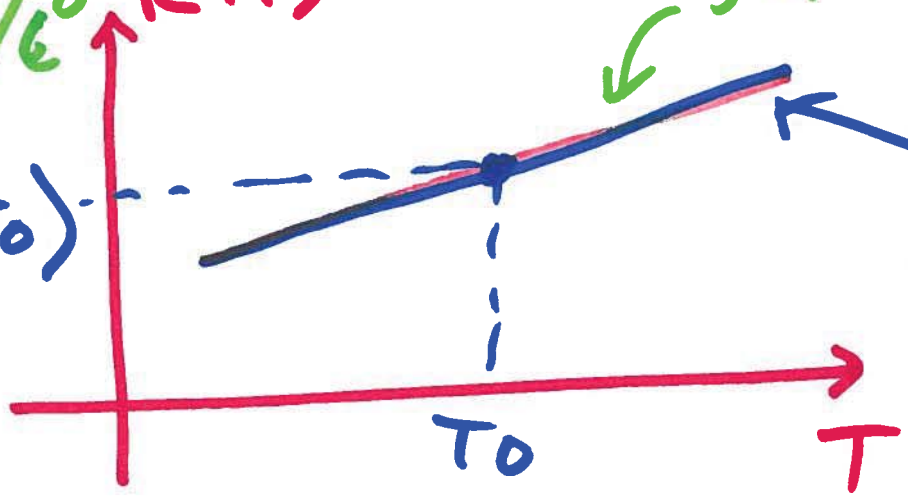
# EE 420/ECG 620
# Analog IC Design
## Lecture 20
## April 13, 2017

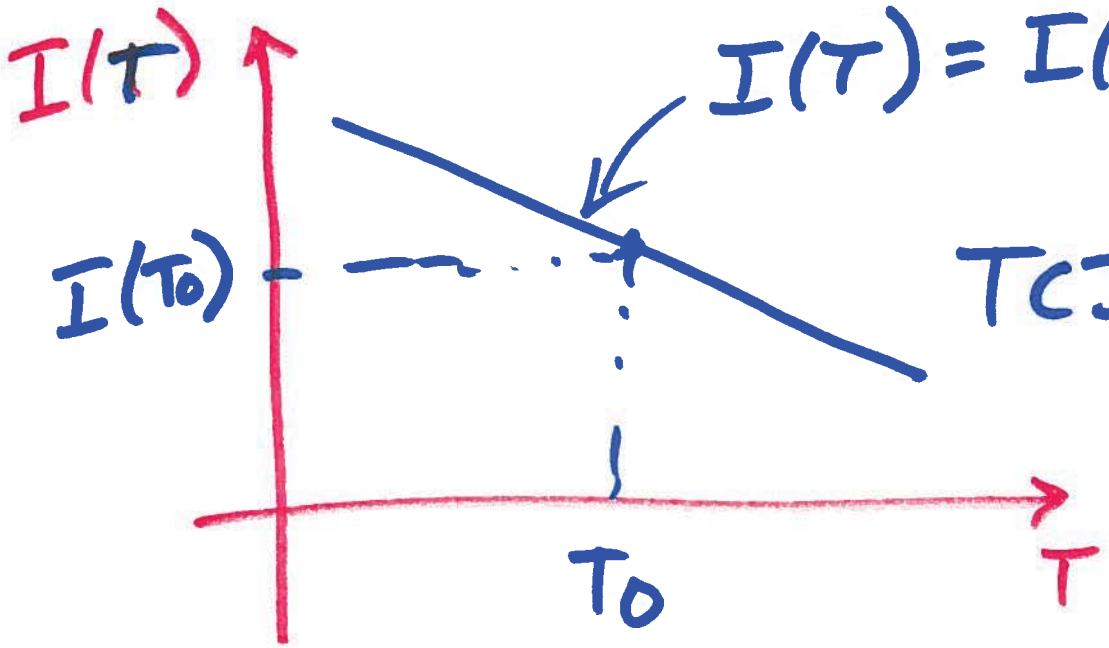
$TCR = \frac{1}{R(T_0)} \cdot \frac{\delta R(T)}{\delta T}$

