Midterm in 1 week in class · 1 page, 2 sides notes
No silicon

CS amplifier

Fixed dimensions, varying bias
scaling
design problem

Midterm
HW 1-4
Lab 1

process: 0.5 μm CMOS $\mu_n C_{ox} = 200 \frac{\mu A}{V^2}$, $\mu_p C_{ox} = 100 \frac{\mu A}{V^2}$

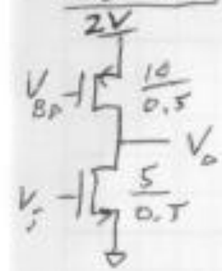
$V_{DD} = 2V$, $V_{tn} = -V_{tp} = 0.5\,V$ $\lambda = \frac{1}{10V} \frac{0.5\mu}{L}$

quadratic model good for $V_{OV} > 100\,mV$

I_s in sub V_t ≈ quadratic model w/ $V_{OV} = 10\,mV$, $n = 2$

velocity saturated when $V_{OV} > 500\,mV$

Last time: analysis of 2 quadratic bias points



$V_I = 0.6$, $V_{BP} = 1.4$ $|V_{GS}| = 0.6$, $|V_{ov}| = 0.1$

$V_I = 0.82$, $V_{BP} = 1.18$ $|V_{GS}| = 0.82$, $|V_{ov}| = 0.32$

today: sub-V_t "weak inversion"?
velocity sat.

and let's add $C_L = 1\,pF$

and calculate ω_u, ω_p, and C_{in}

$C_{gs} = \frac{2}{3}(2.5\,\mu m^2) 5 \frac{fF}{\mu m^2}$
$= 8\,fF + 2.5\,fF$

$C_{gd} = 5(0.5 \frac{fF}{\mu m}) = 2.5\,fF$

	quadratic			
V_{OV}	100mV	320mV	0	1000mV
V_I	0.6	~~1.4~~	0.5	1.5
V_{BP}	0.82	1.18	1.5	0.5
V_{OUT}	1	1	1	1
I_D	10μ	100μA	10nA	2.5mA
g_m	200μS	600μS	2nS	2.5mS
r_o	500k	50k	100M	4kΩ
A_V	100	30	200	10
C_{in}	260fF	85fF	510fF	38fF
swing	(0.1, 1.9)	(0.32, 1.68)	(0.05, 1.95)?	(1V, 1V)
ω_p	2×10^6	2×10^7	$10^4 \frac{rad}{s}$	250m rad/s
ω_u	200×10^6	600×10^6	$2\times10^6 \frac{rad}{s}$	2.5G $\frac{rad}{s}$

$V_I = 0.5 \Rightarrow V_{BP} = 1.5 \quad V_{ovn} = 0 = V_{ovp}$

sub-V_t model

$I_d = I_s e^{V_{GS}/nV_{TH}} \qquad I_s = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)(10\,mV)^2$

$= 100\,nA$

$g_m = \frac{I_D}{nV_{TH}} = \frac{10^{-7}A}{50\,mV} = 2\,\mu S$

$r_o = \frac{1}{\lambda I_D} = \frac{10V}{10^{-7}A} = 100\,M\Omega$ (bad model)

$A_v = 200 \qquad C_{in} = 510\,fF$

$\omega_p = \frac{1}{10^8 10^{-12}} = 10^4 \frac{rad}{s}$

$\omega_u = \frac{2\times10^{-6}}{10^{-12}} = 2\times10^6 \frac{rad}{s}$ } audio? bias circuits

quadratic model scaling

with fixed $\frac{W}{L}$, if $V_{ov} \nearrow$ by α

$I_d \nearrow \alpha^2$
$g_m \nearrow \alpha$
$r_o \searrow \alpha^2$
$A_v \searrow \alpha$
$\omega_p \nearrow \alpha^2$
$\omega_u \nearrow \alpha$
power $\nearrow \alpha^2$ } bandwidth costs power

Compare to vel sat. limited and Sub-V_t

VSL ~ 10x faster than $V_{ov} = 100\,mV$, but 250x more current! and lousy gain

Sub-V_t is slow, but good for power. & gain

$V_I = 1.5V,\ V_{BP} = 0.5V \qquad E_{ch} = \frac{V_{ov}}{0.5\mu m} = \frac{2V}{\mu m}$ vel. sat.

$I_D = W C_{ox} v_{sl} v_{ov} (1+\lambda V_{DS})$ (ignore)

$= (5\mu m)\left(5\frac{fF}{\mu m^2}\right)\left(10^5 \frac{m}{s}\right)(1V) = 25\times10^{-15+5+6} = 2.5\,mA$

$g_m = \frac{I_D}{V_{ov}} = \frac{2.5\,mA}{1V} = 2.5\,mS$ } $A_v = 10$!

