Midterm 2 Friday 80 minutes, either
2:30-4
or 4-5:30

HW8 - 3 midterms online - lots of similarity!

Guest lecture Monday: Prof. Nguyen

~~If both diodes are kept at constant current,~~

$\Delta V_+ = V_{D1} - V_{D2} = V_{TH} \ln 10 = \frac{k_B}{q} \ln 10\, T$

$= 60mV @ 300K = (0.2mV/K)(300K)$

$= 40mV @ 200K$

$= 80mV @ 400K$

What if both diode currents are <u>increased</u> by a factor of 2.7

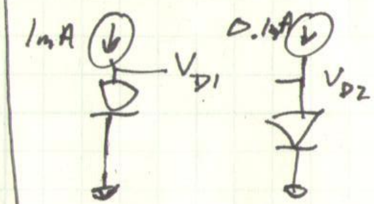
impact on $\Delta V = ?$ no impact

impact on $V_{D1} = ?$ increase V_D by 26mV @ 300K

$\frac{2}{3}$ as much at 200K

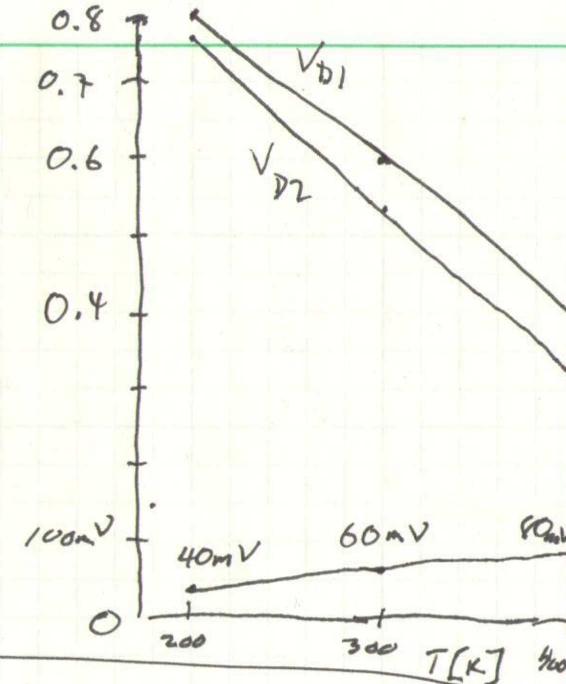
$\frac{4}{3}$ as much at 400K

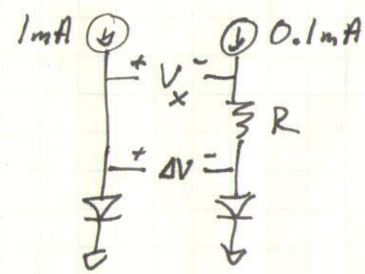
Bandgap



$V_{D1} = 0.6$ @ 300K

$TC\, V_D = -2mV/K$





if $R = 600\Omega$

What is voltage drop? 60mV

What is V_x at R.T.? 0

What is V_x at 400 K?

$V_x = \Delta V - I_{D2} R = 80mV - 60mV$
$= 20mV$

To set $V_x = 0$

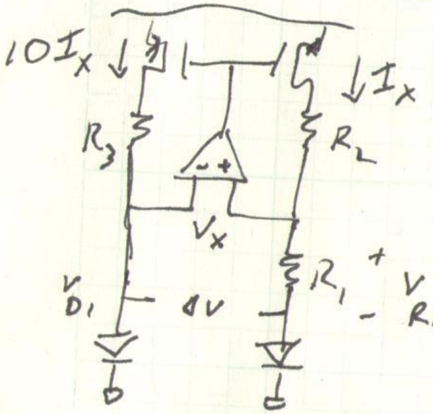
need to increase current by $\frac{1}{3} \Rightarrow 0.13mA = I_{D2}$
$1.3mA = I_{D1}$

$V_x = \Delta V - I_{D2} R = 80mV - 80mV = 0mV$

~~what if~~ - What current makes $V_x = 0$ @ 200K?

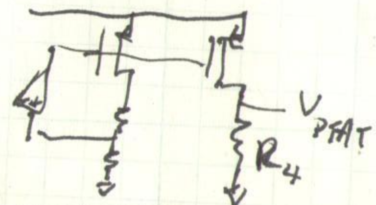
0.066

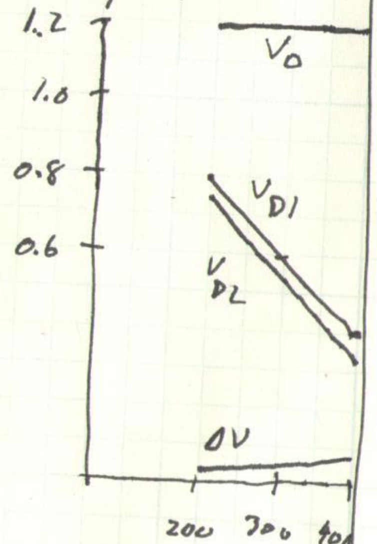
0.66



$+$ $V_{R1} = V_{TH} \ln 10$ $-$

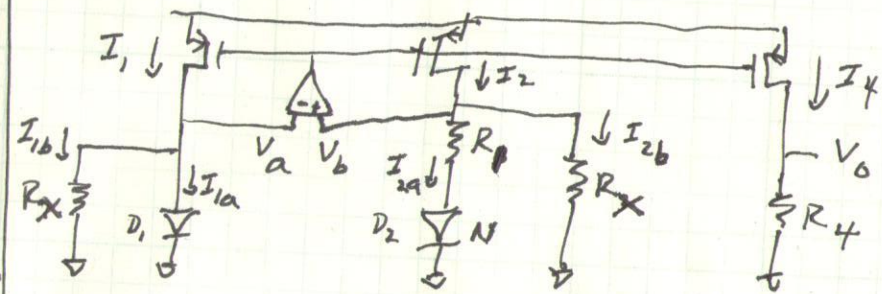
$V_{R2} = I_X R_2 = \frac{R_2}{R_1} V_{TH} \ln(10)$





Great! But how to make it work from 0.8V?

