rightarrow \text{Typical value } 1.25\ V$$





When $V_{o_1} = V_{o_2}$

$$IR = V_{BE_1} - V_{BE_2} = V_T \ln K$$



$$V_{o_2} = IR + V_{BE_2}$$

$$= V_{BE_2} + V_T \ln K$$

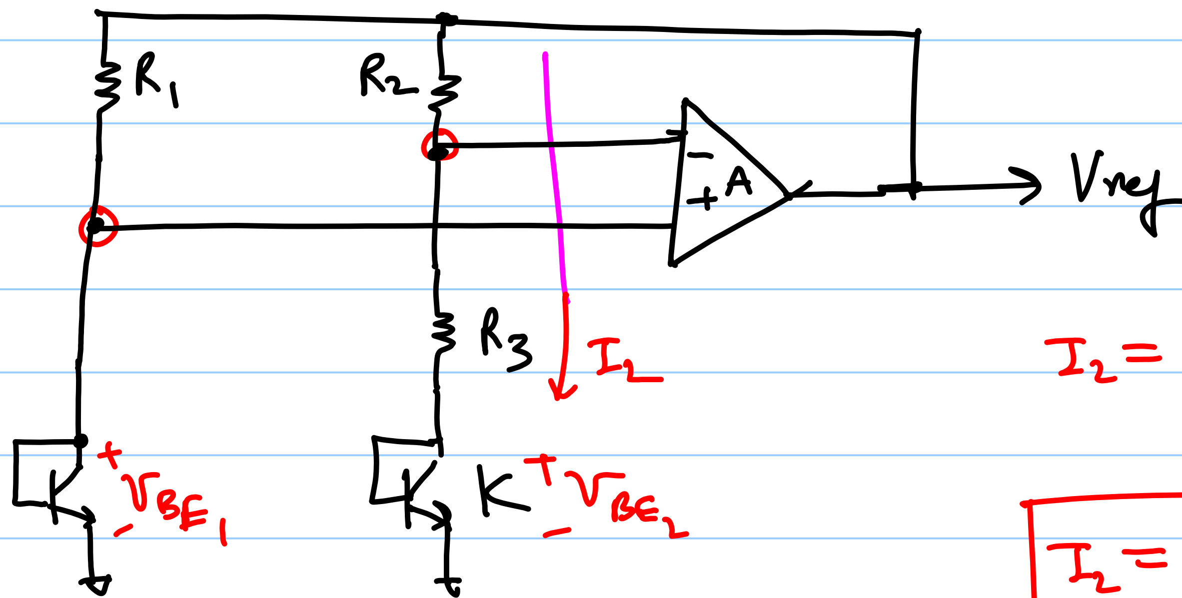
Note that $\alpha_1 = \alpha_2 = 1$

for $\dfrac{\partial V_{o_2}}{\partial T} = 0 \Rightarrow \cancel{\alpha_2}^{\,1} \ln K = 17.2$

$\Rightarrow K = e^{17.2}$ X

$\Rightarrow$ We need a large $\alpha_2 > 1$

Example BGR:



$$I_2 = \frac{v_{BE_1} - v_{BE_2}}{R_3}$$

$$\boxed{I_2 = \frac{v_T \ln K}{R_3}}$$

$$V_{ref} = v_{BE_2} + \left(\frac{v_T \ln K}{R_3}\right)(R_2 + R_3)$$

$$= \underbrace{v_{BE_2}}_{CTAT} + \underbrace{\left(1 + \frac{R_2}{R_3}\right)}_{\alpha_2 > 1} \underbrace{v_T \ln K}_{PTAT}$$

