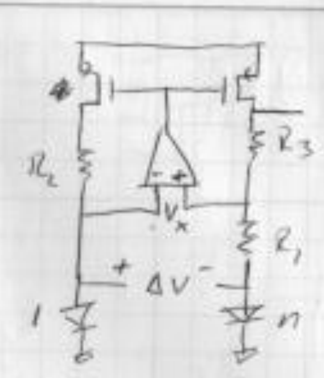
Midterm Friday in class
HW1-8
Las 1-3
2 pages, 4 sides notes

Bandgap

Temp sensor

Cascode



Driving $V_x = 0$ enforces that

$IR_1 = V_{TH} \ln(n)$ PTAT

$V_{D1} = V_{D2} + IR_1$

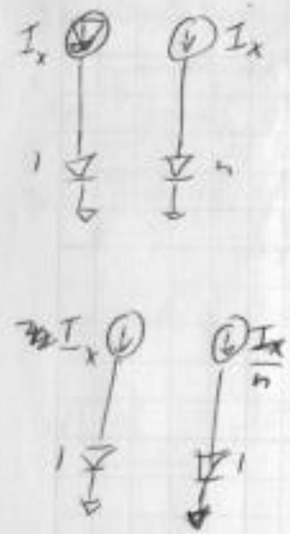
$V_{BG} = V_{D1} + IR_3$

$= V_{D1} + V_{TH} \ln(n) \frac{R_3}{R_1}$ ← M, choose to set 0 temp coeff.

$\Delta V = \frac{K_B}{q} \ln(n)\, T$

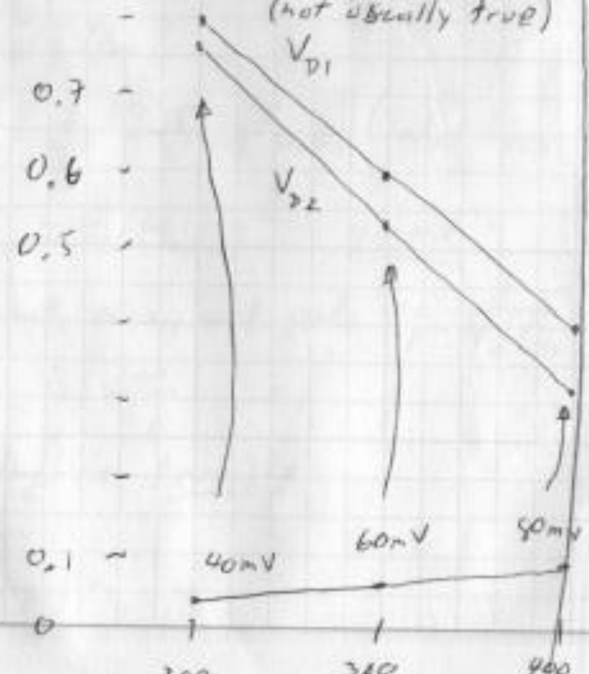
$86 \frac{\mu V}{K}$

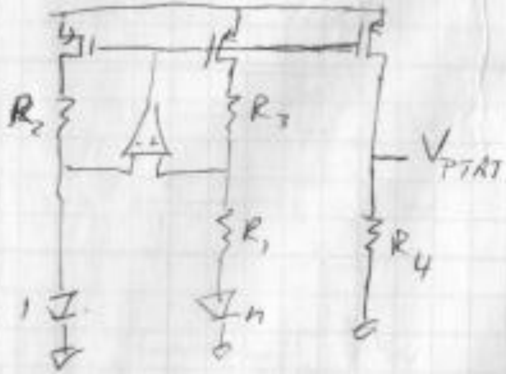
$0.2 \frac{mV}{K}$ if n=10



n=2?
n=7?
both current and diodes?

assume I_x constant (not usually true)





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

feed to ADC for temp measurement.

what topology to use?

NMOS input: trouble w/ input common mode

PMOS input 5T: trouble w/ output swing.

2 stage? current mirror?

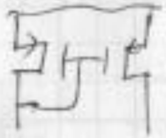
~0 V_{th} transistors?

