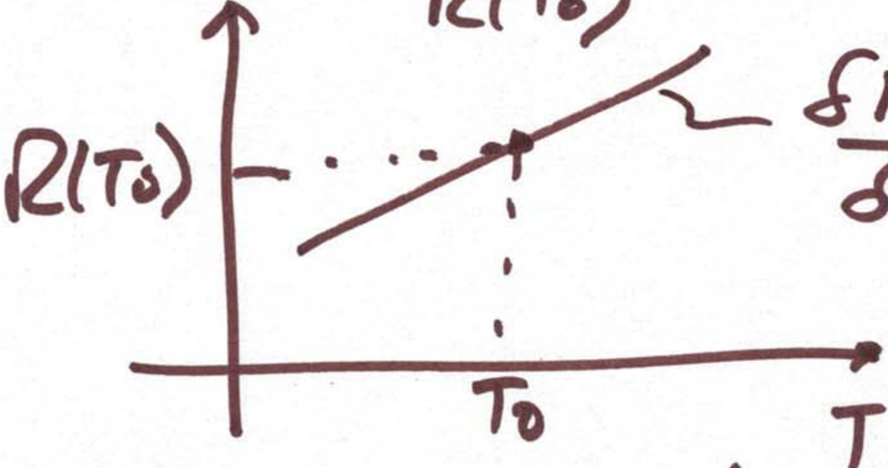
EE 420 / ECG 620
Analog IC Design

April 15, 2019

Lecture 19

$$R(T) = R(T_0)(1 + TCR(T - T_0))$$

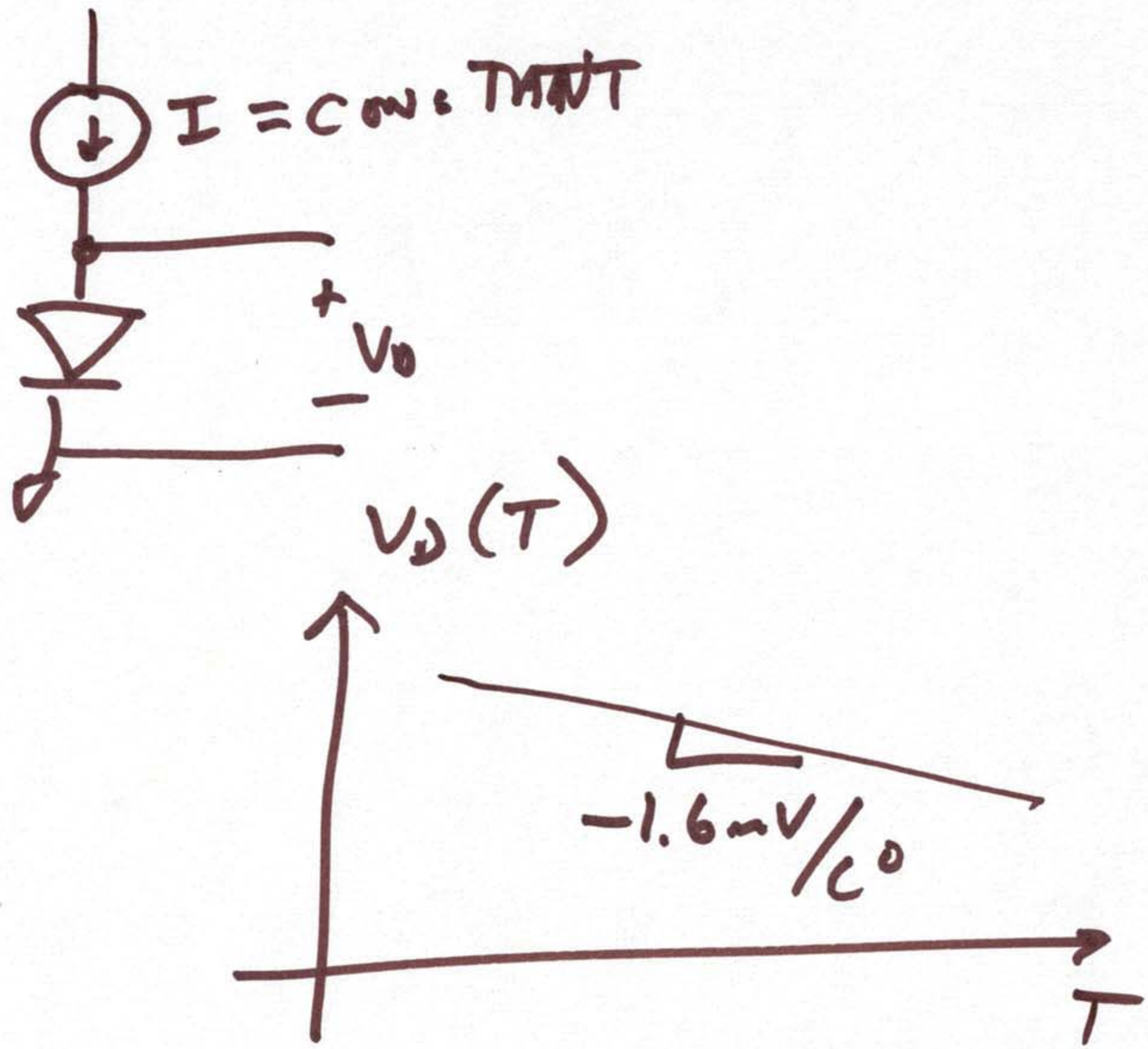


