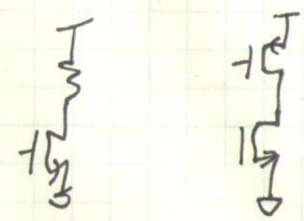
OH tomorrow
HW3

CS amplifier.
Resistive load
quadratic, low, med bias
sub-V_t
scl

CS w/ quadratic model



Say $\mu_n C_{ox} = 200\mu A/V^2$

$\mu_p C_{ox} = 100\mu A/V^2$

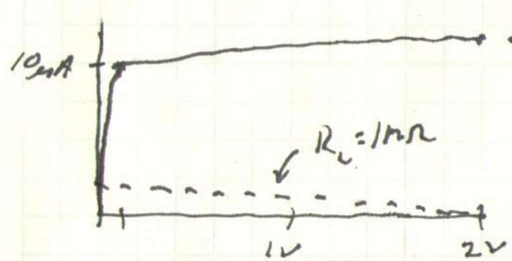
$\lambda = \frac{1}{10V}$ when $L = 0.5$

$-V_{tp} = V_{tn} = 0.5V$

$V_{DD} = 2V$

$\frac{W}{L} = \frac{5\mu}{0.5\mu m}$, resistive load, $V_I = 0.6V$

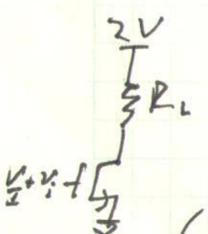
$I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_I - V_{tn})^2(1+\lambda V_{DS}) = \left(\frac{1mA}{V^2}\right)(0.1V)^2\left(1+\frac{V_{DS}}{10V}\right)$
2?



$\leftarrow 10\mu A\left(1+\frac{2V}{10V}\right) = 12\mu A$

$r_o = \frac{1+\lambda V_{DS}}{\lambda I_D} = \frac{10V}{10\mu A}$
$= 1M\Omega$

$g_m = \frac{2I_D}{V_{ov}} = \frac{20\mu A}{0.1V} = 0.2mS$



How to choose R_L?

TRY: pick $R_L >> r_o$ to get close to intrinsic gain

$\left(A_v = -g_m(r_o \| R_L) \approx -g_m r_o = \text{int. gain}\right)$

possible? NO!

TRY2: $R_L = r_o$? possible? NO.

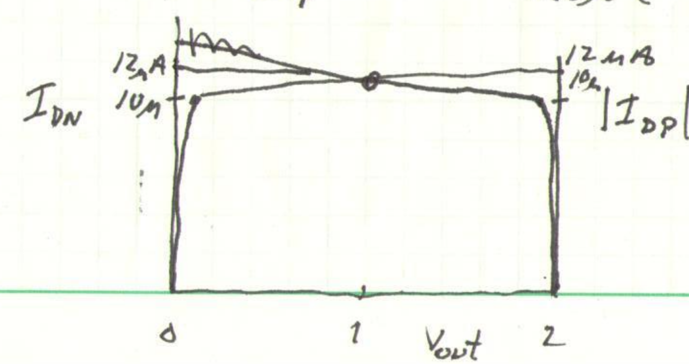
CMOS active load

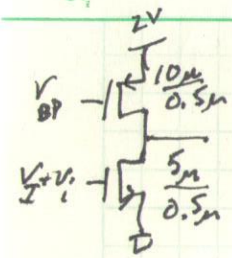
choose $|V_{ovp}| = V_{ovn} = 0.1V$

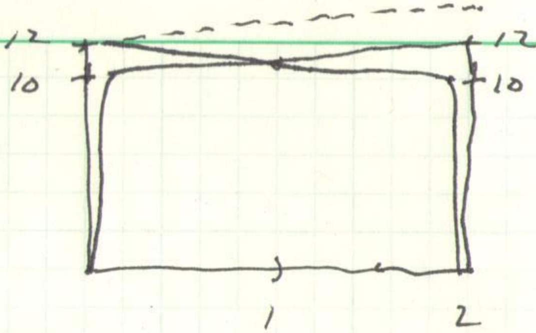
Solve for $\left(\frac{W}{L}\right)_p$ $\quad 10\mu A = \frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)_p (V_{ovp})^2(1+\lambda V_{DSp})$

$10\mu A = \frac{50\mu A}{V^2}\left(\frac{W}{L}\right)_p (0.1V)^2(1+\lambda V_{DSp})$

$\left(\frac{W}{L}\right)_p = 20 = \frac{10\mu}{0.5\mu} \leftarrow$ choose







What if I increase v_i by 10mV?

