4/11/20

Lecture 49

Bandgap Reference

* Create V_{ref} that is independent of temperature
* C, R, M, V_T, V_t → all vary with temp.
* At least at one temp. T_0 → make $\frac{dV_{ref}}{dT} = 0$

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

-ve Temp Co

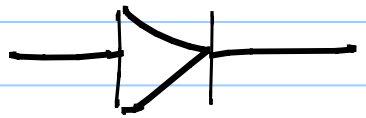
-ve $\frac{\partial V_1}{\partial T}$

+ve Temp Co

+ve $\frac{\partial V_2}{\partial T}$

@ RT : set $\left.\frac{\partial V_{ref}}{\partial T}\right|_{RT} = 0$ → temperature coefficient

BE junction of a BJT

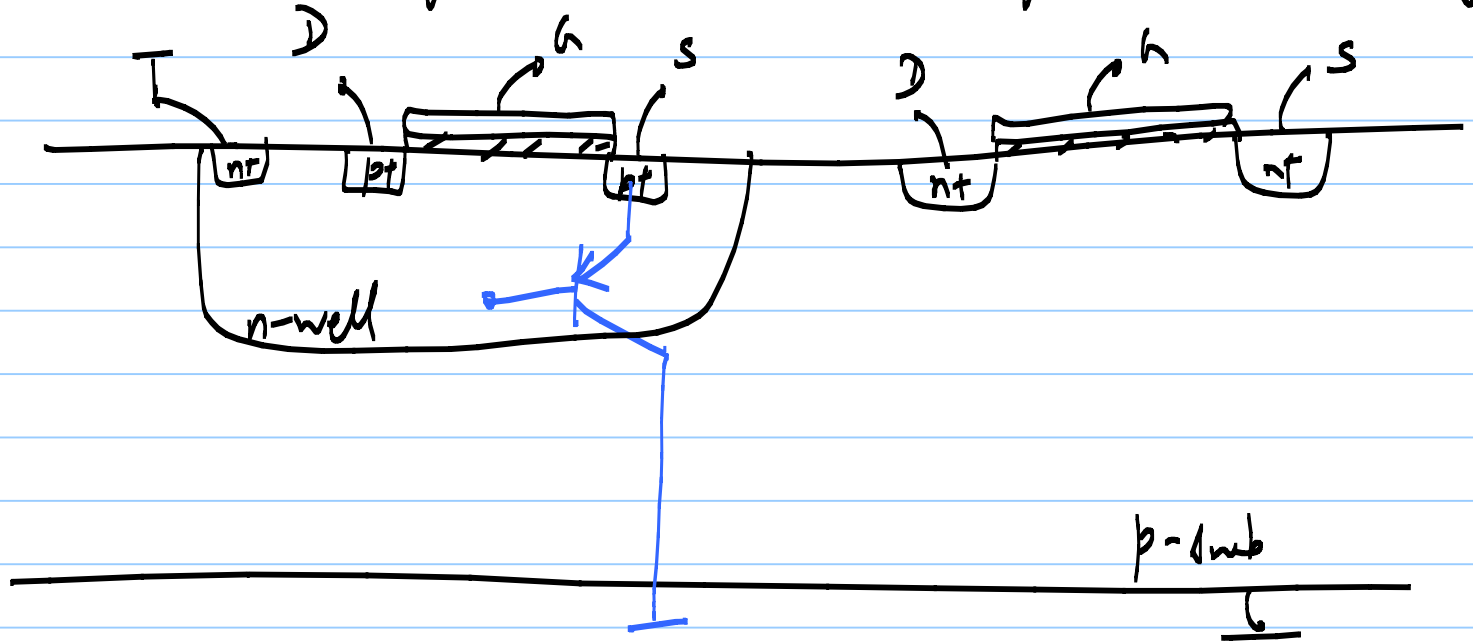


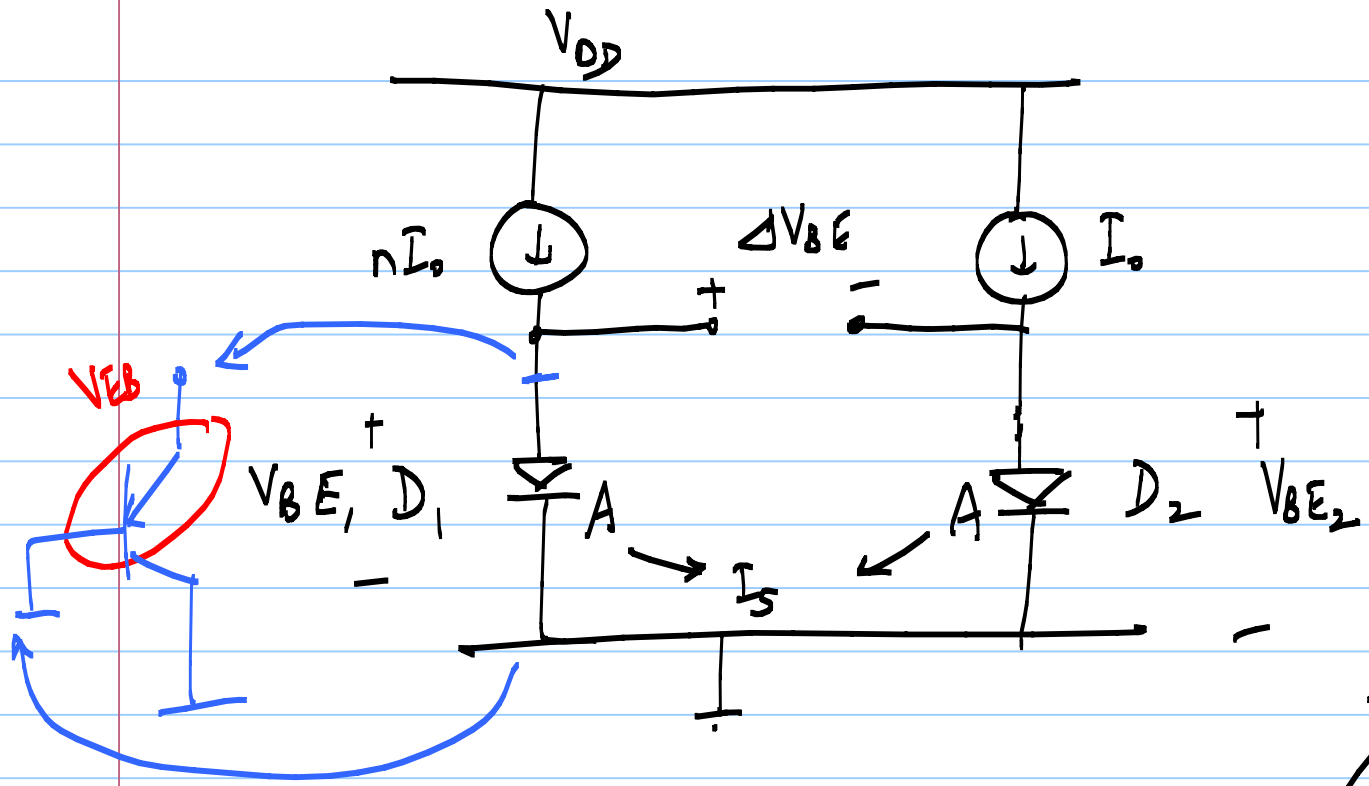
(e.g. parasitic BJT in a CMOS process)

$\approx 0.65V$

$\left.\frac{\partial V_{BE}}{\partial T}\right|_{RT} \simeq -1.5 \text{ to } -2 \text{ mV/K}$ → use to create V_1

$V_t = \frac{kT}{q}$ → $\frac{\partial V_t}{\partial T} = \frac{k}{q}$ → use to create V_2





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

$$= V_t \ln\left(\frac{I_{C_1}}{I_S}\right) - V_t \ln\left(\frac{I_{C_2}}{I_S}\right)$$