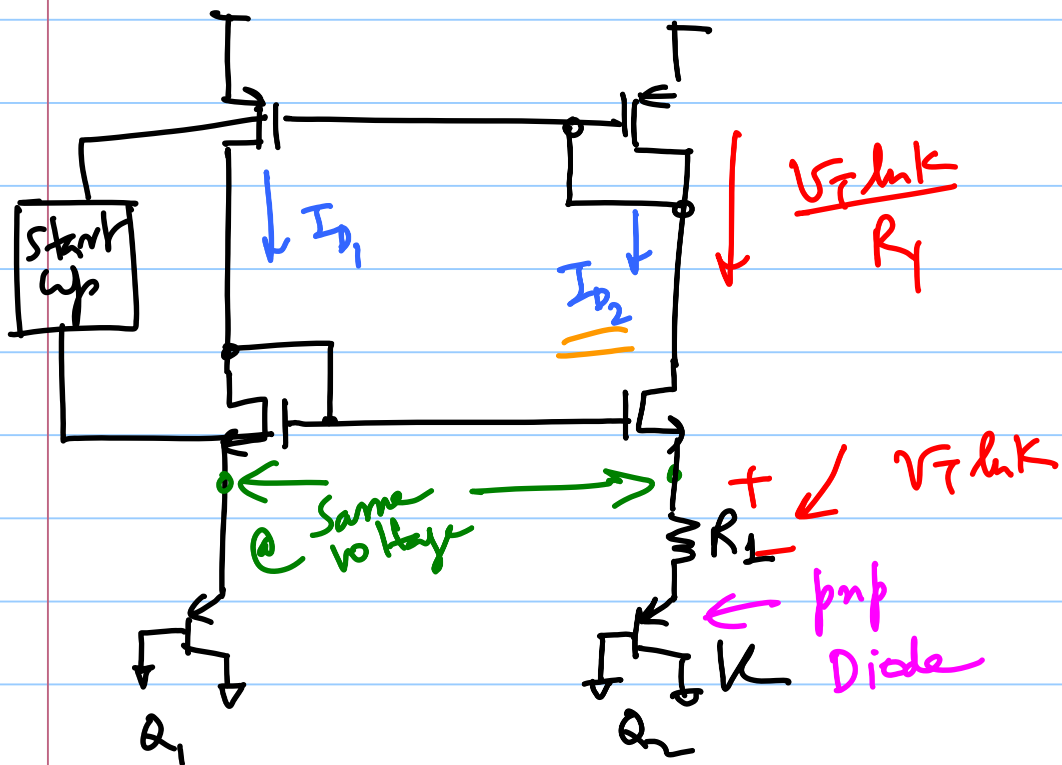
Example

$\alpha_2 \ln K = 17.2$

$\Rightarrow$

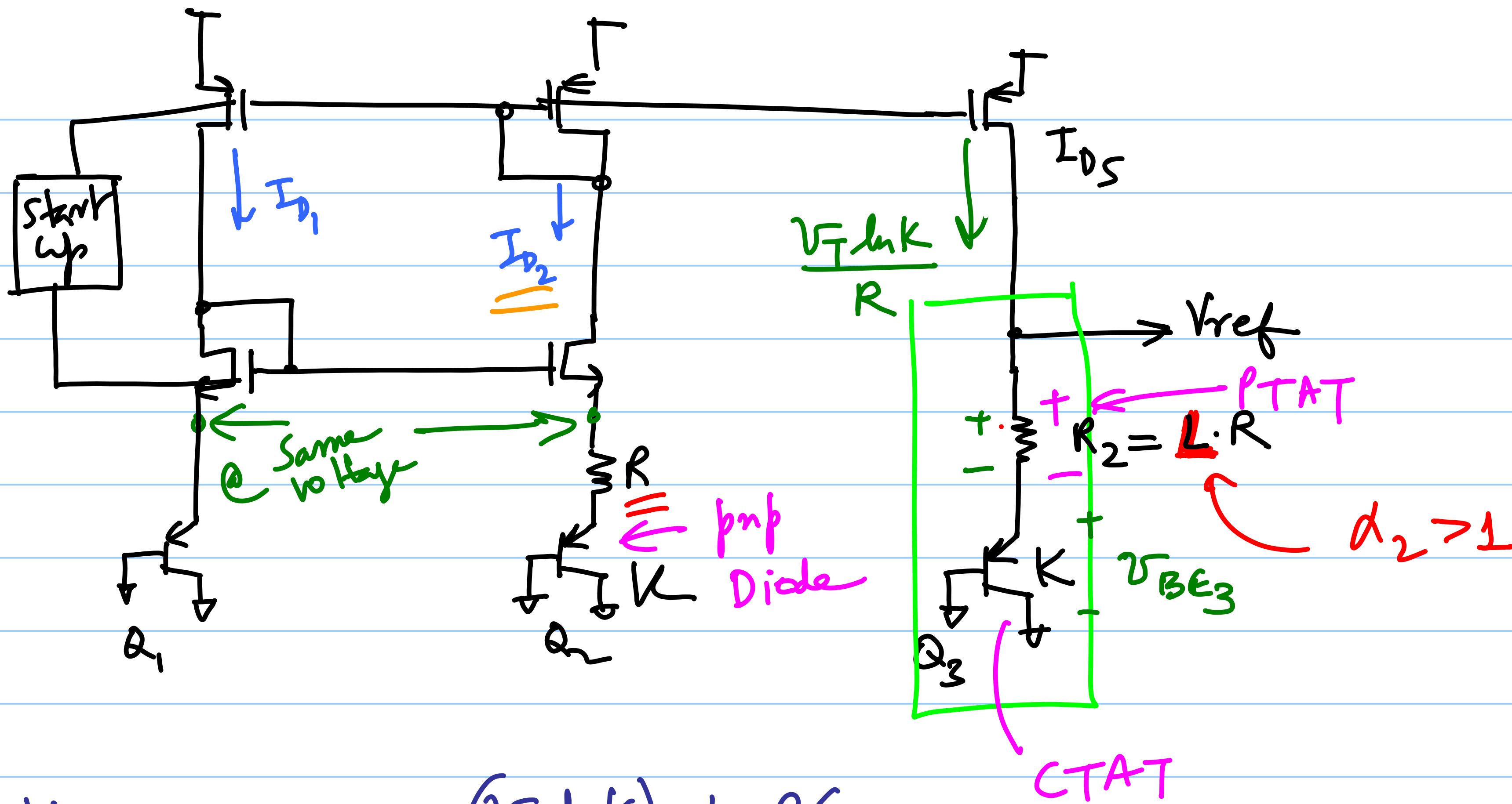
$K = 31$ & $\frac{R_2}{R_3} = 4$

"∞ solutions"



$$I_{D_1} = I_{D_2} = \frac{V_T \ln K}{R}$$

$$\frac{PTAT}{R}$$



$$V_{ref} = v_{BE_3} + \left(\frac{V_T \ln K}{\cancel{R}}\right) \cdot L \cdot \cancel{R}$$

$$V_{ref} = \underbrace{v_{BE_3}}_{\text{CTAT}} + \underbrace{L}_{\alpha_2 > 1} \cdot \underbrace{V_T \ln K}_{\text{PTAT}}$$

Ex. $K = 8$,

$$L = \frac{17.2}{\ln(8)} \simeq 8.4834$$