15-3-13

Lec 38

Bandgap Reference

* Create V/I that is independent of P, V, T variations

$$V = \alpha_1 V_1 + \alpha_2 V_2$$

$$\frac{\partial V}{\partial T} = 0 \Rightarrow \alpha_1 \underbrace{\frac{\partial V_1}{\partial T}}_{-ve\ T.C.} + \alpha_2 \underbrace{\frac{\partial V_2}{\partial T}}_{+ve\ T.C.} = 0$$

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) \quad ; \quad V_t = \frac{kT}{q}$$

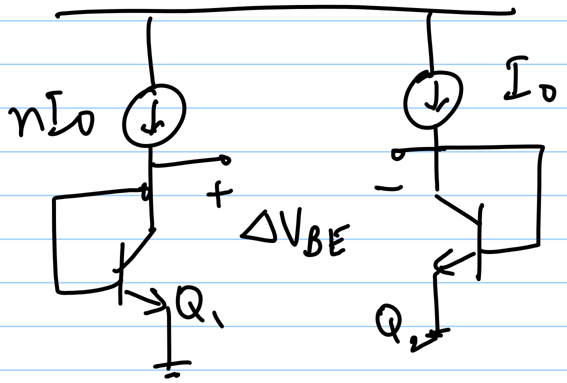
$$\frac{\partial V_{BE}}{\partial T} = \frac{(4+m)}{T} I_S + \frac{E_g}{kT^2} \cdot I_S$$

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

$V_{BE} = 0.75V$, $T = 300k$,

$$\frac{\partial V_{BE}}{\partial T} \approx -1.5 mV/K$$

positive TC



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

$$= V_t \ln\left(\frac{nI_0}{I_s}\right) - V_t \ln\left(\frac{I_0}{I_s}\right)$$

$$= V_t \ln(n)$$

$$\frac{\partial}{\partial T}(\Delta V_{BE}) = \frac{k}{q}\ln(n) \quad (\text{+ve temp co})$$