$= 0.002/°$

2,000 ppm/°

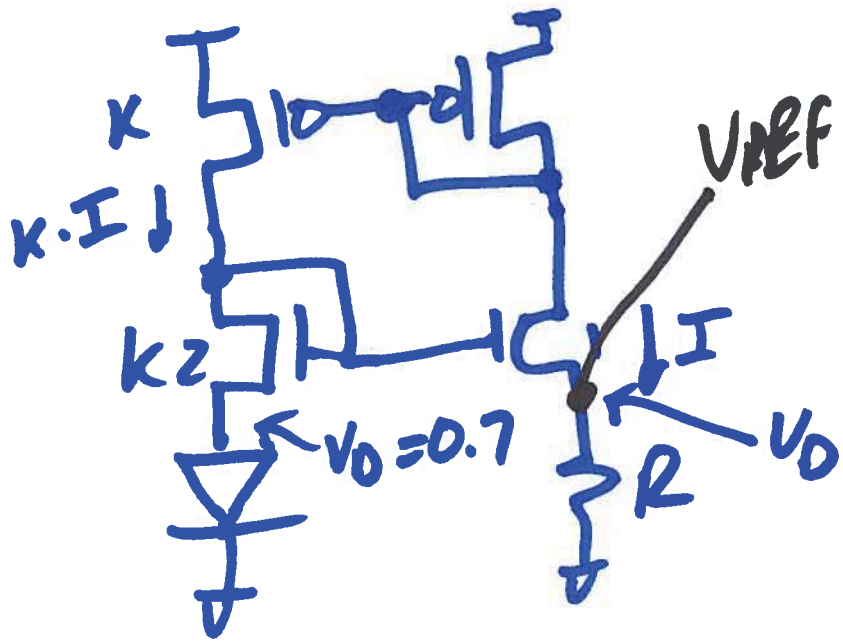



$R(T) = R(T_0)(1 + TCR \cdot (T - T_0))$




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

$$TCI = \frac{1}{I(T_0)} \cdot \frac{\delta I}{\delta T}$$



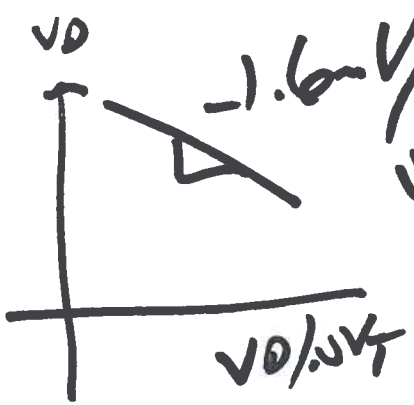

$$kI = k \cdot \frac{kp_n}{2} \cdot \frac{W}{L} \left(V_{GSE} - V_{TN}\right)^2$$

$$I = \frac{kp_n}{2} \cdot \frac{W}{L} \left(V_{GS1} - V_{TN}\right)^2$$

$$V_D = \eta n V_T \ln = \frac{kI_D}{I_S}$$

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

$$= \frac{1}{R}\frac{\delta V_D}{\delta T} + V_D\frac{(-1)}{R^2}\frac{\delta R}{\delta T}$$




$$\frac{dV_D}{dT}\frac{\delta I}{\delta T} = \frac{V_D}{\frac{R_1}{I}}\cdot\frac{1}{V_D}\cdot\frac{\delta V_D}{\delta T} + I^{-}\cdot\frac{1}{R}\frac{\delta R}{\delta T}$$

$I_D \propto I_S e$

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

$\frac{\delta V_I}{\delta T} = 0.08\frac{mV}{°C}$

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

$= \frac{K}{q}$

$$I(T) = I(T_0) \cdot (1 + TCI(T - T_0))$$

$$I(T_0) = \frac{.7}{1K} = .7\,mA \qquad TCI = \frac{1}{V_D}\cdot\frac{\delta V_D}{\delta T} = \frac{1}{R}\frac{\delta R}{\delta T}$$

