Midterm Friday

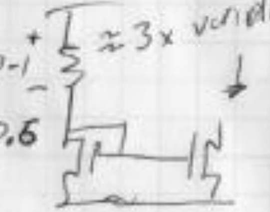
- HW1-8
- Labs 1-3
- 2 pages, 4 sides notes

Supply indep biasing

Bandgap

temp sensor

0.9–1.6



Bad. Why do I care?

supply variation

Affects bias currents

$\Rightarrow g_m, r_o, C_j (C_{db}, \ldots)$

$\Rightarrow$ performance specs

→ overdesign to meet the worst case, waste power elsewhere

Stability: complicates compensation

Simplest fix - V_{th} reference

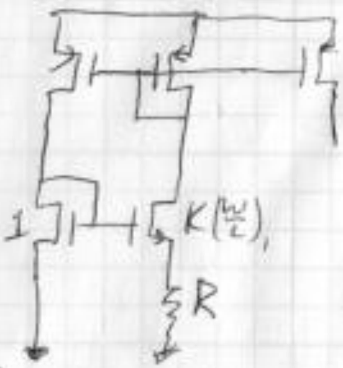
$I_{ref} = \frac{V_{GT}}{R_2}$

$V_{th} + V_{ov1} = V_{th} + \sqrt{\frac{2 I_{D1}}{\mu_n C_{ox} (\frac{W}{L})_1}}$

can have much smaller variation

still get 3x variation in I_{D1} from 1.6 → 0.9, but

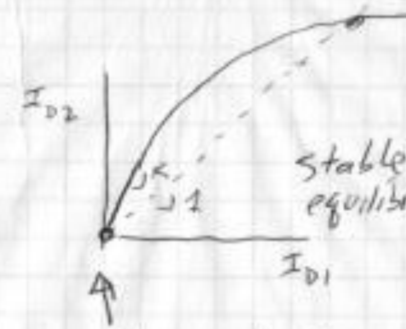
temp-indep



$K = 4$

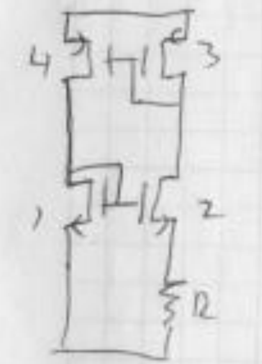
$V_{ov1} = 2V_{ov2}$

$V_{ov2} = I_{D2} R$



nominally unstable equilibrium

but not always

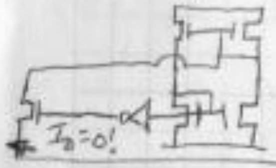


$$\frac{\partial I_{D2}}{\partial V_{DD}} = \frac{i_o}{v_{dd}} \approx \frac{1}{r_{o4}(2K-1)}$$

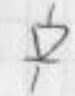
(much ugly algebra)

so use long-channel, or cascode or both.