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

$$\Delta V_{BE} = V_t \ln(n)$$

$$= \frac{kT}{q} \ln(n)$$

$$\propto T$$

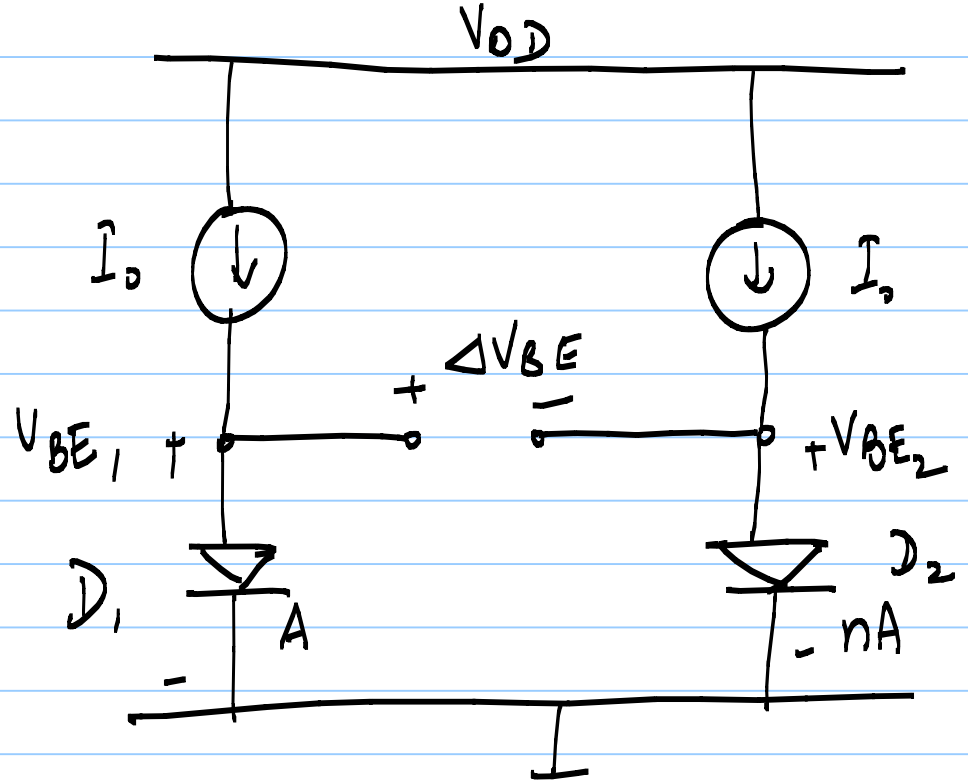
V_2 with +ve T.C.

* exact value of I_S does not matter

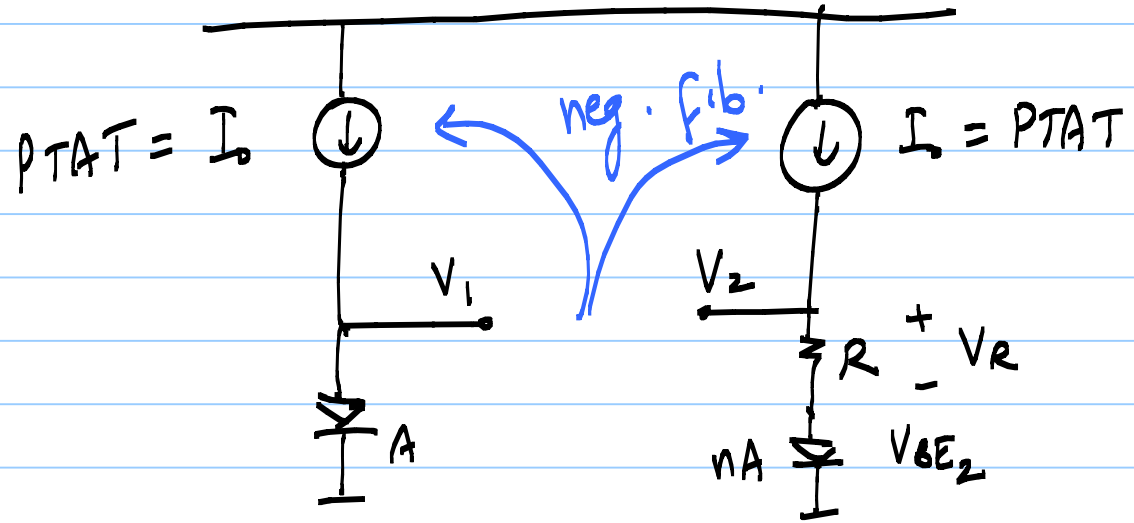
ΔV_{BE} is called a "PTAT" voltage

↳ proportional to absolute temperature

$$\Delta V_{BE} = V_t \ln\left(\frac{I_0}{I_S/n}\right) - V_t \ln\left(\frac{I_0}{I_S}\right)$$