$$= \frac{-1.6\,mV/C^\circ}{.7} * \frac{0.002}{C^\circ}$$

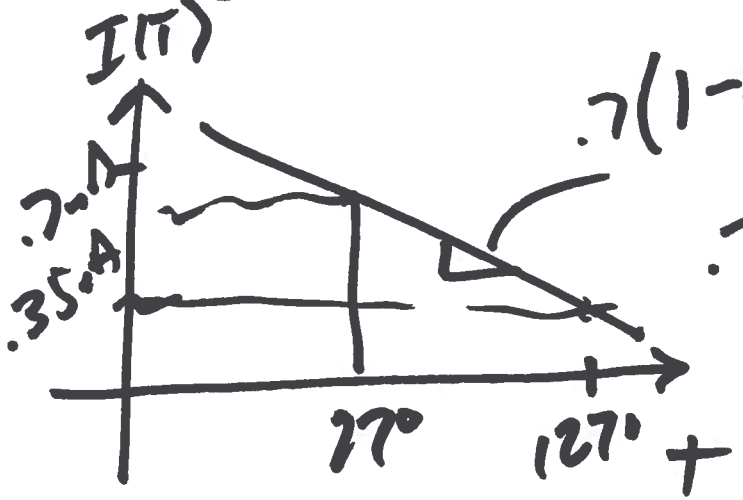
$$I(T) = 0.7\,mA \cdot (1 + (-0.004286)(T - 300))$$