$r_o = \frac{10V}{2.5\,mA} = 4\,k\Omega$ } swing $= (1V, 1V)$ gone!

$C_{in} = C_{gs} + (1-(-10))C_{gd} = 10.5\,fF + 11(2.5\,fF) = 38\,fF$

$\omega_p = \frac{1}{(4\times10^3)(10^{-12})} = 0.25\times10^9 = 250\,M\frac{rad}{s}$

$\omega_u = \frac{2.5\,mS}{10^{-12}} = 2.5\,G\frac{rad}{s}$ ($\approx$ 400 MHz)

$\omega_T = \frac{2.5\,mS}{10\,fF} = 0.25\times10^{12} = 250\,G\frac{rad}{s}$ ($\approx$ 40 GHz)

Design Ex: Spec: $A_{v0} = 50$, $A(1\,G\frac{rad}{s}) = 2$, $C_L = 100\,fF$, $C_{in} < 1\,pF$

Pick $L_n = L_p$ $\Rightarrow r_{on} = r_{op} \Rightarrow A_v = \frac{1}{\lambda V_{ov}}$

$A_v = \frac{10V}{V_{ov}}\frac{0.5\mu}{L}$ pick $L_n = 0.5\,\mu m$

$A_v = \frac{10V}{V_{ov}}$ Calc $V_{ov} = 200\,mV$

Calc $g_m = \omega_u C_o = 2\times10^9\, 10^{-13} = 200\,\mu S$ assume $C_o = C_L$

Calc $\left(\frac{W}{L}\right)_n = \frac{g_m}{\mu_n C_{ox} V_{ov}} = \frac{200\,\mu S}{200\frac{\mu A}{V^2}(0.2V)} = 5$ calc $W_n = 5L_n = 2.5\,\mu m$

Pick $V_{ovp} = V_{ovn}$

$I_{DN} = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_n V_{ov,n}^2 = \frac{\mu_p C_{ox}}{2}\left(\frac{W}{L}\right)_p V_{ov,p}^2$

$I_{DN} = |I_{DP}|$, $L_n = L_p$, $\mu_n C_{ox} = 2\mu_p C_{ox} \Rightarrow W_p = 2W_n$
$= 5\mu m$

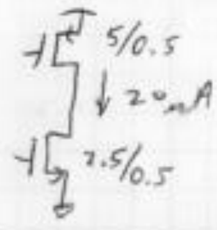
$C_{in} = C_{gsn} + C_{gdn}(1-A)$

$= \frac{2}{3} WL C_{ox} + 2W C'_{oe}(1-50)$ <u>Miller</u>

$= \frac{2}{3}(2.5\mu)(0.5\mu)\frac{5fF}{\mu m^2} + 52(2.5\mu m)(0.5\frac{fF}{\mu m})$

$= 4fF + 65fF$

$= 70fF$



$I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}V_{ov}^2 = \frac{500\mu A}{V^2}(0.2V)^2 = 20\mu A$

$C_o = 100fF$?

$C_{gdn} = (2.5\mu m)(0.5\frac{fF}{\mu m}) = 1.25fF$

$C_{gdp} = 2C_{gdn} = 2.5fF$

$C_o = C_L + C_{gdn} + C_{gdp} = 103.75fF$
noise

What if spec said $A_v = 500$?

pick $L_n = L_p$

$A_v = \frac{10V}{V_{ov}}\left(\frac{L}{0.5\mu m}\right)$ pick $V_{ov} = min = 100mV$ for quadratic

$= 100\left(\frac{L}{0.5\mu m}\right)$

<u>calc</u> $L = 2.5\mu m$

$g_m = 200\frac{\mu A}{V} = \mu_n C_{ox}\left(\frac{W}{L}\right)(V_{ov})$

$= 200\frac{\mu A}{V^2}\left(\frac{W}{L}\right)(0.1V)$

<u>calc</u> $\left(\frac{W}{L}\right)_n = 10$ $W_n = 25\mu m$

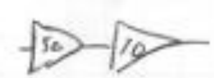
$C_{in} = \frac{2}{3}WL C_{ox} + (1-A)W C'_{oe}$

$= \frac{2}{3}(25\mu m)(2.5\mu m)(5\frac{fF}{\mu m^2}) + 501(25\mu m)(0.5\frac{fF}{\mu m})$

$= 200fF + 6.3pF$

big problem for input cap spec!

Solutions:

1) 2 stages 

2) cascode