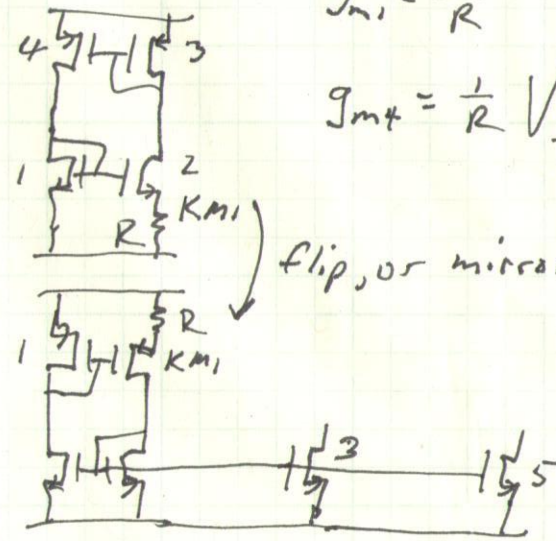
Supply indep. bias
startup
Bandgap reference

Midterm next friday 80 minutes

Last time



$g_{m1} = \frac{1}{R}$

$g_{m4} = \frac{1}{R}\sqrt{\frac{\mu_p C_{ox}(W/L)_p}{\mu_n C_{ox}(W/L)_n}}$

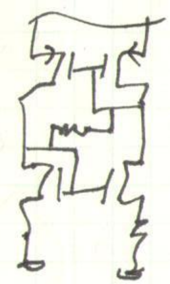
flip, or mirror currents

from small signal model (usly)

$$\frac{\partial I_2}{\partial V_{DD}} = \frac{i_o}{v_{dd}} = \frac{1}{r_{o4}(2K-1)} = \frac{1}{7 r_{o4}} \text{ if } K=4$$

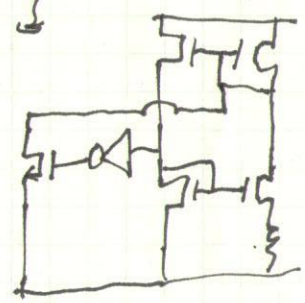
so long channel, or cascode PMOS
to set stable current (supply indep)

startup: $V_{gs}=0$, $I_d=0$ is a stable state!



add resistor

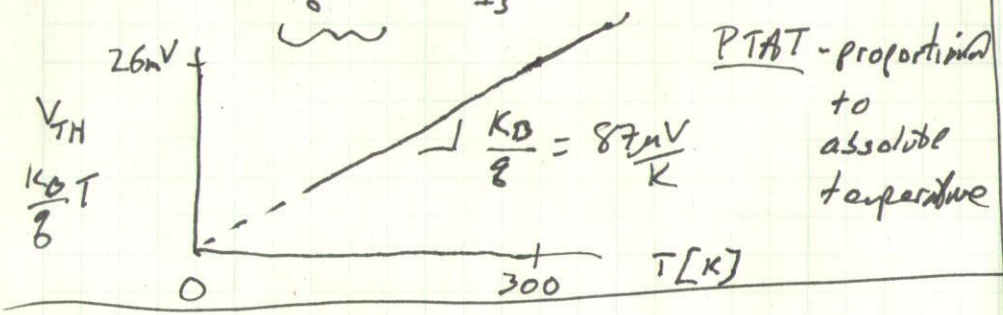
or detect $V_{gs}=0$



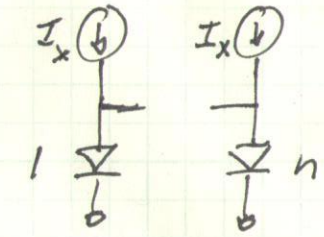
Diodes $I_D \cong I_S e^{V_D/V_{TH}}$

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

$= \frac{K_B}{q} T \ln \frac{I_D}{I_S}$



PTAT - proportional to absolute temperature

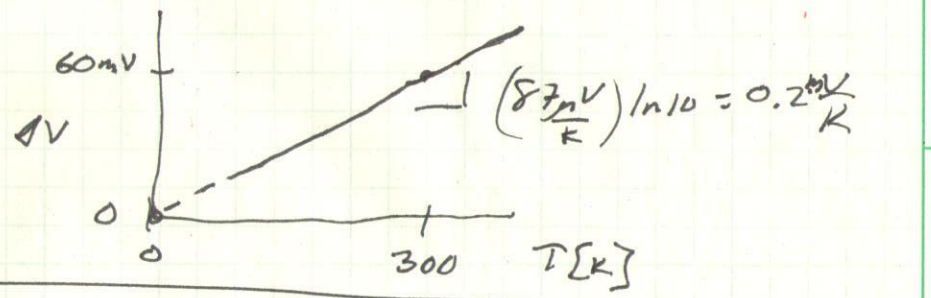


$\Delta V = V_{D1} - V_{D2}$

$= V_{TH} \ln n$

if n=10, at room temp

$\Delta V = 60mV$



Goal: find something with a negative temp co. and cancel! (voltage)

I_x = const indep of temp.