$$\frac{\delta R(T)}{\delta T} = R(T_0) \cdot TCR$$

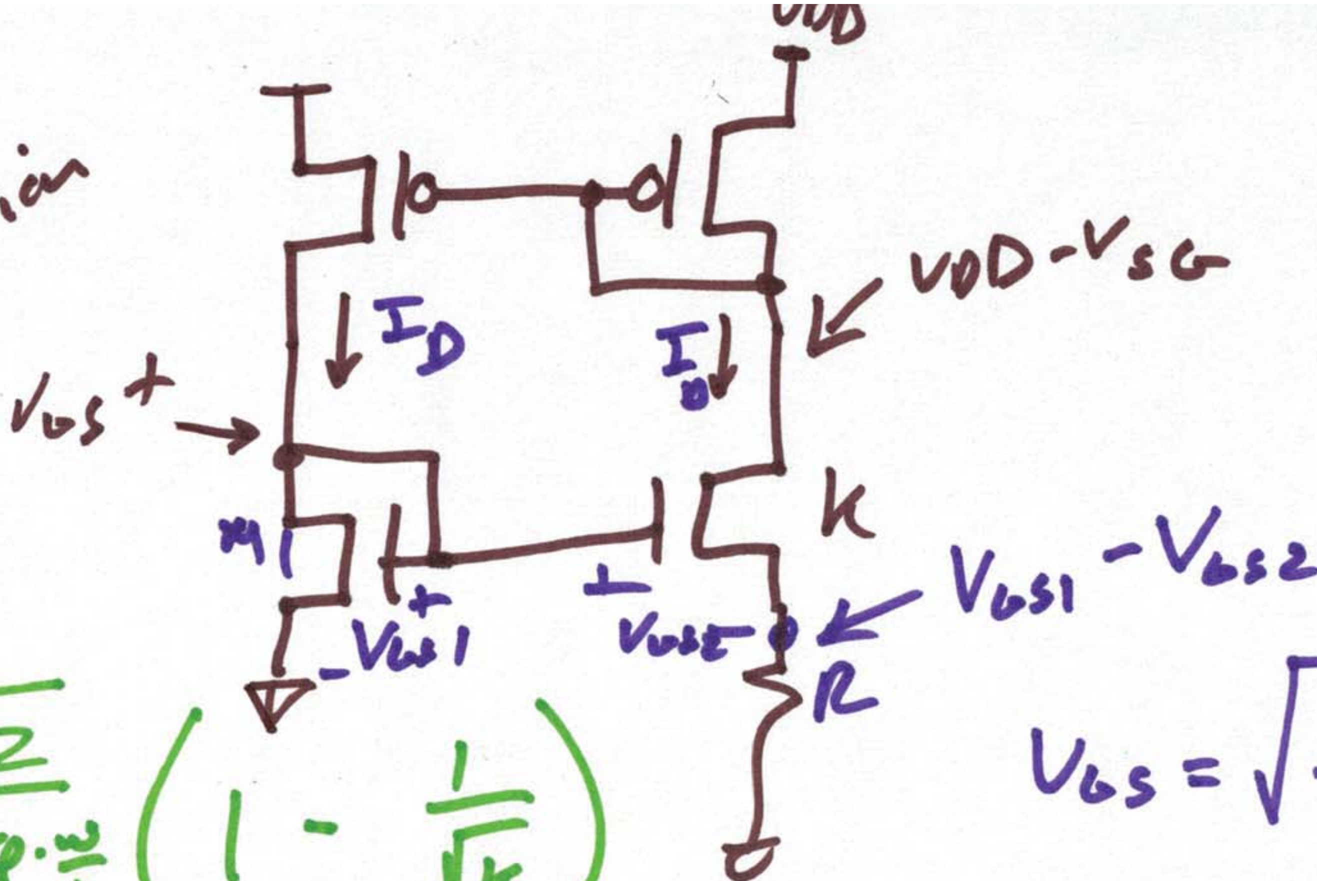
$$TCR = \frac{1}{R(T_0)} \cdot \frac{\delta R}{\delta t}$$

