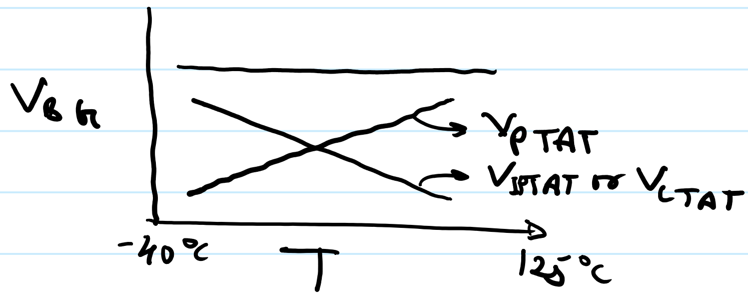
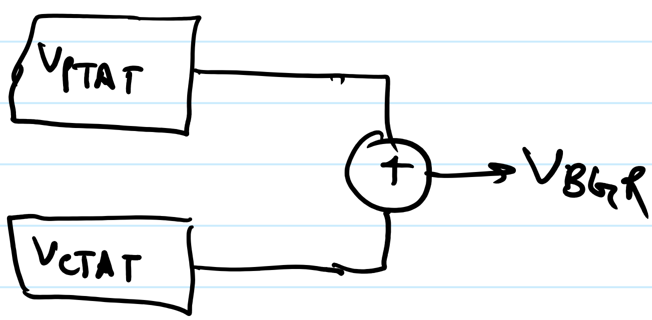
Bandgap Voltage Reference (Basic Concept)



PTAT → Proportional to absolute Temperature

IPTAT → Inversely proportional to absolute temperature

CTAT → complementary to absolute temp

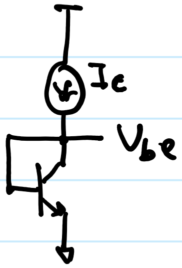


$$V_{bgr} = V_{PTAT} + V_{CTAT}$$

$$\frac{\partial V_{bgr}}{\partial T} = \frac{\partial V_{PTAT}}{\partial T} + \frac{\partial V_{CTAT}}{\partial T} = 0$$

$$\Rightarrow \frac{\partial V_{PTAT}}{\partial T} = -\frac{\partial V_{CTAT}}{\partial T}$$

CTAT Voltage Reference



$$I_c = I_s e^{V_{be}/V_T}$$

$$\Rightarrow \quad e^{V_{be}/V_T} = \frac{I_c}{I_s}$$

$$\frac{V_{be}}{V_T} = \ln\left(\frac{I_c}{I_s}\right)$$

$$V_{be} = V_T \ln\left(\frac{I_c}{I_s}\right)$$

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

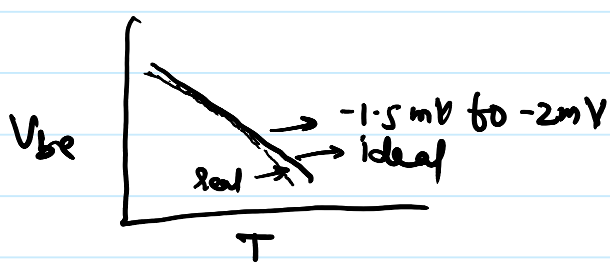
$$\frac{\partial V_T}{\partial T} = \frac{k}{q}$$

$$k = 1.38 \times 10^{-23}$$

$$q = 1.61 \times 10^{-19}\ C$$

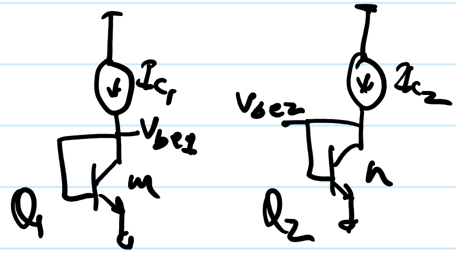
$$\frac{\partial V_T}{\partial T} = \frac{1.38}{1.61} \times 10^{-4} = 8.61 \times 10^{-5}$$

$$\frac{\partial V_{be}}{\partial T} \simeq -1.5\,mV \text{ to } -2\,mV$$



PTAT Voltage Reference

PTAT



$$V_{be1} = V_T \ln\left(\frac{I_{c_1}}{I_{s_1}}\right) \quad \text{--- (1)}$$

$$V_{be2} = V_T \ln\left(\frac{I_{c_2}}{I_{s_2}}\right) \quad \text{--- (2)}$$

(1) − (2)