One more op-amp topology family: cascode.

issues/goals: gain ~ $g_m r_o$ often not enough
stability single stage is nice
I/O range prefer more flexibility

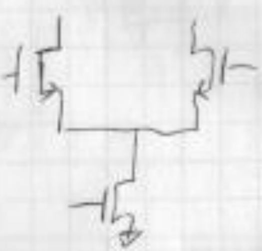
telescopic cascode: solves first 2
trouble w/ third

vs. resistor



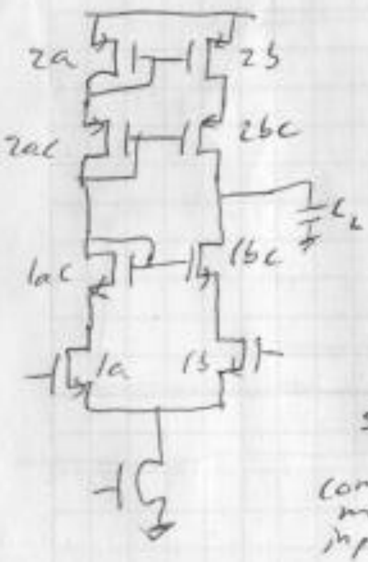
high output impedance (r_o)
easy biasing
2× g_m

want to add output resistance
cascodes boost by $(g_m r_o)_{casc.}$



common mode rejection
differential current

simplest bias



$G_m = g_{m1}$

$R_o = (g_m r_o)_{1c} r_{o1b} \| (g_m r_o)_{2c} r_{o2b}$

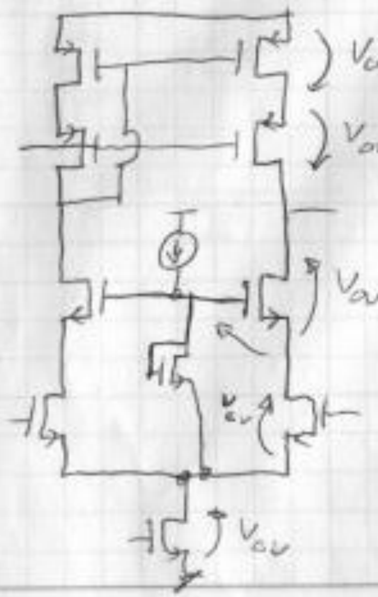
$A_v \approx \frac{1}{2} (g_m r_o)^2$ good

single dominant pole $\omega_{p1} = \frac{1}{R_o C_o}$

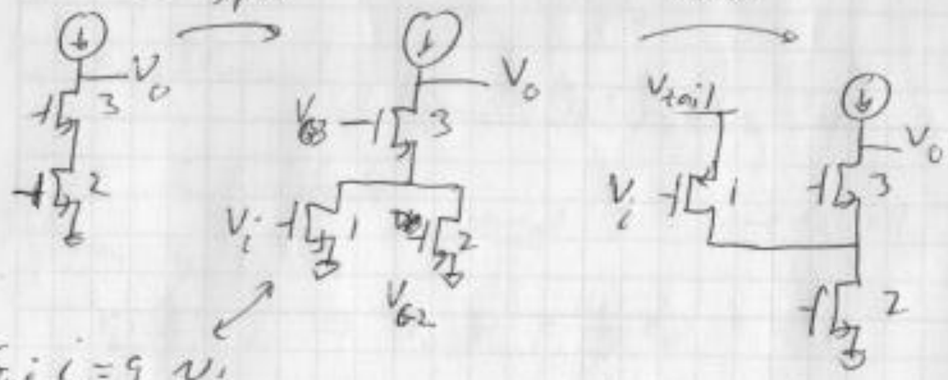
$\omega_u \approx \frac{g_{m1}}{C_o}$

swing, common mode input range } is terrible

with some tricks



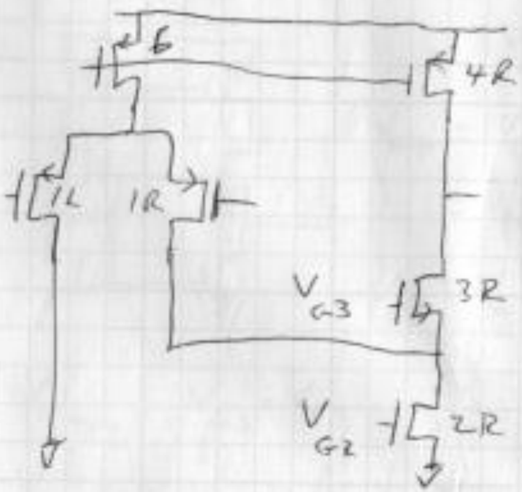
folding



G_m: $i_o = g_{m1} v_i$

G_m: $i_o = g_{m1} v_i$!

