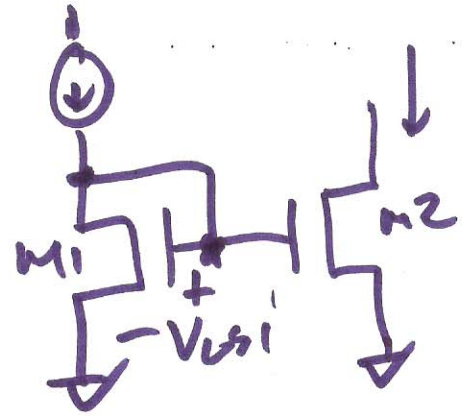

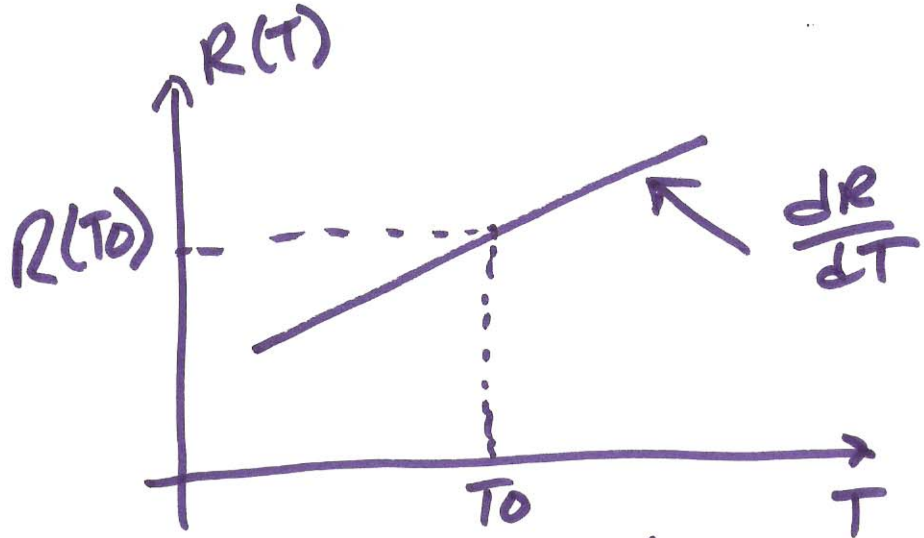

$$R(T) = R(T_0)\left(1 + TCR(T - T_0)\right)$$

$$TCR = \frac{1}{R(T_0)} \cdot \frac{dR}{dT}$$

$$= 2000\ ppm/C° = 0.002$$

ppm → 10^{-6}

V_{THN} → see Eq. 9.28

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

$$TCV_{THN} = \frac{1}{V_{THN}(T_0)} \cdot \frac{\delta V_{THN}}{\delta T}$$

Eq. (9.52)

$$\frac{1}{KP}\frac{\delta KP}{\delta T} = \frac{-1.5}{T}$$

← Kelvin

$$I_{REF} = \frac{VDD - V_{GS}}{R}$$

@ 300°K

$$\frac{\delta I_{REF}}{\delta T} = \frac{\delta}{\delta T}\left(R^{-1}(VDD - V_{GS})\right)$$

$$\frac{1}{KP}\frac{\delta KP}{\delta T} = -5{,}000\ ppm/C^{\circ}$$

$$= -0.005/C^{\circ}$$

$$\frac{\delta I_{REF}}{\delta T} = -R^{-2}\cdot\frac{\delta R}{\delta T}(VDD - V_{GS}) + R^{-1}\left(0 - \frac{\delta V_{GS}}{\delta T}\right)$$

$$\frac{\delta I_{REF}}{\delta T} = I_{REF}\cdot\left(-\frac{1}{R}\frac{\delta R}{\delta T}\right) - \frac{1}{R}\frac{\delta V_{GS}}{\delta T}$$

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

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2)

$$TCI_{REF} = \frac{1}{I_{REF}} \frac{\delta I_{REF}}{\delta T}$$

$$= -\frac{1}{R}\frac{\delta R}{\delta T} - \frac{1}{I_{REF}}\frac{\delta V_{GS}}{\delta T}$$

↑ TCR ↑

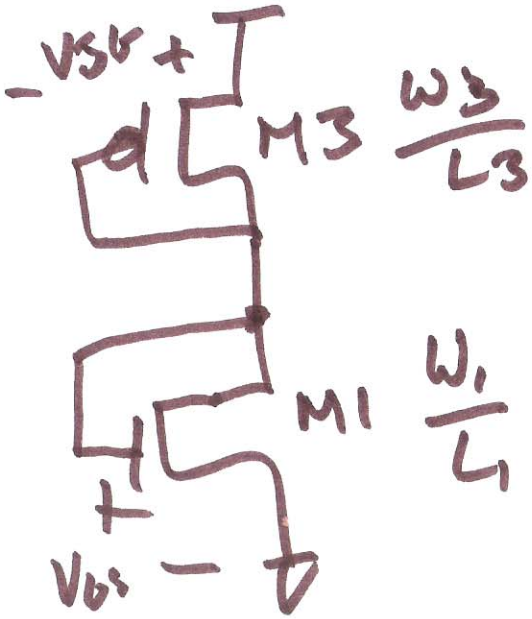
$$TCI_{REF} = -\frac{1}{R}\frac{\delta R}{\delta T} - \frac{1}{V_{DD}-V_{GS}} \cdot \frac{\delta V_{GS}}{\delta T}$$