$$= \frac{-0.0016}{.7} * 0.002$$

$$.7(1 - 0.004286 \cdot 100)$$

$$.7 * (.5714)$$

$$= -4{,}286 \ \frac{ppm}{C^\circ}$$

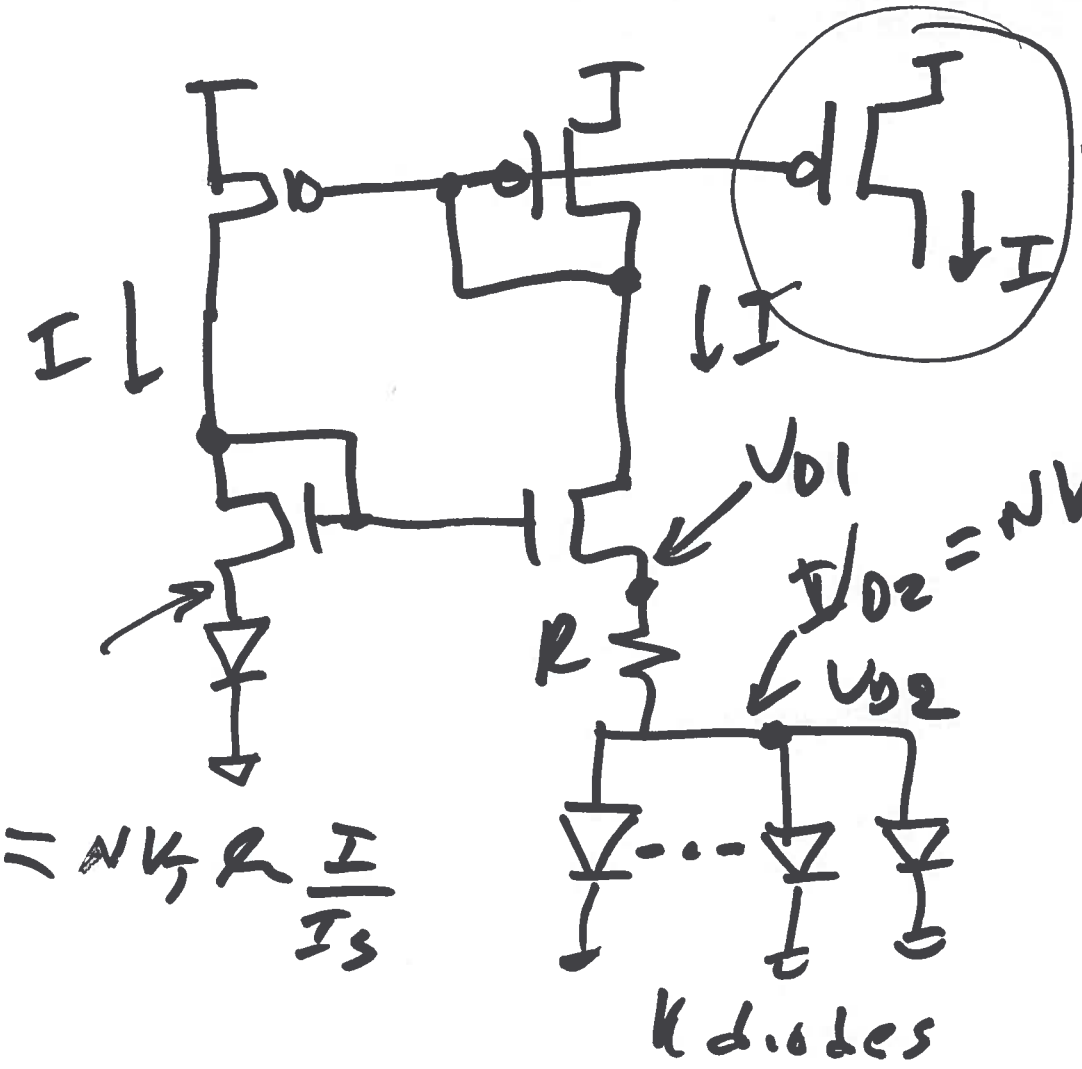


$$\frac{\delta V_{REF}}{\delta T} = \frac{\delta I \cdot R}{\delta T} = R \cdot \frac{\delta I}{\delta T} + I \cdot \frac{\delta R}{\delta T}$$

$$V_{REF} = I \cdot R$$

$$TC_{V_{REF}} = \frac{1}{V_{REF}} \cdot \frac{\delta V_{REF}}{\delta T} = \overbrace{\frac{R \cdot \frac{\delta I}{\delta T}}{I \cdot R}}^{TC_I} + \overbrace{\frac{I \cdot \frac{\delta R}{\delta T}}{I R}}^{TC_R}$$

$$V_{REF}(T) = V_{REF}(T_0)\left(1 + TC_{V_{REF}} \cdot (T - T_0)\right)$$




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

$$V_D = NV_T \ln \frac{I_D}{I_S}$$

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

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

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

$$V_D = NV_T \ln \frac{I_D}{KI_S}$$

$$I = \frac{V_{D1} - V_{D2}}{R} = \frac{NV_T \ln \frac{I}{I_S} - NV_T \ln \frac{I}{KI_S}}{R}$$

$$= \frac{NV_T \ln K}{R}$$

$$\frac{\delta I}{\delta T} = \frac{\delta N V_T R^{-1} \ln K}{\delta T}, \quad I = \frac{N V_T}{R} \cdot \ln K$$