startup - what if $I_{D1} = I_{D2} = 0$ $V_{GS1} \approx 0$



More fun: Bandgap reference, PTAT

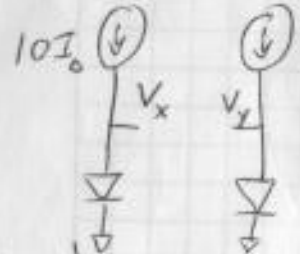


$$I_D = I_S\left(e^{V_D/V_{TH}} - 1\right) \approx I_S e^{V_D/V_{TH}}$$

$$V_D = V_{TH} \ln \frac{I_D}{I_S}$$ $\frac{60\,mV}{decade}$ @ R.T. 300K

$$V_{TH} = \frac{k_B}{q} T$$

V_{TH} is Proportional To Absolute Temperature



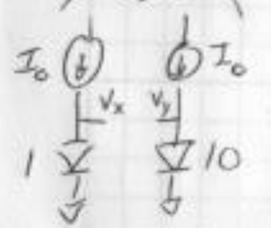
$$V_x = V_{TH} \ln \frac{10 I_o}{I_S}$$

$$V_y = V_{TH} \ln \frac{I_o}{I_S}$$

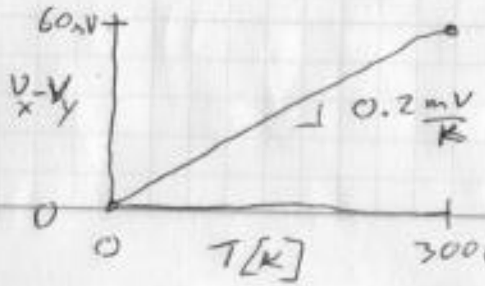
$$V_x - V_y = V_{TH}\left(\ln \frac{10 I_o}{I_S} - \ln \frac{I_o}{I_S}\right)$$

$$= V_{TH} \ln(10)$$

Same result



true even if I_o changes w/ temp.



$$V_D = V_{TH} \ln \frac{I_{fixed}}{I_S}$$

temp response?

$V_{TH} = \frac{k_B}{q} T$ contributes positive coeff.

factor of ≈ 2 over automotive temp.

I_S increases by 10^5 from -40 to +85 C

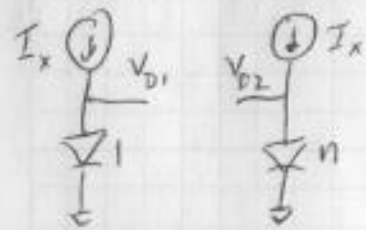
result: at const current, V_D has a negative temp coeff $\approx -2\frac{mV}{K}$

depends on current density

mag decreases w/ decreasing current

Say V_{D1} temp co $= -2\frac{mV}{K}$

$V_{D1} = 0.6V$ at $300K$

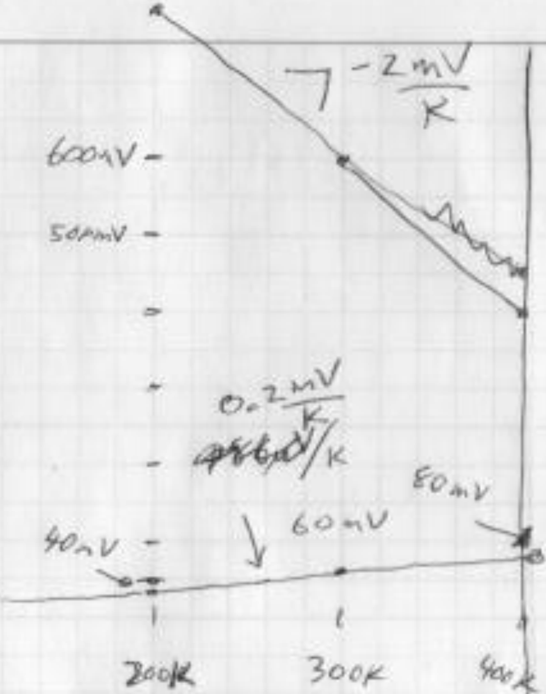


if I_x constant

$V_{D1} = V_{D1}(300K) - \left(2\frac{mV}{K}\right)\Delta T$

$V_{D1} - V_{D2} = V_{TH} \ln(n)$

Say n=10



goal: $V_{D1} + M(V_{D1} - V_{D2}) = V_{out}$

$V_{out} = V_{D1}(300K) - 2\frac{mV}{K}\Delta T + M\left([illegible]\right)T$

$0.2mV/K$

choose $M = 10$

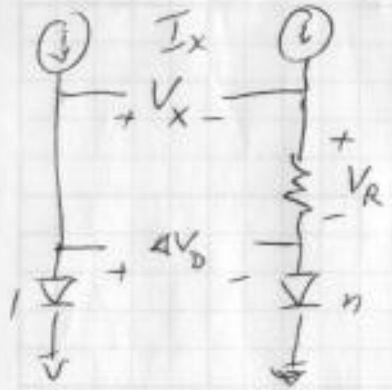
$V_{out} = 0.6V - 2\frac{mV}{K}\Delta T + 2\frac{mV}{K}(300 + \Delta T)$

$= 1.2V + \left(-2\frac{mV}{K} + 2\frac{mV}{K}\right)T$

$= 1.2V$ indep of T!