Ex. 20.4

$$TCI = -1000 \frac{ppm}{C^{\circ}} = -0.001$$

~~$(1 - 10mA \cdot (-.001)$~~

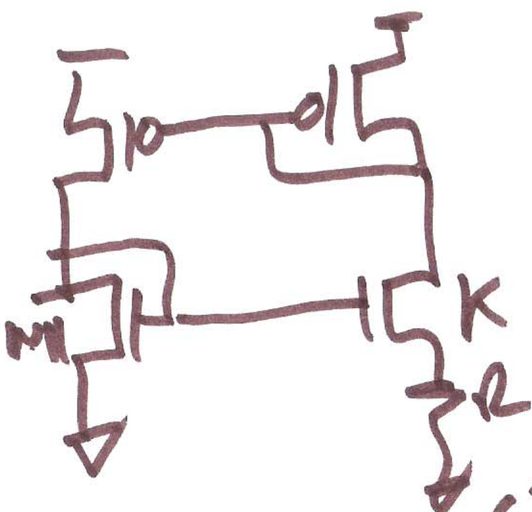
$$I(T) = 10mA(1 - .001(T - T_0))$$



$$VDD = V_{SG} + V_{GS}$$

$$V_{SG} = \sqrt{\frac{2I_{REF}}{\beta_P}} + V_{THP}$$

$$V_{GS} = \sqrt{\frac{2I_{REF}}{\beta_N}} + V_{THN}$$



$$\frac{\delta I_{REF}}{\delta T} = \frac{\delta}{\delta T}\frac{2}{R^2\beta_1}\left(1 - \frac{1}{\sqrt{K}}\right)^2$$

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4)

$$\frac{\delta I_{REF}}{\delta T} = \frac{\delta}{\delta T} 2R^{-2}\beta_1^{-1}\left(1-\frac{1}{\sqrt{K}}\right)^2$$

$$= 2\cdot(-2)R^{-3}\cdot\beta_1^{-1}\left(1-\frac{1}{\sqrt{K}}\right)^2\cdot\frac{\delta R}{\delta T} +$$

$$2R^{-2}\left(-\tfrac{1}{2}\right)\beta_1^{-2}\left(1-\frac{1}{\sqrt{K}}\right)^2\cdot\frac{\delta \beta}{\delta T}$$

$\beta = KP\cdot\frac{W}{L}$

$= \mu_n C_{ox}$

$$= \underbrace{\frac{2}{R^2\beta_1}\left(1-\frac{1}{\sqrt{K}}\right)^2}_{I_{REF}}\left(-\frac{2}{R}\cdot\frac{\delta R}{\delta T} - \frac{1}{\beta_1}\frac{\delta\beta}{\delta T}\right)$$

TC of a resistor

$$\frac{1}{I_{REF}}\cdot\frac{\delta I_{REF}}{\delta T} = -2\left(\frac{1}{R}\frac{\delta R}{\delta T}\right) - \frac{1}{KP_n}\frac{\delta KP_n}{\delta T}$$

$\frac{-1.5}{T}$

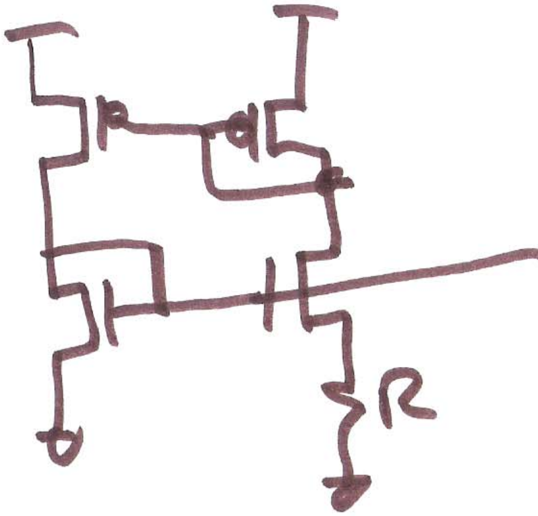
$$TC_{BMR} = -2\left(\frac{1}{R}\frac{\delta R}{\delta T}\right) - \frac{1}{KP}\frac{\delta KP}{\delta T}$$

$$= -.004 \quad + .005$$

$$TC_{BMR} = 1000\ ppm/C°$$

$$\frac{1}{R}\frac{\delta R}{dT} = 0.002$$

$$\frac{-1.5}{300} = -0.005$$



$$V_{REF} = V_{GS1} = \frac{2}{R \cdot KP_n \cdot \frac{W}{L}}\left(1 - \frac{1}{\sqrt{K}}\right) + V_{THN}$$

$$TCV_{REF} = \frac{1}{R}\frac{\delta R}{\delta T} + \frac{1}{KP}$$

Eq. (20.39) Show