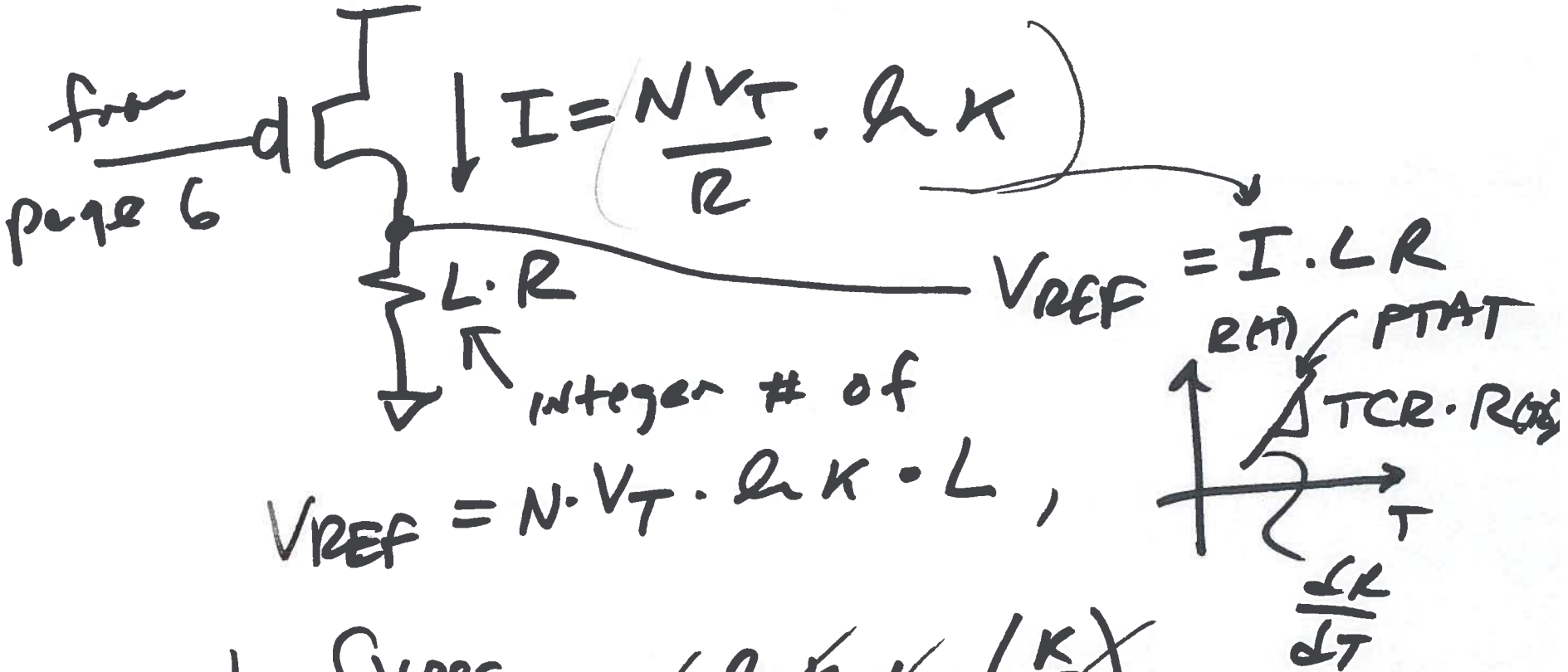
$$V_T = \frac{kT}{q}$$

$$\frac{1}{I}\frac{\delta I}{\delta T} = \frac{N \cdot \ln K}{N \ln K \cdot V_T}\left(\frac{1}{R}\frac{\delta V_T}{\delta T} + V_T \cdot \frac{-1}{R^2}\frac{\delta R}{\delta T}\right)$$

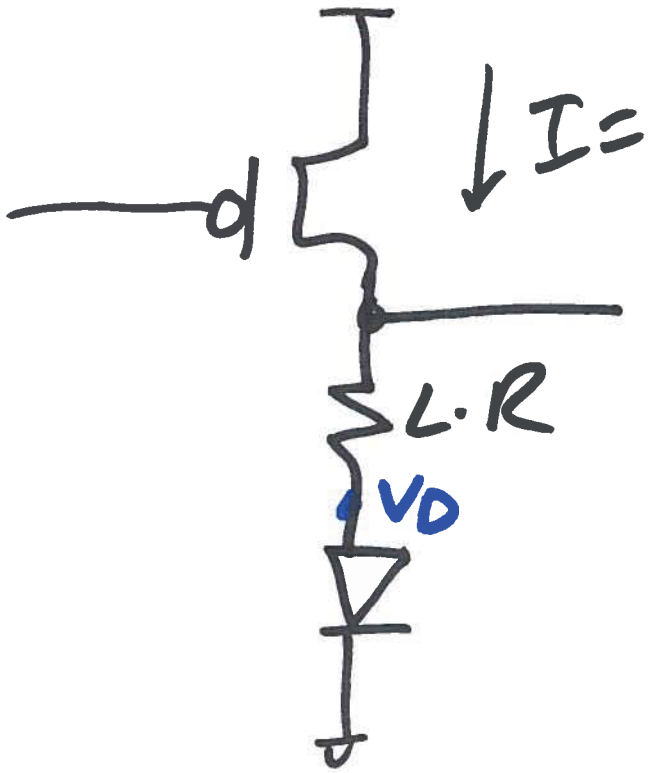
$$\frac{1}{V_T} \quad 0.085 \sim V$$

$$\frac{}{\infty}$$

$$TCI = \frac{1}{I}\frac{\delta I}{\delta T} = \frac{1}{V_T}\frac{\delta V_T}{\delta T} + \frac{-1}{R}\frac{\delta R}{\delta T}$$




$$TC_{V_{REF}} = \frac{1}{V_{REF}} \frac{\delta V_{REF}}{\delta T} = \frac{N \cdot \ln K \cdot L \cdot \left(\frac{K}{q}\right)}{N \cdot \frac{K}{q} \cdot T \cdot \ln K \cdot L}$$




$I = \frac{NV_T}{R} \ln K$

Bandgap voltage $\frac{\delta V_{REF}}{\delta T} = 0$

$V_{REF} = NV_T \ln K \cdot L + V_D$

$\frac{\delta V_{REF}}{\delta T} = 0 = N \cdot \frac{K}{q} \ln K \cdot L - 1.6 \frac{mV}{C^\circ}$

$\frac{N K}{q} \cdot \ln K \cdot L = 0.0016$

$0.000085 \cdot L = 0.0016$

$L = 9.41$