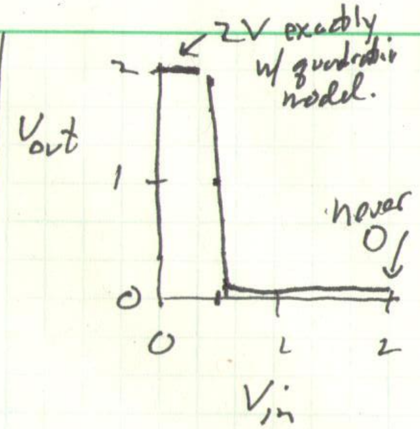
$i_d = g_m v_i = \left(200\frac{\mu A}{V}\right)(0.01V) = 2\mu A$

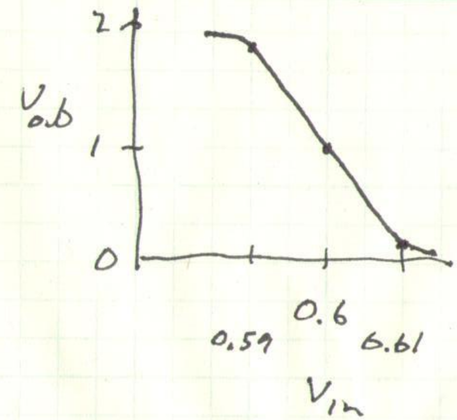
What if I decrease v_i by 10mV?

$i_d = -2\mu A$

$V_{out} \downarrow < 0.1V$ NMOS out of saturation

$V_{out} \nearrow > 1.9V$ PMOS out of saturation



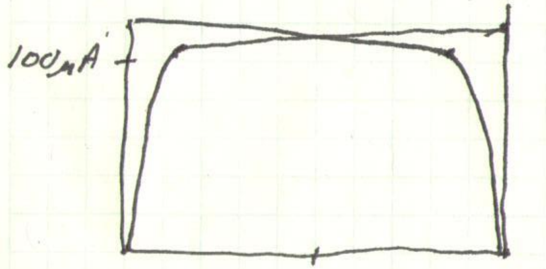


$A_v = -g_m (r_{on} \| r_{op})$

$= -200\frac{\mu A}{V^2}(1M \| 1M) = -100$

$= \frac{2I_D}{V_{OV}}\left(\frac{1}{\lambda I_D} \| \frac{1}{\lambda I_D}\right) = \frac{1}{\lambda V_{OV}} = \frac{V_A}{V_{OV}}$

What if $V_I = 0.82V$? $V_{OV} = 0.32$ $0.32^2 = 0.1$



$V_{BP} = 2V - (|V_{tp}| + |V_{ov}|)$

$= 2V - 0.82$

$= 1.18V$

$I_D \nearrow 10X$

$r_o = 100K$ $\searrow 10X$

$g_m = \frac{2I_D}{V_{OV}} = \frac{200nA}{0.32V} = \sout{64\frac{\mu A}{V^2}}\ 640\frac{nA}{V^2}$ $g_m \nearrow \sqrt{10}$

$A_v = g_m \frac{r_o}{2}$ $\searrow \sqrt{10}$ ≈ 32

What if $V_I = 0.5V$? SUB-V_t model

if currents are equal around $V_{OV} = 10mV$

then $I_s e^{\frac{V_{GS}}{nV_{TH}}} = 0.1\mu A$ when $V_{GS} = 0.510V$

if $n=1$ $e^{-\frac{10mV}{26mV}} = 0.68$

if $n=2$ $e^{-\frac{10mV}{52mV}} = 0.82$

so current is around 0.07 or $0.08\mu A$

$r_o \approx 100M = \frac{1}{\lambda I_D}$ ← not a great model

$g_m = \frac{I_D}{nV_{TH}} = \frac{75nA}{26mV} = 3\mu S$

$A_v \approx 300$

what if $V_I \simeq 1.5V$? $V_{OV} = 1V$ $\frac{V_{OV}}{L} = \frac{2V}{\mu m}$

scattering limited!

$I_D = W C_{ox} v_{scl} (1 + \lambda V_{DS}) V_{OV}$ — $(1+\lambda V_{DS})$: not a great model

$g_m = \frac{\partial I_D}{\partial V_{OV}} = \frac{I_D}{V_{OV}}$

$I_D = (5\ \mu m)(5 \frac{fF}{\mu m^2})(10^5 \frac{m}{s})(1V)$

$= 25 \times 10^{-10} \frac{C}{\mu m} \frac{m}{s}$

$= 25 \times 10^{-4} A = 2.5 mA$

$g_m = 2.5 mS$

$r_0 = \frac{10V}{2.5mA} = 4K\Omega$

$A_v = 10$

$\omega_u = \frac{g_m}{C_L} = \frac{2.5mA}{100 fF} = 25 G\ rad/sec$

$= 3 GHz$

	quadratic		sub V_t	SCL.
V_{OV}	100mV	320mV	0mV	1V
I_d	10μA	100μA	75nA	2.5mA
swing	0.1-1.9	0.32-1.68	0.05-1.95	crap.
g_m	200 μA/V	640 μA/V	3 μA/V	2.5 mA/V
r_o	1M	100K	100M?	4K?
A_v	100	32	300	10
ω_u	2G rad/s	6G rad/s	30M rad/s	25G rad/s

200X (30M → 6G)   1000X (30M → 25G)

quadratic: $V_{OV} \nearrow X$

$I_d \nearrow X^2$

$g_m \nearrow X$

$r_0 \searrow \frac{1}{X^2}$

$A_v \searrow X$

$\omega_u \nearrow X$

power $\nearrow X^2$

SCL is ~100x faster than $V_{OV} = 100mV$ and 2,500 times more power hungry and the gain sucks

sub-V_t is parsimonious w/ power, but slow gain is good