$$ppm = 10^{-6}$$

$$0.002 = 2{,}000\ ppm/C^\circ$$


I = CONSTANT
+
V_D
−
V_D(T)
−1.6 mV/C°
T

BMR
Temp
behavior



$$V_{GS} = \sqrt{\frac{2 I_D}{KP \cdot \frac{W}{L}}} + V_{THN}$$

$$\sqrt{I_D} = \frac{\sqrt{\frac{2 \cancel{I_D}}{KP \cdot \frac{W}{L}}} - \sqrt{\frac{2 \cancel{I_D}}{KP \cdot \frac{K \cdot W}{L}}}}{R}$$

$$\sqrt{I_D} = \frac{1}{R}\sqrt{\frac{2}{KP \cdot \frac{W}{L}}}\left(1 - \frac{1}{\sqrt{K}}\right)$$

$$I_D = \frac{2}{R^2 KP \cdot \frac{W}{L}}\left(1 - \frac{1}{\sqrt{K}}\right)^2$$

$$I_0 = \frac{2}{R^2 \cdot KP \cdot \frac{W}{L}} \left(1 - \frac{1}{\sqrt{K}}\right)^2$$

let $$X = \frac{2}{\frac{W}{L}} \left(1 - \frac{1}{\sqrt{K}}\right)^2$$

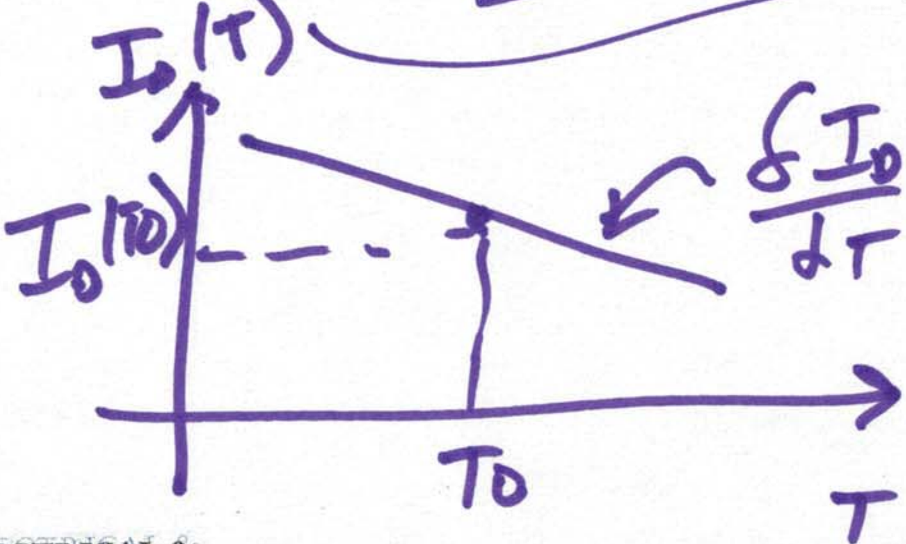
$$I_0 = R^{-2} \cdot KP^{-1} \cdot X$$

$$\frac{\delta I_0}{\delta T} = X\left(-2R^{-3}\frac{\delta R}{\delta T} \cdot KP^{-1} + \left[R^{-2}(-1)KP^{-2}\frac{\delta KP}{\delta T}\right]\right)$$