$$\frac{k}{q} = 0.087\, mV/K$$

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

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

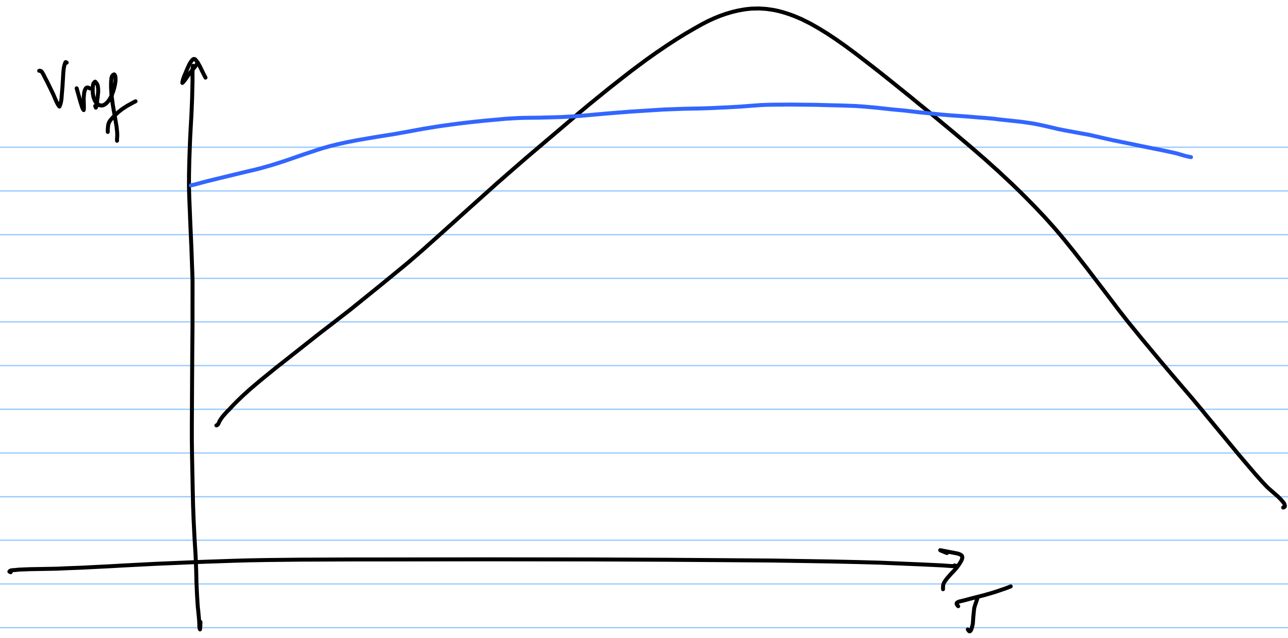
set $\alpha_1 = 1$

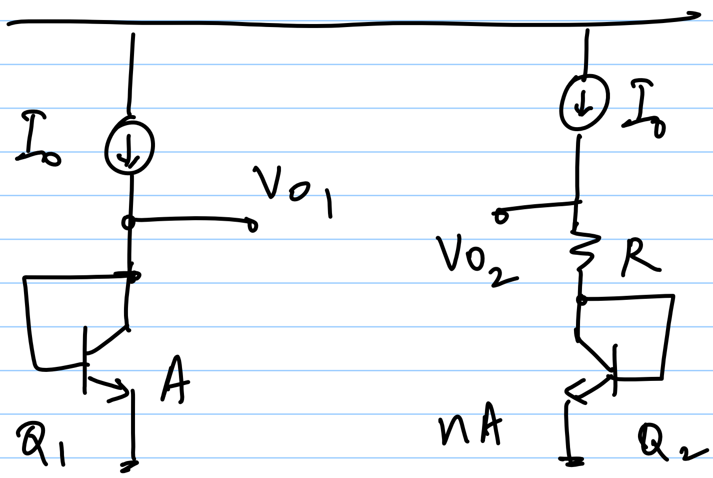
@ 300K $(\alpha_2 \ln n)(0.087\, mV/K) \simeq 1.5\, mV/K$

$$\alpha_2 \ln n \approx 17.2$$

$$V_{ref} = V_{BE} + (17.2) V_T$$

$$\simeq 1.25V \text{ @ } 300K$$





* neglect I_B
* Force $V_{o_1} = V_{o_2}$

$$V_{BE_1} = V_{BE_2} + I_0 R$$

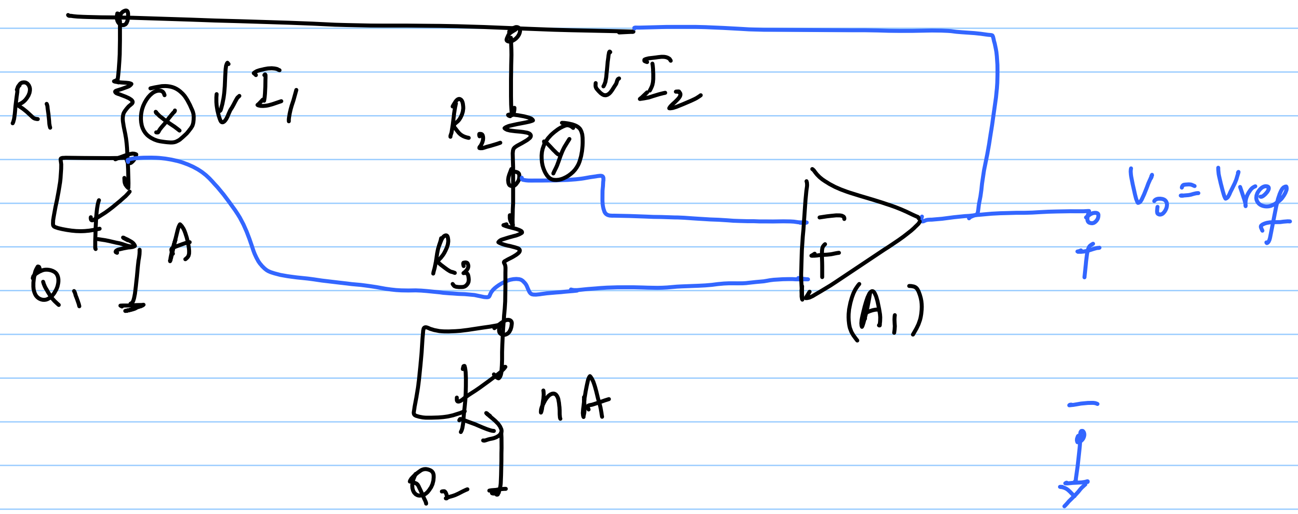
$$\Rightarrow \quad I_0 R = V_T \ln(n)$$

$$V_{o_2} = V_{BE_2} + V_T \ln(n)$$

$\ln(n) = 17.2 \Rightarrow n$ is very large

* Force $V_{o1} = V_{o2}$

$\Rightarrow$ Use an opamp in $-ve$ f.b.



$V_x = V_y$ (due to $-ve$ f.b.)

$$I_2 R_3 = V_{BE_1} - V_{BE_2} = V_T \ln(n)$$

$$I_2 = \frac{V_t \ln(n)}{R_3}$$ PTAT current (proportional to absolute temp.)

$$V_o = V_{BE_2} + \frac{V_t \ln(n)}{R_3}(R_2 + R_3)$$

$$= V_{BE_2} + V_t \ln(n)\left[1 + \frac{R_2}{R_3}\right]$$

for zero TC

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

e.g. $n = 31$, $\frac{R_2}{R_3} = 4$