P1.

(i) $$f(E) = \frac{1}{1+e^{(E-E_f)/kT}}$$

(a) $E - E_f = 0.5kT$

$$f(E) = \frac{1}{1+e^{0.5}} = 0.3775$$

(b) $E - E_f = 5kT$

$$f(E) = \frac{1}{1+e^{5}} = 0.0067$$

(ii)

(a) $$N_D \cancel{\ } = \cancel{\ } n\, e^{\left(\frac{-E_c - E_f}{kT}\right)}$$

$$E_f - E_c = kT \times \ln\left(\frac{N_D}{\cancel{\ }n}\right) = \cancel{\alpha}\, kT \cdot \ln \frac{1\times10^{13}}{1.5\times10^{10}} = 0.026 \times 6.5023$$

$$= 0.1691\,eV$$

(b) $$E_f - E_c = kT \cdot \ln\left(\frac{5\times10^{14}}{1.5\times10^{10}}\right) = -0.2708\,eV$$

(c). $np = n_i^2$

$n = 45\times10^5\ cm^{-3}$

(iii) (a)

$$V_0 = V_T \cdot \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$V_T = \frac{kT}{q} \approx 0.0259\ V$$

$$V_0 = 0.0259 \times \ln\left(\frac{1.0\times10^{13} \times 5\times10^{14}}{(1.5\times10^{10})^2}\right) = 0.438\ V$$

(b) $W_{dep} = W_p + W_n$

$\varepsilon_S = 11.7 \times 8.85 \times 10^{-4}$

$$= \sqrt{\frac{2\varepsilon_S}{q}\left[\frac{1}{N_A} + \frac{1}{N_D}\right] V_0}$$

$$= \sqrt{\frac{11.7\times10^{-4} \times 8.85}{1.602\times10^{-19}}\left[\frac{1}{5\times10^{14}} + \frac{1}{10^{13}}\right] \times 0.438}$$

$$= 7.605\times10^{-4}\ cm$$

$$\frac{W_p}{W_n} = \frac{N_D}{N_A} = \frac{1}{50} \qquad W_p + W_n = 51 W_p = 7.605\times10^{-4}\ cm$$

$$W_p = 1.49\times10^{-5}\ cm$$

$$W_n = 7.46\times10^{-4}\ cm$$

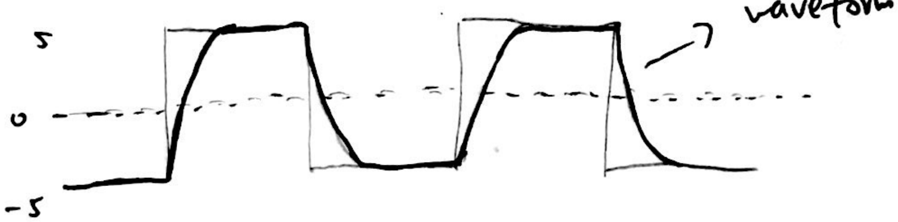
2. (a)

when the voltage reaches 5.7V, the top diode is on and higher voltage will not increase the value.

when the voltage is below -5.7, the bottom diode is on and -5.7V is the lowest that can be observed

$-5.7 \leq out \leq 5.7$

(b)



$t_p = 0.69RC = 0.69 \times 1000000 \times 1 \times 10^{-12} < \frac{1}{2} T$

$T = \frac{1}{100k}$

(C) $C_j = \frac{dQ_j}{dV_d} = A_D\sqrt{\frac{2q\varepsilon_s N_A \cdot N_D}{N_A+N_D}(\phi_0 - V_d)^{-1}}$

$A_D = \cancel{A_D}\ 12\ um^2 = 12\times10^{-6}\ cm^2$ $\varepsilon_s = 11.7 \times 8.85\times10^{-4}$ $q = 1.602\times10^{-19}$

$N_A = 10^{16}$

$N_D = 10^{17}$ $\phi_0 = 0.65$

when $V_{out} = 5.7$. the top diode is on.

the bottom diode is off.

V_d cross it is $\cancel{5.7+5=10.7}$ $-5.7-5=-10.7$

sub in all values.

$C_j = 1.95\times10^{-13}\ f$

P3.

