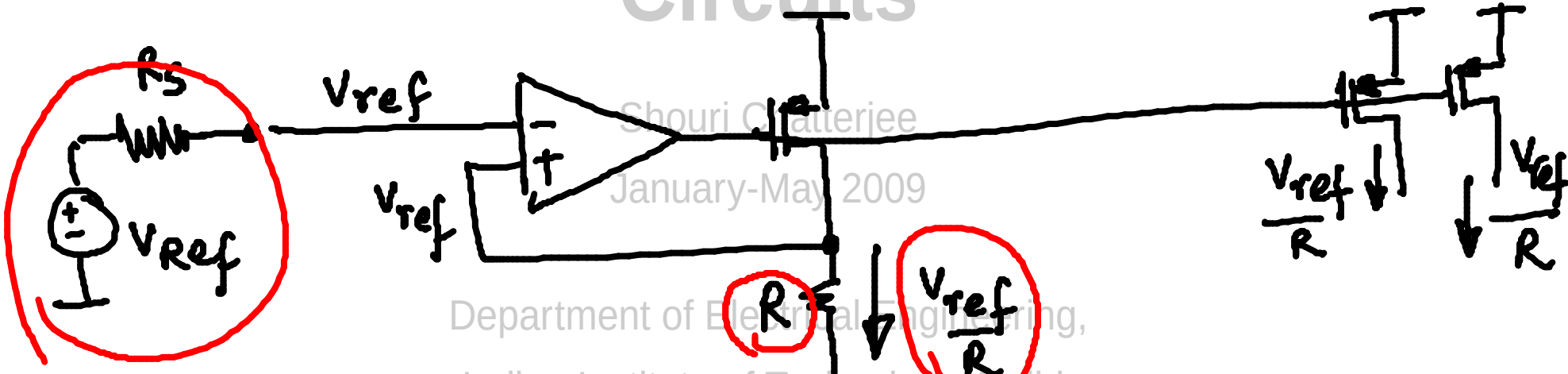
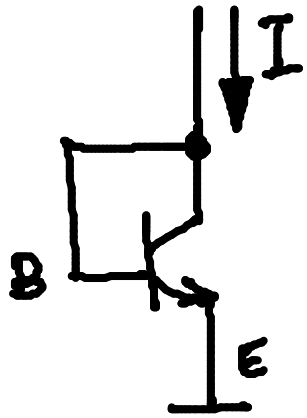
One current source of known value

→ temperature
→ power supply
→ process variations



Bandgap Voltage Reference

BJTs



V_{BE} $f(T)$

$$\frac{\partial V_{BE}}{\partial T} = ?$$

$$I_E = I_S \exp\left(\frac{V_{BE}}{\eta V_T}\right)$$

$$I = I_S \exp\left(V_{BE}/\eta V_T\right)$$

$$V_{BE} = \eta V_T \ln\left(\frac{I}{I_S}\right)$$

$$\frac{\partial V_{BE}}{\partial T} = \eta \cdot \frac{k}{q} \ln\left(I/I_S\right) + \eta V_T \cdot \frac{I_S}{I} \cdot \left(-\frac{I}{I_S^2}\right) \cdot \frac{\partial I_S}{\partial T}$$

$$= \eta \cdot \frac{k}{q} \ln\left(I/I_S\right) - \eta \frac{V_T}{I_S} \cdot \frac{\partial I_S}{\partial T}$$

$$I_S = bT^{4+m} \exp\left(-E_g/kT\right)$$

$$\frac{\partial I_S}{\partial T} = b(4+m)T^{3+m}\exp\left(-E_g/kT\right)$$

$$+ bT^{4+m}\exp\left(-\frac{E_g}{kT}\right)\cdot\left(+\frac{E_g}{kT^2}\right)$$

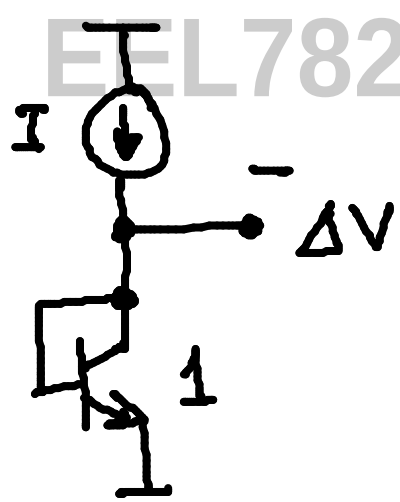
$$= \frac{(4+m)I_S}{T} + \left(\frac{E_g}{kT^2}\right)I_S$$

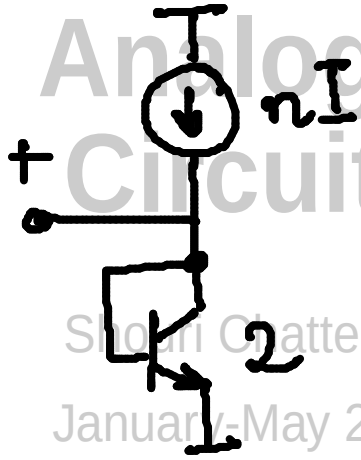
$$\frac{\partial V_{BE}}{\partial T} = \eta\cdot\left(\frac{k}{q}\right)\ln\left(\frac{I}{I_S}\right) - \eta V_T\left\{\frac{4+m}{T} + \frac{E_g}{kT^2}\right\}$$