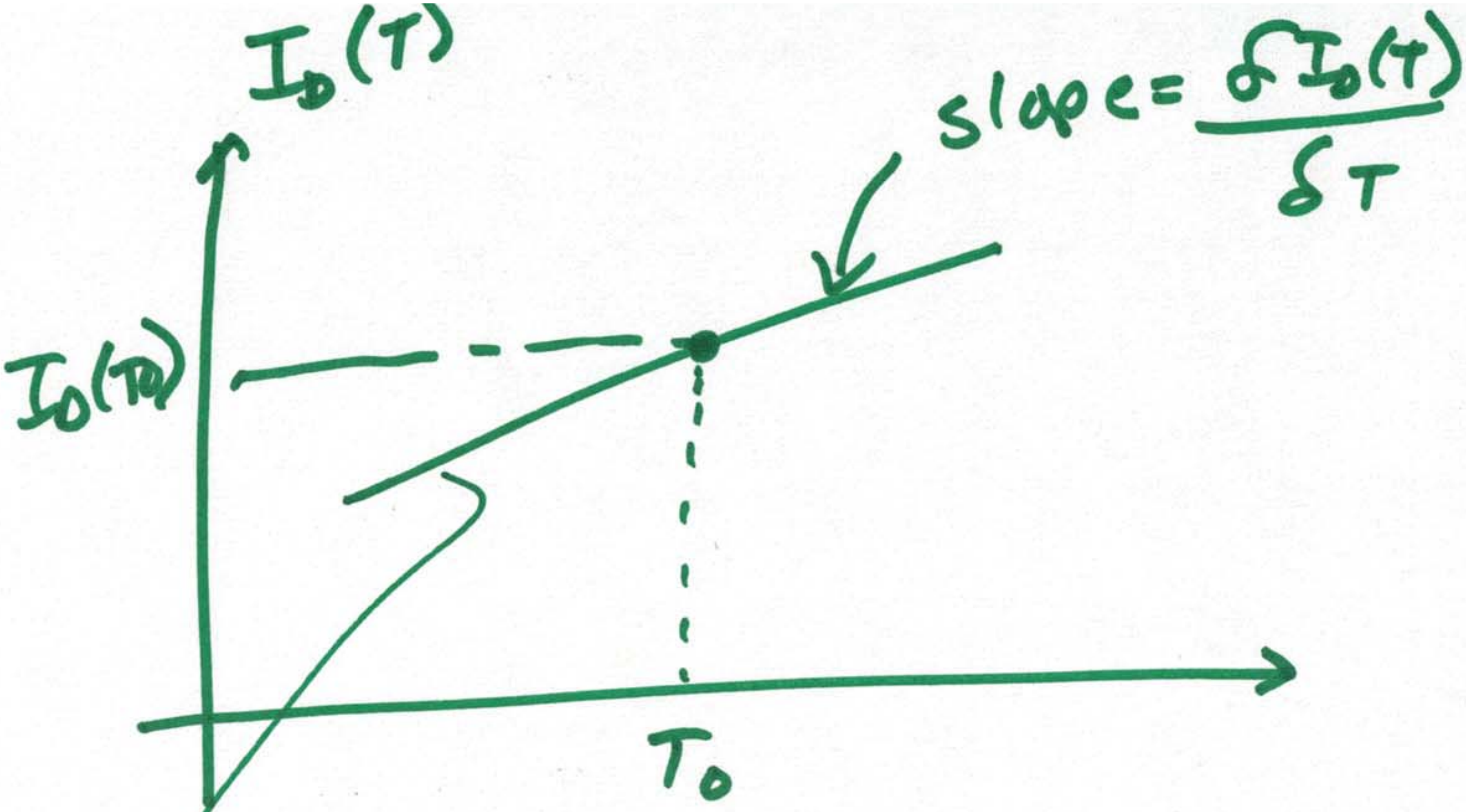
$$= X \cdot R^{-2} KP^{-1}\left(-2 \cdot \frac{1}{R}\frac{\delta R}{\delta T} - \frac{1}{KP}\frac{\delta KP}{\delta T}\right)$$

$$TCI = \frac{1}{I_D}\frac{\delta I_D}{dT} = \underbrace{\frac{2}{R^2 \frac{W}{L} KP}\left(1-\frac{1}{\sqrt{K}}\right)^2}_{I_D}\underbrace{\left(-2\underbrace{\frac{1}{R}\frac{\delta R}{\delta T}}_{TCR}-\frac{1}{KP}\frac{\delta KP}{dT}\right)}_{=\,TCI}$$