"bandgap reference"

How?



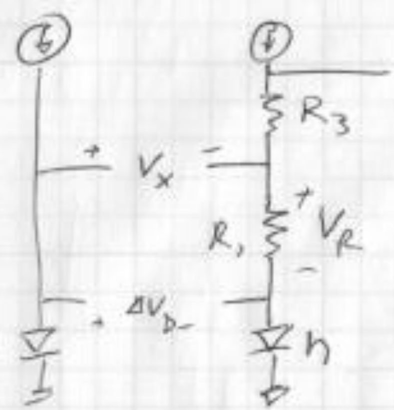
Increase I_x until $V_x = 0$

$V_R = I_x R_1$

if $V_x = 0$ then

$V_R = \Delta V_D = V_{TH} \ln(n)$

$= PTAT!$



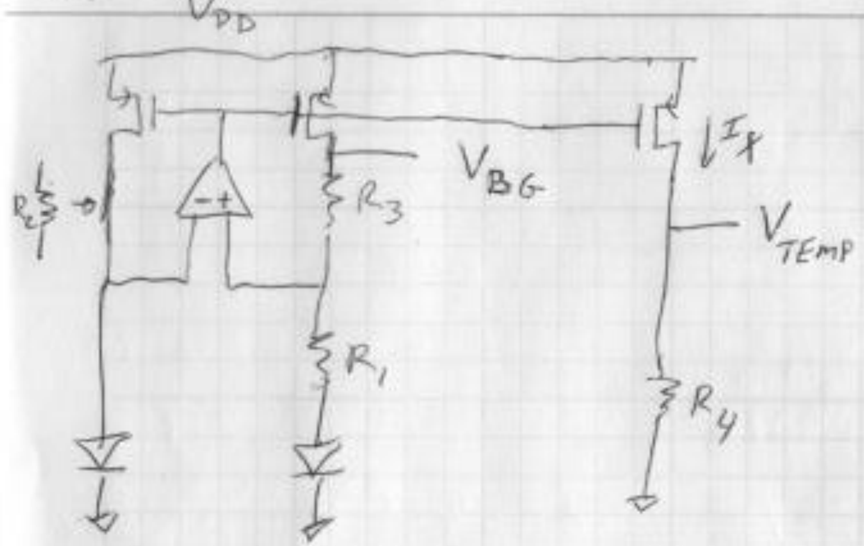
$V_{out} = V_{D2} + I_x(R_1 + R_3)$

$= V_{D2}(300K) + \alpha \Delta T$

$+ \underbrace{V_{TH} \ln(n) \frac{R_1 + R_3}{R_1}}$

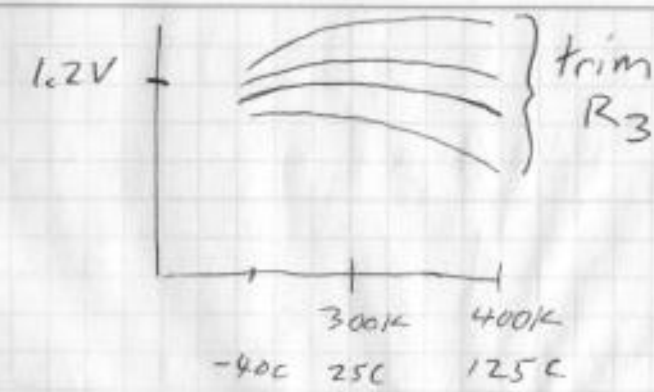
$\underbrace{\frac{R_1 + R_3}{R_1} \frac{k_B}{q} \ln(n) T}$

choose to be $-\alpha$



$$V_{TEMP} = I_x R_4 = V_{TH} \ln(n) \frac{R_4}{R_1}$$

Result



10s of mV of variation over temp.