N: $V_{GS} = V_G - V_S$

$= 5 - V_o$

$V_{DS} = V_D - V_S$

$= 5 - V_o$

P: $V_{SG} = V_S - V_G = V_o - V_{in}$

$V_{SD} = V_S - V_D = V_o$

(a) when $V_{in} = 0$ V

N: $V_{DS} > V_{GS} - V_T \Rightarrow$ Sat

P: $V_{SD} > V_{SG} - V_T \Rightarrow$ Sat.

$I_P = I_N$

$k_P (|V_{GS}| - |V_{TH}|)^2 = k_n (V_{GS} - V_{TH})^2$

$\frac{10}{10} \times \frac{20}{10} \times \frac{10}{20} (V_o - \cancel{V_{in}}^{0} - 1)^2 = (5 - V_o - 1)^2 \Rightarrow V_o = 2.5$

when $V_{in} = 5$ V

P: off

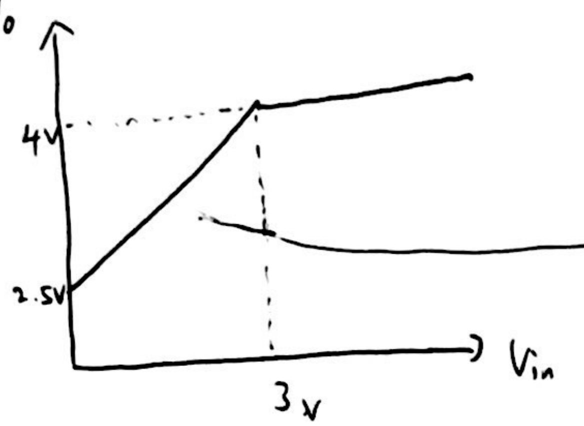
N: Sat

NMOS will be off as well if $V_{GS} < V_{TON}$

$5 - V_o < 1$

Therefore the maximum V_o is $5 - V_{TON} = 4V$

(b)



$$(5 - V_o - 1)^2 = (V_o - V_{in} - 1)^2$$

$$V_o = \frac{5 + V_{in}}{2}$$

(c) $V_T = V_{T0} + \underbrace{\gamma\left(\sqrt{2|\phi_F| + V_B} - \sqrt{2|\phi_F|}\right)}_{A}$

both in sat.

$5 - V_o - V_{T0} - A = V_o - V_{in} - \cancel{V_{T0}A}$ (no body effect for PMOS)

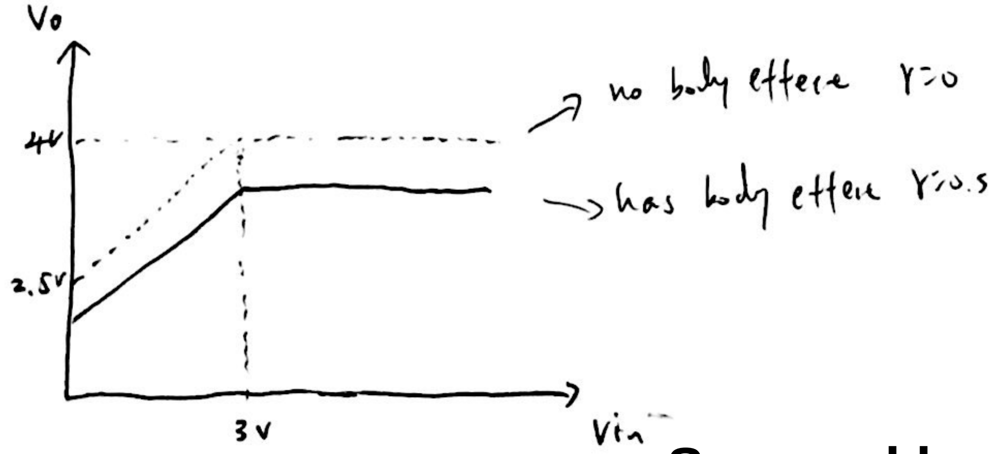
$V_o = \frac{5 + V_{in}}{2} - \frac{A}{2}$ Vo decrease

when P is off.