$$\Rightarrow \underbrace{V_{be1} - V_{be2}}_{\Delta V_{be}} = V_T \ln\left(\frac{I_{c_1}}{I_{s_1}} \times \frac{I_{s_2}}{I_{c_2}}\right)$$

$$\frac{I_{s_2}}{I_{s_1}} = \frac{n}{m}$$

$$\Delta V_{be} = V_T \ln\left(\frac{n}{m} \times \frac{I_{c_1}}{I_{c_2}}\right)$$

if Q_1 & Q_2 are symmetric

$$m = n$$

$$\Delta V_{be} = V_T \ln\left(\frac{I_{c_1}}{I_{c_2}}\right)$$

$$\frac{I_{c_1}}{I_{c_2}} = k_1$$

$$\Delta V_{be} = V_T \ln(k_1)$$

$$V_T = \frac{kT}{q} \Rightarrow \frac{\partial V_T}{\partial T} = \frac{k}{q}$$

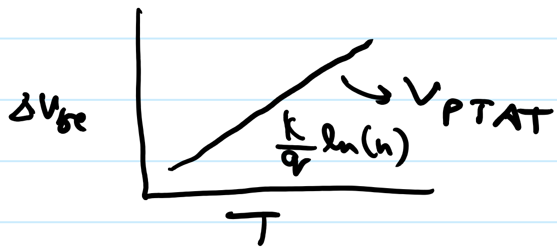
PTAT Voltage Reference

Let's assume Q_1 & Q_2 have different sizes but $I_{C_1} = I_{C_2}$

$$\Delta V_{be} = V_T \ln\left(\frac{n}{m}\right)$$

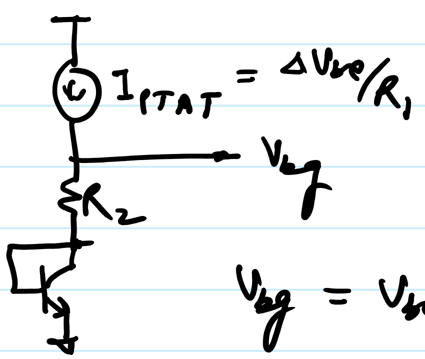
assume $m = 1$

$$\Delta V_{be} = V_T \ln(n)$$



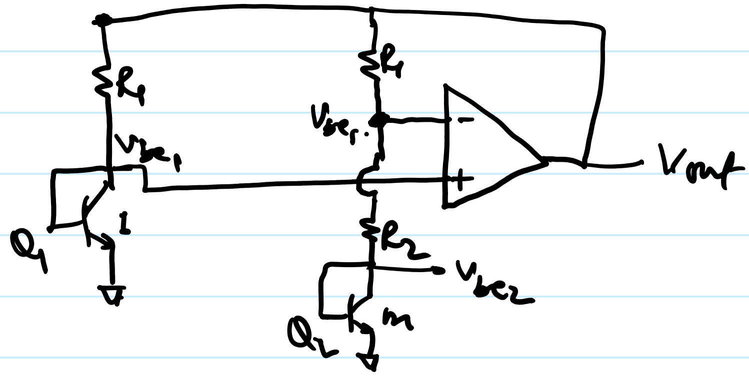
$$V_{bg} = V_{CTAT} + V_{PTAT}$$

$$= V_{be} + \Delta V_{be}$$



$$V_{bg} = V_{be} + \frac{R_2}{R_1} \times \Delta V_{be}$$

Bandgap Circuit



$$I_{R_2} = \frac{V_{be_1} - V_{be_2}}{R_2} = \frac{\Delta V_{be}}{R_2}$$

$$V_{out} = V_{be_1} + \frac{\Delta V_{be}}{R_2} \times R_1$$

$$V_{bg} \boxed{= V_{be_1} + \frac{R_1}{R_2} \times \Delta V_{be}}$$

$$\frac{\partial V_{bg}}{\partial T} = \frac{\partial V_{be1}}{\partial T} + \frac{\partial \Delta V_{be}}{\partial T}\left(\frac{R_1}{R_2}\right)$$

$$\Delta V_{be} = V_T \ln(m)$$

$$\frac{\partial V_{bg}}{\partial T} = \frac{\partial V_{be1}}{\partial T} + \underbrace{\left(\frac{R_1}{R_2}\right)(\ln(m))}_{\alpha} \frac{\partial V_T}{\partial T}$$

$$\frac{\partial V_{bg}}{\partial T} = \frac{\partial V_{be}}{\partial T} + \alpha \frac{\partial V_T}{\partial T} = 0 \qquad \text{—— (1)}$$