Fewest transistors folded differential input stage



$G_m = g_{m1R}/2$

$R_o = r_{o4R}$

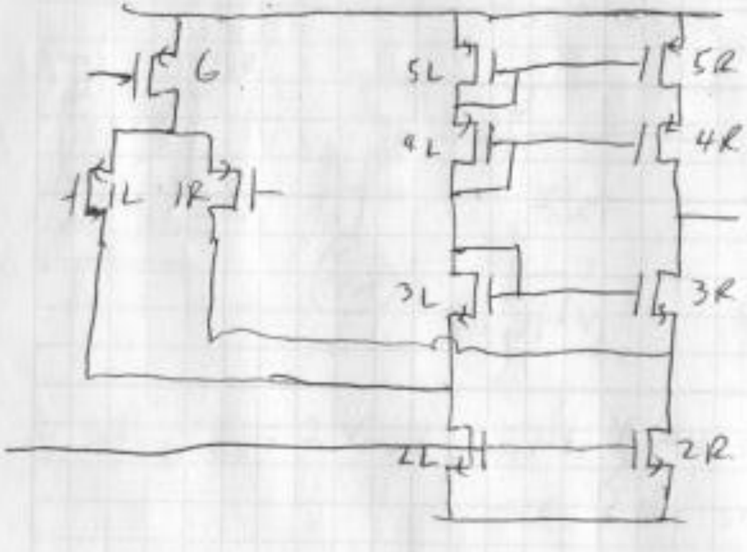
(could cascode)

V_{icm} min $= V_{ov2} - |V_{tp}|$

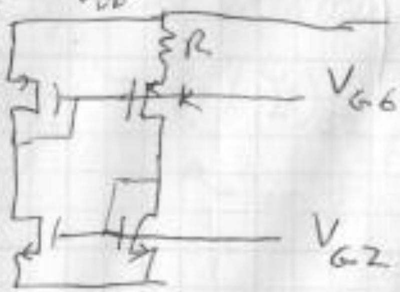
typ < 0 !

 works!

simplest folded cascode (self-biased)



Bias



V_{G6} ⇐ not the smallest V_{ov} possible, but often $V_{icm,max}$ is not important.

V_{G2}

e.g. 

$G_m = g_{m1}$ $\quad R_{o,up} = (g_m r_o)_4 r_{o5}$

$R_o = R_{o,up} \| R_{o,down}$ $\quad R_{o,down} = (g_m r_o)_3 (r_{o2} \| r_{o1})$

<u>if</u> $I_{D1} = I_{D345}$ <u>and</u> λ = same for all

then $I_{D2} = 2 I_{D1}$

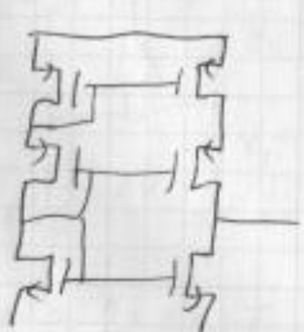
$r_{o2} = \frac{1}{2} r_{o1} \Rightarrow r_{o2} \| r_{o1} = \frac{1}{3} r_{o1} = \frac{1}{3} r_{o5}$

<u>if</u> g_m same for all then

$R_o = (g_m r_o)_{345} (r_{o5} \| \frac{1}{3} r_{o5}) = \frac{1}{4} (g_m r_o)_{345} r_{o5}$

$A_v = \frac{1}{4} (g_m r_o)^2_{1345}$ <u>lots</u> of "if"s

output swing of self-biased:



$V_{G5} = V_{DD} - |V_{tp} + V_{ov5}|$

$V_{G4} = V_{G5} - |V_{tp} + V_{ov4}|$

$= V_{DD} - 2|V_{tp} + V_{ov4}|$

$V_{G3} = V_{G4}$

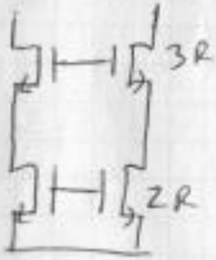
$V_{o,min} = V_{G3} - V_{tn}$

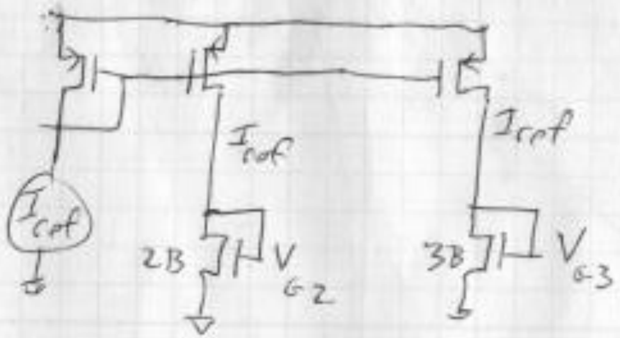
$V_{o,max} = V_{G4} + |V_{tp}|$

$\Big\} \; V_{tn} + |V_{tp}|$

better biasing

<u>like</u> $V_{G3} = V_{G3,min} = V_{th} + V_{ov3} + V_{ov2}$





to set $V_{ov3} = 2 V_{ov2}$, either $\begin{cases} 4\times \text{ current} \\ \text{or } 4\times \text{ smaller } (\frac{W}{L}) \end{cases}$

typically add a little margin

$\left(\frac{W}{L}\right)_{B3} = \frac{1}{5} \left(\frac{W}{L}\right)_{B2}$

↖ or $\frac{1}{6}$ integer multiples

(B2 is 5 or 6 <u>copies</u> of B3)