Banba, 1999



Assume $V_a = V_b$ (op-amp)

$I_1 = I_2 = I_3$ (long channels)

$I_{1b} = I_{2b}$ same voltage, same R_X

$I_{1a} = I_{2a}$ $I_1 = I_2$, $I_{1b} = I_{2b}$

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

$V_{R1} = \Delta V = V_{TH} \ln(n)$

$I_{2a} = \frac{\Delta V}{R_1}$

$I_{2B} = I_{1B} = \frac{V_{D1}}{R_X}$

$I_4 = I_2 = I_{2a} + I_{2B} = \frac{\Delta V}{R_1} + \frac{V_{D1}}{R_X}$

$V_o = R_4 \left(\frac{V_{TH} \ln(n)}{R_1} + \frac{V_{D1}}{R_X} \right) = \frac{R_4}{R_X} \left(\frac{R_X}{R_1} V_{TH} \ln(n) + V_{D1} \right)$

choose $\frac{R_X}{R_1}$ to match temp coefficients

e.g. 10:1

choose $\frac{R_4}{R_X}$ to scale output, e.g. 1:2

$$V_o = \frac{1}{2}\Big(\underbrace{10\left(0.2\tfrac{mV}{K}\right)(T)}_{\frac{R_X}{R_1} V_{TH} \ln 10} + \underbrace{0.6 + \left(-2\tfrac{mV}{K}\right)(T - 300K)}_{V_{D1}} \Big)$$

$$= \frac{1}{2}(0.6 + 0.6) + \left(+\frac{2mV}{K} - \frac{2mV}{K}\right)(T - 300K)$$

$$= 0.6$$

Back to 2 stage.

$$A_v = \frac{A_{v0}\left(1+\frac{s}{\omega_{zm}}\right)\left(1-\frac{s}{\omega_{zc}}\right)}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)\left(1+\frac{s}{\omega_{pm}}\right)}$$

RHP zero: push higher w/ R_z or other trick

Mirror doublet: usually not too much trouble
design for a bit higher PM to address

Would be much easier w/o that 2^{nd} pole, but we'd like more gain than just $\left(\frac{g_m r_o}{2}\right)$

Problem ~~Headroom~~ later

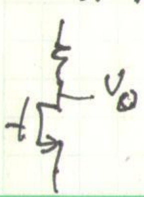
Benefit: single pole? well no, but close

$\omega_{p1} = \frac{1}{R_O C_o}$ $\quad R_o = \frac{1}{2} g_m r_o^2$

others: ω_{pm}, ω_{zm}

$\omega_{pcascode}$

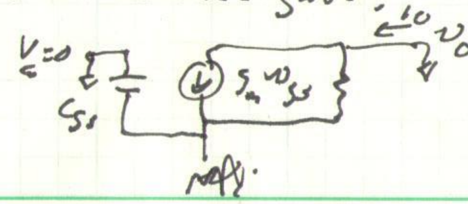
What is freq response of a common gate?



$G_m = \frac{i_o}{v_i}\Big|_{v_o=0}$

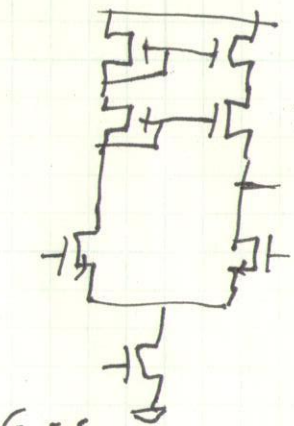
$i_o = -g_m v_i$

$G_m = -g_m$



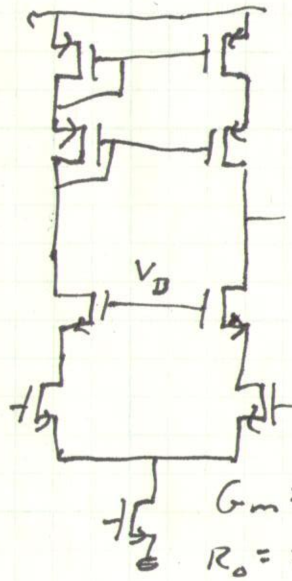
Solution: cascode

① telescopic



$G_m = g_{m1}$

$R_O = r_{o1b} \leftarrow 2X$

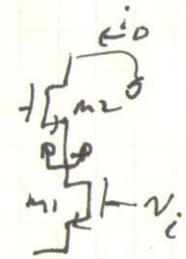


$G_m = g_{m1}$

$R_o = \frac{1}{2}(g_m r_D) r_o$

but $Z_i = \frac{v_i}{i_i} = \frac{1}{g_m + sC_{gs}} = \frac{1}{g_m}\frac{1}{1+\frac{s}{\omega_p}}$

$\omega_p = \frac{g_m}{C_{gs}}$



$$i_o = -g_{m1}\underbrace{\left(\frac{1}{g_{m2}}\frac{1}{1+\frac{s}{\omega_{pm}}}\right)}_{v_{s2}}(-g_{m2})$$

$$= g_{m1}\frac{1}{1+\frac{s}{\omega_{pm}}}$$