$$I_D(T) = I_D(T_0)\left(1 + TCI\cdot(T - T_0)\right)$$



$$TCI = \frac{1}{I_D}\frac{\delta I_D}{\delta T}$$



$$I_D(T) = I_D(T_0)\left(1 + TCI\,(T - T_0)\right)$$

$$= I_D(T_0) + TCI \cdot I_D(T_0) \cdot T + TCI \cdot I_D(T_0) \cdot T_0$$

$$TCI = \frac{1}{I_D}\frac{\delta I_D}{\delta T}$$

$$\frac{\delta I_D(T)}{\delta T} = TCI \cdot I_D(T_0)$$

$$TCI = \left(-2 \cdot TCR + \left(\frac{+1.5}{T}\right)\right)$$

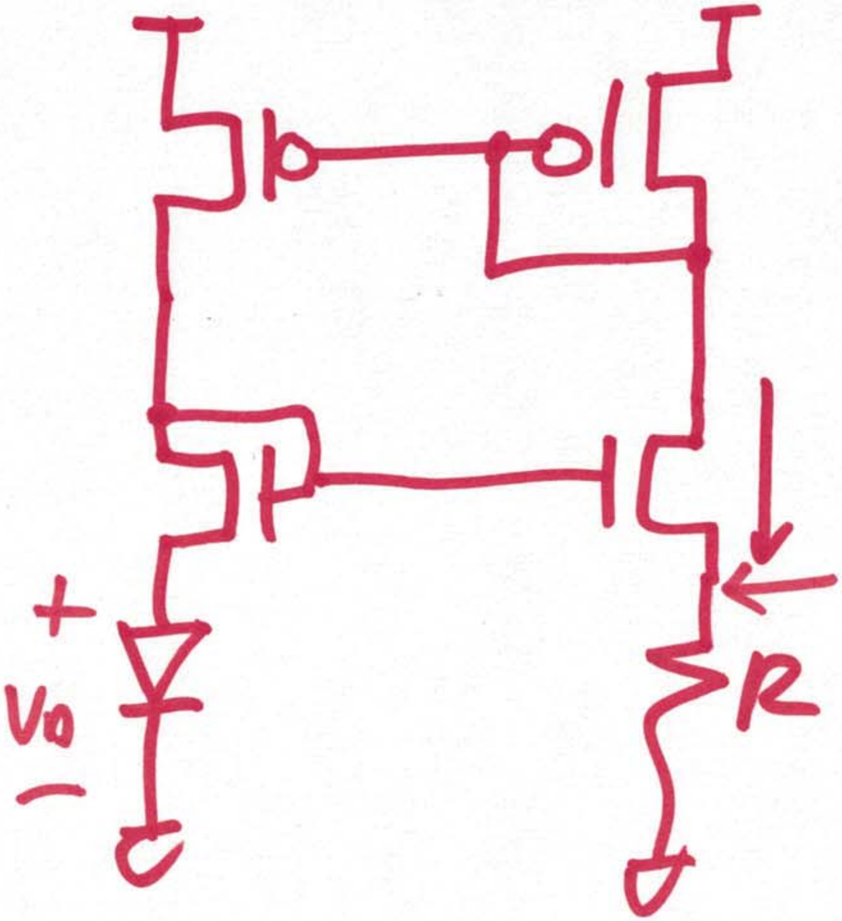
$$TCR = \frac{0.002}{C^\circ} = 2{,}000\,ppm/C^\circ$$