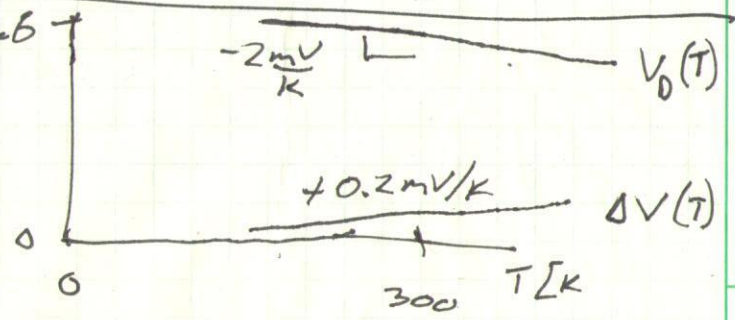
$V_D(T) = V_D(300K) + \alpha \Delta T$

$\frac{K_B}{q} T \ln \frac{I_x}{I_S}$

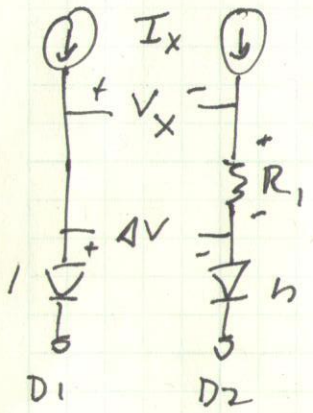
positive charge w/T

huge positive charge w/T ~ 10^5 from -40 to +85

result: $\alpha \cong -1.5 - 2\frac{mV}{K}$



multiply ΔV by ≈10 and add it to $V_D(T)$



$V_{R1} = I_x R_1$

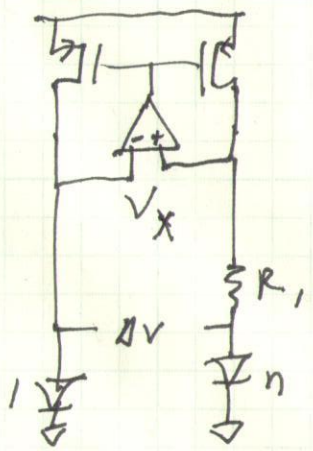
$V_{x-} = V_{D2}(T) + I_x R_1$

increase I_x from 0 until V_{x-} equals V_{x+}, i.e. $V_x = 0$

therefore $I_x R_1 = \Delta V = V_{TH} \ln n$

$= PTAT$

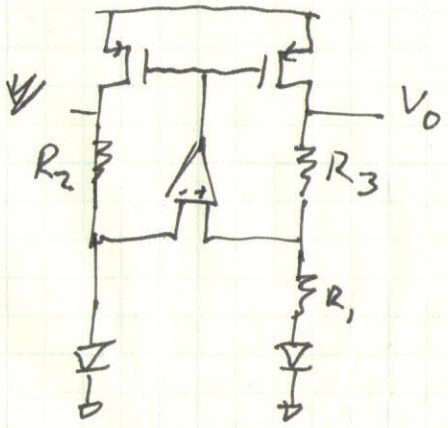
How to set $V_x = 0$



enforces $V_x = 0$

$I_x R_1 = \Delta V$

$= \frac{k_B T}{q} \ln n$



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

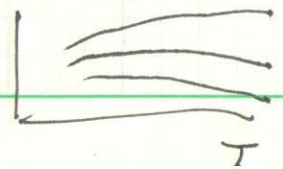
$$V_o = \underbrace{V_{D2}(300K) + \alpha \Delta T}_{\text{negative}} + \underbrace{\frac{k_B T}{q} \ln(n)}_{\text{positive}} \underbrace{\frac{R_1 + R_3}{R_1}}_{\text{pick}}$$

V_{D2}, ~~negative~~ temp co. $\simeq -2 \frac{mV}{K}$

~~positive~~ temp co. $\simeq 0.2 \frac{mV}{K}$

result: $V_o \simeq$ indep of temperature

physics/math: V_o = silicon bandgap at $T = 0$ K



trim to get flat.