$$\Delta V_{BE} = V_t \ln(n)$$



force $V_1 = V_2$

$\Rightarrow V_R = \Delta V_{BE_1} = V_t \ln(n)$

Use an opamp in negative f.b.

$V_{ref}: \quad V_2 = V_{BE_2} + V_R = V_{BE_2} + \Delta V_{BE}$ ← set equal to V_{ref}

Set temp. coeff. @ RT of V_2 to be zero

$$\left.\frac{\partial V_{ref}}{\partial T}\right|_{300K} = 0$$

$$\frac{\partial}{\partial T}\left(V_{BE_2} + \frac{kT}{q}\ln(n)\right)\Bigg|_{RT} = 0$$

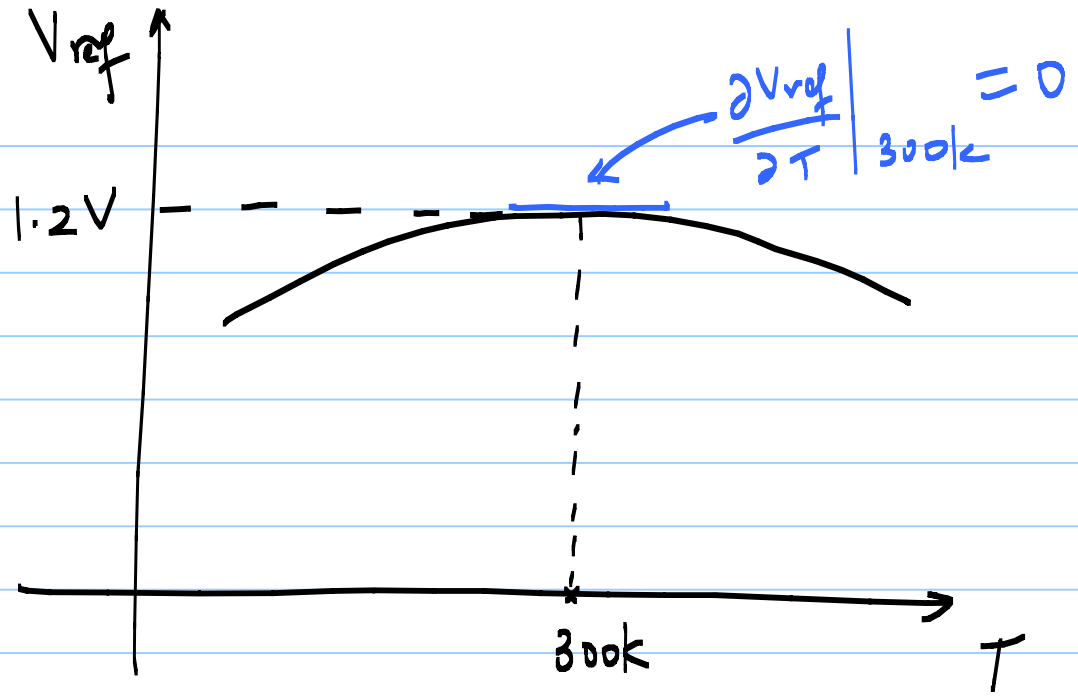
$$\left.\frac{\partial V_{BE_2}}{\partial T}\right|_{RT} + \frac{k}{q}\ln(n) = 0$$

$\rightarrow +1.5\,mV/K$

$\rightarrow -1.5\,mV/K$

$$\ln(n) = 1.5 \times \frac{q}{k} \simeq 17.4$$

$$V_{ref} \simeq 1.2V$$


V_{ref}
1.2V
300k
T
$\frac{\partial V_{ref}}{\partial T}\Big|_{300k} = 0$