$$T = 300^\circ K \quad 0.005 = \frac{1.5}{300} = 5{,}000\,ppm$$

$$TCI = (-.004 + 0.005)$$

$$TCI = 1{,}000\,ppm/C^\circ$$

$$I = I(T_0)(1 + 0.001(T - T_0))$$



$$I = \frac{V_D}{R} = V_D \cdot R^{-1}$$

$$\frac{\delta I}{\delta T} = \frac{\delta V_D}{\delta T} \cdot R^{-1}$$

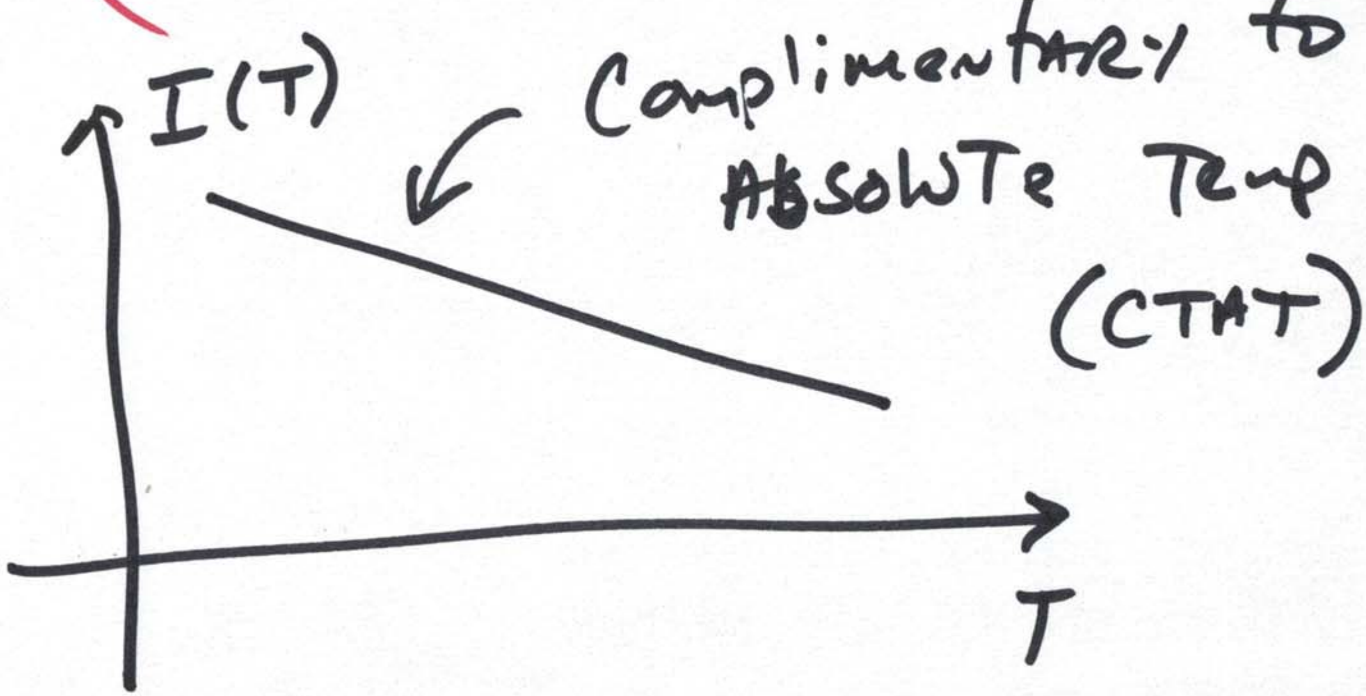
TCI

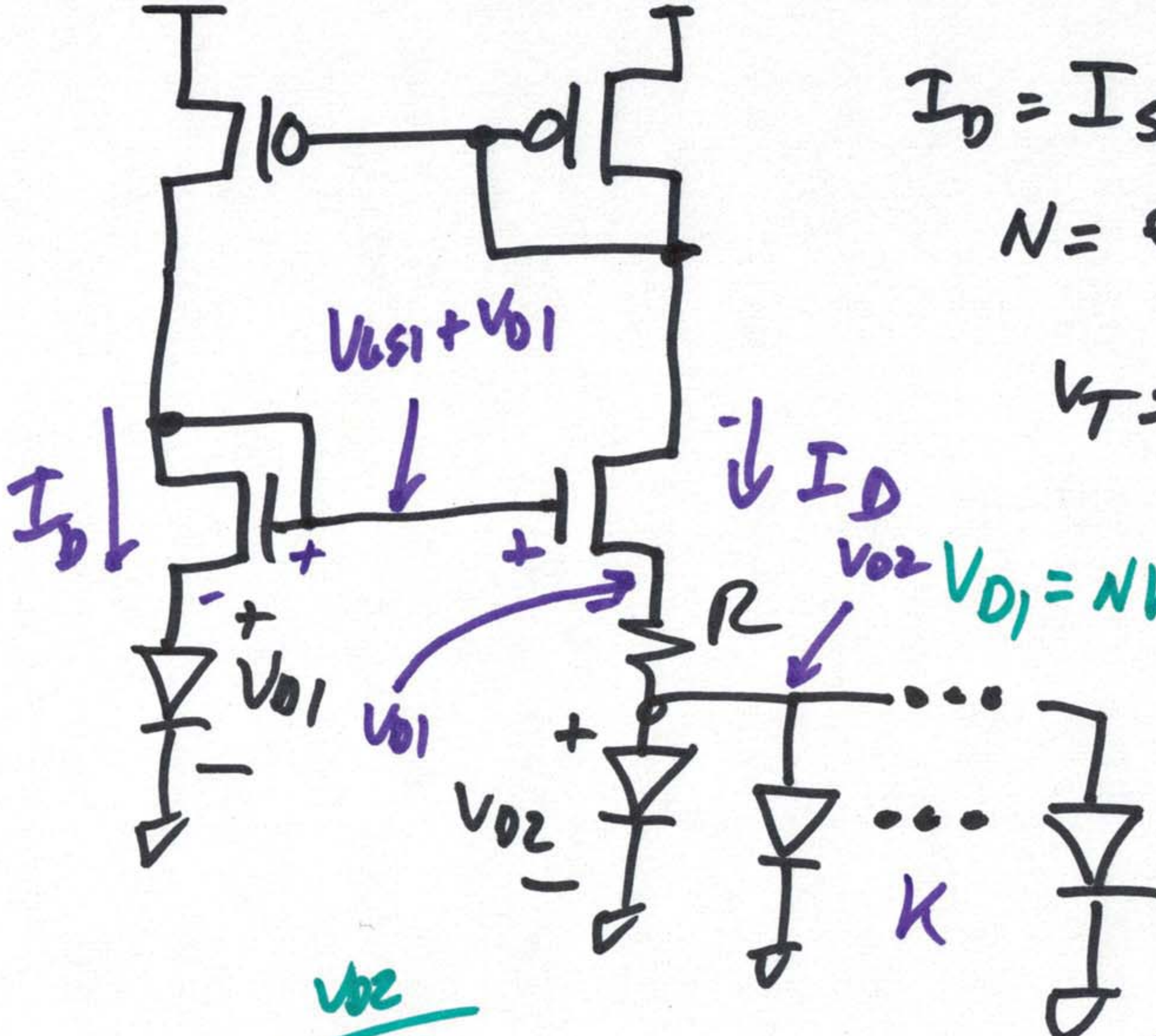
$$\frac{1}{I} \cdot \frac{\delta I}{\delta T} = \frac{R}{V_D}\left(\frac{1}{R}\frac{\delta V_D}{\delta T} - \frac{V_D}{R^2}\frac{\delta R}{\delta T} \right)$$