$$= \frac{V_{BE}}{T} - \frac{\eta k}{q}\left\{\underbrace{4+m}_{1.5} + \underbrace{\frac{E_g}{kT}}_{44.8}\right\} = \frac{\eta k}{q}\left[\ln\left(\frac{I}{I_S}\right) - \underbrace{\quad}_{50}\right]$$

$$\eta\frac{kT}{q}\cdot\ln\left(\frac{I}{I_S}\right) = 0.6\,V$$

$T \uparrow \quad V_{BE} \downarrow$



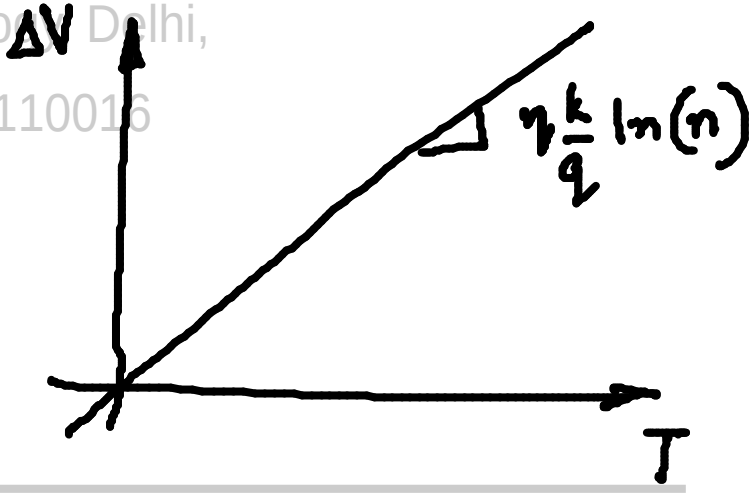


$$V_{BE_1} = \eta V_T \ln\left(\frac{I}{I_S}\right)$$

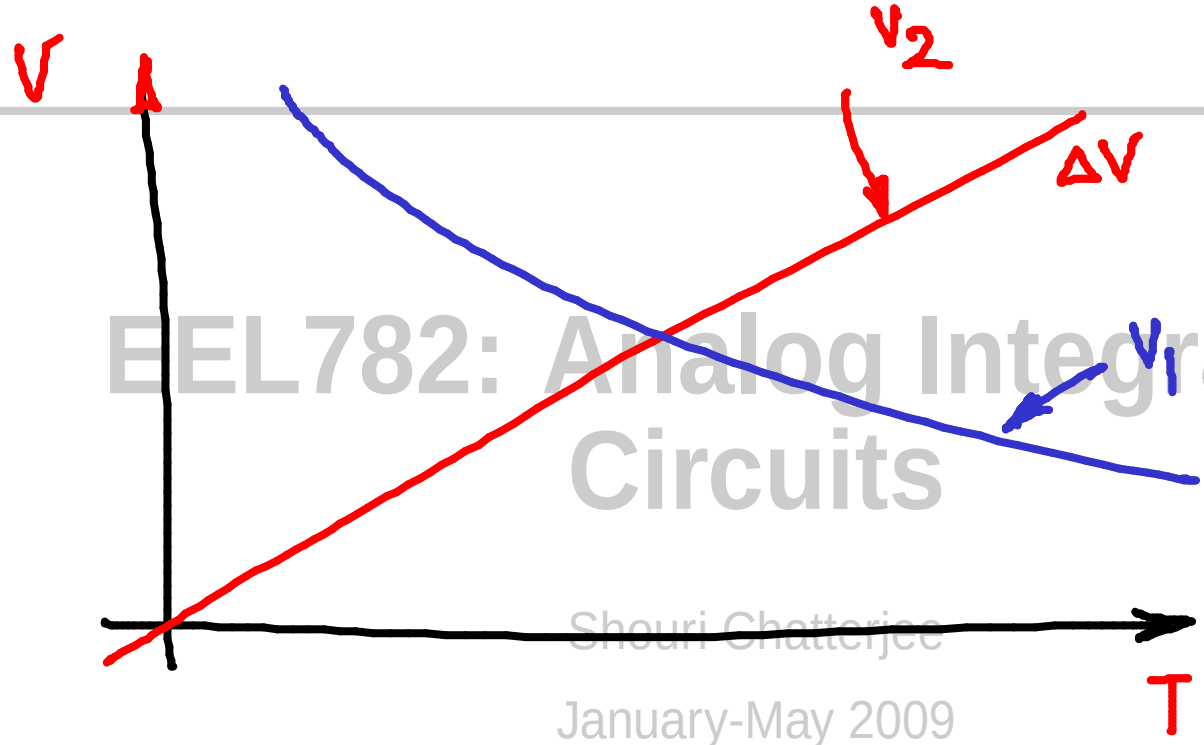
$$V_{BE_2} = \eta V_T \ln\left(\frac{nI}{I_S}\right)$$

$$\Delta V = V_{BE_2} - V_{BE_1} = \eta V_T \ln(n)$$

$$\frac{\partial \Delta V}{\partial T} = \eta \frac{k}{q} \ln(n)$$



PTAT



$$V_{ref} = \alpha V_1 + \beta V_2$$

$$\frac{\partial V_{ref}}{\partial T} = \alpha \frac{\partial V_1}{\partial T} + \beta \frac{\partial V_2}{\partial T}$$

EEL782: Analog Integrated Circuits

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