$V_{gs} - V_{tn} + A = 0$

$V_o = 4 - A$

Vo decrease



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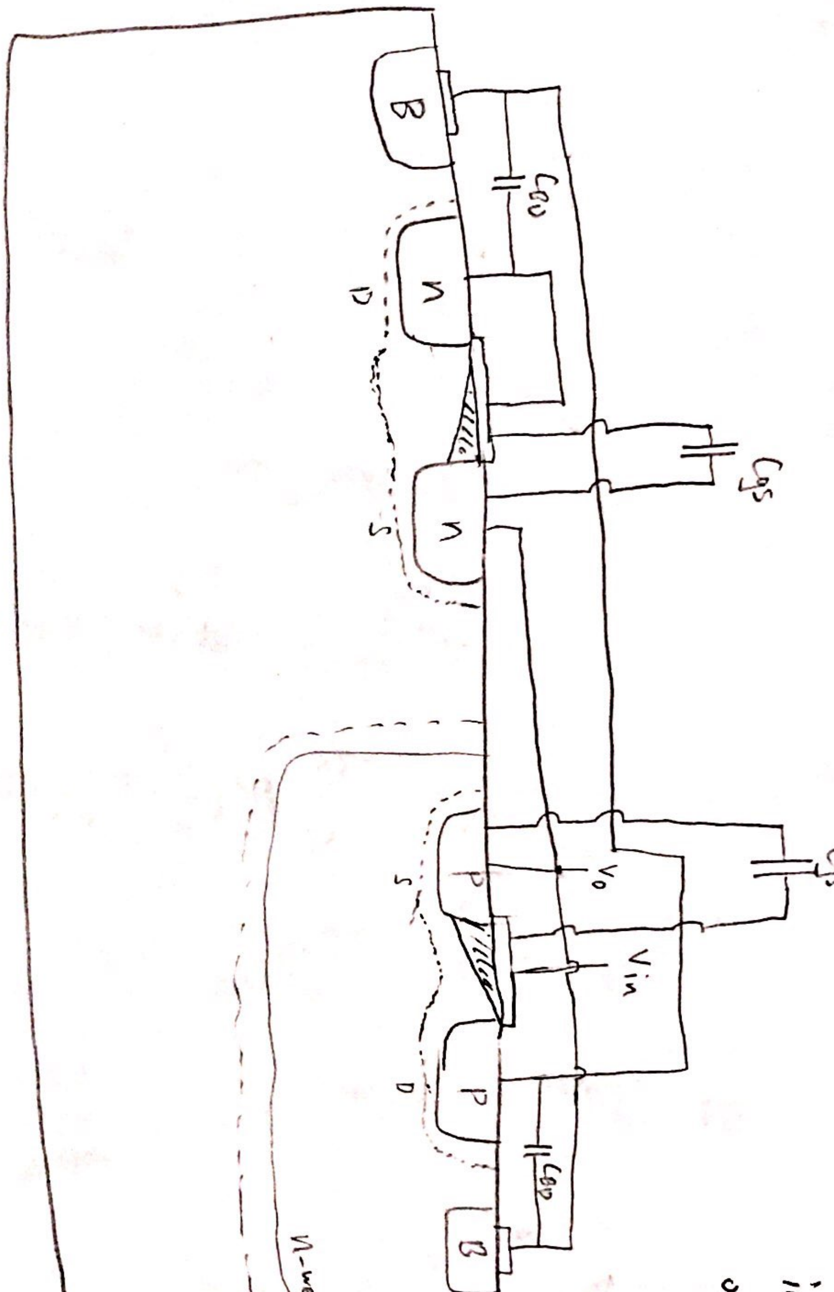

in Saturation only Cgs and Cgd

Extra credit:

(a) $V_o = \frac{5+V_{in}}{2}$

$$g = \frac{dV_o}{dV_{in}} = \begin{cases} \frac{1}{2} & V_{in} < 3 \quad (\max) \\ 0 & \text{else} \end{cases}$$

(b) $I dt_r = C_L dV_o$

$\cancel{4 \times 1.5}$

$4 - 1.5 \times 10\% = 3.85$

$2.5 + 1.5 \times 10\% = 2.65$

$$t_r = \cancel{C_L \int_{2.5}^{4\times 90\%} dV_o} \quad C_L \int_{2.65}^{3.85} \frac{dV_o}{I(V_o)}$$

$$= C_L \int_{2.65}^{3.85} k_n \left(\frac{W}{L}\right)_n \frac{1}{2} (V_{gs} - V_{tn})^2 dV_o$$

$$= C_L \int_{2.65}^{3.85} 10 \times 10^{-6} \times (5 - 1 - V_o)^2 dV_o$$

$$= 5.93 \times 10^{-5} C_L$$