$$+\left(-1 \cdot R^{-2} V_D \cdot \frac{dR}{dT}\right)$$

$$TCI = \frac{1}{I}\frac{\delta I}{\delta T} = \left(\frac{1}{V_D}\frac{\delta V_D}{\delta T} - \frac{1}{R}\frac{\delta R}{\delta T}\right)$$

$$TCI = \left(\frac{1}{0.7}\left(\frac{-1.6\,mV}{C^{\circ}}\right) - TCR\right)$$





$$I_D = I_S e^{V_D/NV_T}$$

N = emission coefficient

$$V_T = \frac{kT}{q} = \text{thermal voltage}$$

$$V_{D1} = NV_T \ln \frac{I_D}{I_S}$$

$$I_D = K \cdot I_S e^{\frac{V_{D2}}{NV_T}}$$

$$V_{D2} = NV_T \ln \frac{I_D}{KI_S}$$

$$I_D = \frac{V_{D1} - V_{D2}}{R}, \quad \ln a - \ln b = \ln \frac{a}{b}$$

$$= \frac{NV_T \ln \frac{I_D}{I_S} - NV_T \ln \frac{I_D}{KI_S}}{R}$$

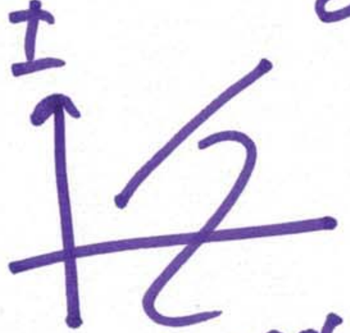
$$\boxed{I_D = \frac{NV_T \ln K}{R}}, \quad \begin{aligned} N &= 1 \\ V_T &= 25\,mV \\ K &= 8 \\ R &= 10k \end{aligned}$$

$$I_D = \frac{52\,mV}{10k}$$

$$= 5\,\mu A$$

$$\underline{I_D} = N V_T R^{-1} \ln K$$

$$\frac{\delta I_D}{\delta T} = N \frac{\delta V_T}{\delta T} \cdot R^{-1} \ln K +$$



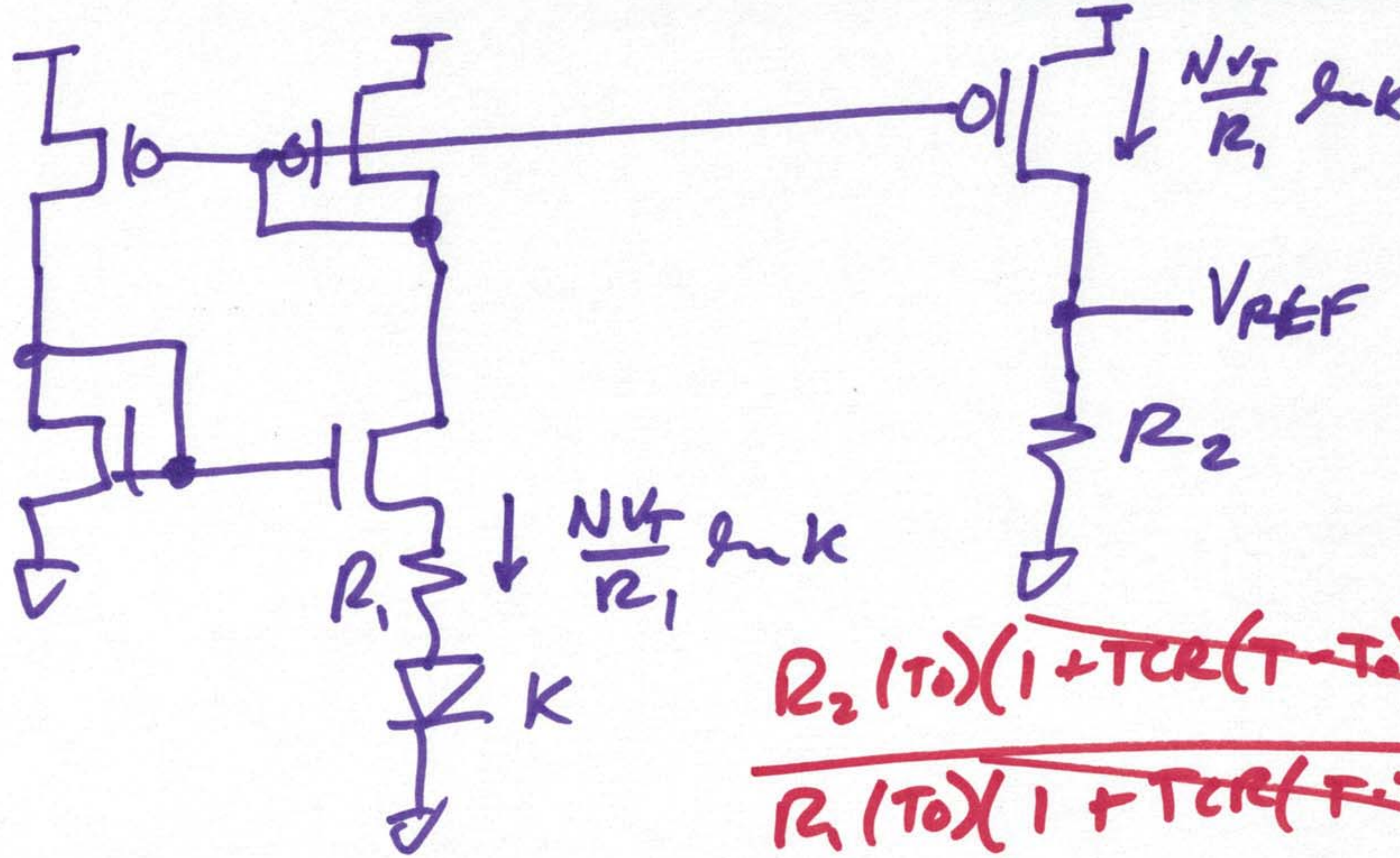
$$N V_T (-1) R^{-2} \cdot \frac{\delta R}{\delta T} \cdot \ln K$$

pos — Neg

proportional to absolute temp (PTAT)

$$= \frac{N V_T}{R} \ln K \left(\frac{1}{V_T} \frac{\delta V_T}{\delta T} - \frac{1}{R} \frac{\delta R}{\delta T} \right)$$

$$V_T = \frac{KT}{q}, \quad \frac{\delta V_T}{\delta T} = \frac{K}{q} = 0.085 \frac{mV}{C^o}$$



$$\frac{R_2(T_0)(1+TCR(T-T_0))}{R_1(T_0)(1+TCR(T-T_0))}$$

$$V_{REF} = NV_T \frac{R_2}{R_1} \ln K$$