2.2

$I_{ds} = \mu C_{ox}\frac{W}{L}\left[V_{gs} - V_t - \frac{V_{ds}}{2}\right]V_{ds}$ in general

$I_{ds1} = \mu C_{ox}\frac{W}{2L}\left[(V_{DD}-0) - V_t - V_{DS}\right]V_{DS}$

$I_{ds2t} = \mu C_{ox}\frac{W}{L}\left[(V_{DD}-V_1) - V_t - V_{DS} - V_1\right](V_{DS}-V_1)$

$I_{ds2b} = \mu C_{ox}\frac{W}{L}\left[V_{DD} - 0 - V_t - V_1\right](V_1 - 0)$

$I_{dst} = \beta\left[V_{DD}-V_t-2V_1\right](V_{DS}-V_1) = \beta\left[V_{DD}V_{DS} - V_tV_{DS} - 2V_1V_{DS} - V_{DD}V_1 + V_tV_1 + 2V_1^2\right]$

$\frac{-b\pm\sqrt{b^2-4ac}}{2a}$

$= \beta\left[2V_1^2 + V_1(V_t - V_{DD} - 2V_{DS}) + (V_{DD}V_{DS} - V_tV_{DS})\right]$

$-V_t + V_{DD} + 2V_{DS} \pm \sqrt{(V_t^2 - 2V_{DD}V_t - 4V_{DS}V_t + V_{DD}^2 - 4V_{DS}V_{DD} + 4V_{DS}) - 8V_{DD}V_{DS} + 8V_tV_{DS}}\ /4$

$2V_{DS} + V_{DD} - V_t \pm \sqrt{V_t^2 - 2V_{DD}V_t - 12V_{DS}V_t + V_{DD}^2 - 12V_{DS}V_{DD} + 4V_{DS}}\ /4$

$I_{dst} = I_{dsb}$ $\quad \cancel{\beta}\left[V_{DD}V_{DS} - V_tV_{DS} - 2V_1V_{DS} - V_{DD}V_1 + V_tV_1 + 2V_1^2\right] = \cancel{\beta}\left[V_{DD} - V_t - V_1\right]V_1$

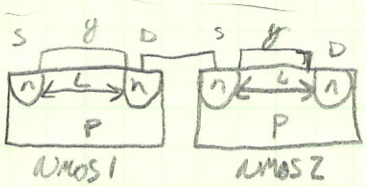
$2V_1^2 - 2V_1V_{DS} - V_1V_{DD} + V_1V_t + V_{DD}V_{DS} - V_tV_{DS} = V_1V_{DD} - V_1V_t - V_1^2$

$3V_1^2 - 2V_1V_{DD} - 2V_1V_{DS} + 2V_1V_t + V_{DD}V_{DS} - V_tV_{DS} = 0$

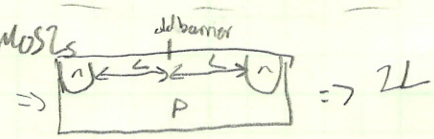
$3V_1^2 + V_1(2V_t - 2V_{DD} - 2V_{DS}) + (V_{DD}V_{DS} - V_tV_{DS}) = 0$

$$\frac{(-2V_t + 2V_{DD} + 2V_{DS}) \pm \sqrt{(2V_t - 2V_{DD} - 2V_{DS})^2 - 12(V_{DD}V_{DS} - V_tV_{DS})}}{6}$$

$(V_{DD} - V_t + V_{DS}) \pm \frac{1}{2}\sqrt{\cdots}\ /3 = (V_{DD} - V_t + V_{DS}) + \sqrt{(2V_t - 2V_{DD} - 2V_{DS})^2/4 - 3V_{DS}(V_{DD} - V_t)}\ /3$



$NMOS1_D = NMOS2_S$



2.3

No, $I_{ds2} < I_{ds1}$

2.6

$t_{ox} = 100\,Å$ $N_A = 2\times10^{17}$ $V_t = 0.7$ when $V_{sb}=0$ $V_t = V_{t0}$

$\varepsilon_{ox} = 3.9 \times 8.854\times10^{-12}$ $\varepsilon_{si} = 1.05\times10^{-10}$ $q = 1.602\times10^{-19}$

$\phi = 24.4$ $\gamma = 751e{-6}$ $V_t = 700.29e{-3}$

$\Delta V_t = 293\,mV$

2.10

as $V_t \uparrow$ $I_{ds} \Downarrow$ as $T\uparrow$ $V_t\uparrow$ for ON

while ON, the current will decrease
while OFF, the current (non-idealities) will decrease

A higher current would result in slower switching speeds, resulting in a slower chip

2.20

PMOS $V_{gs} = -V_{out}$ $V_{ds} = V_{DD} - V_{out}$ $V_{DD} - < V_{tp}$ Linear: $V_{ds} < V_{gs} - V_t = V_{DD} - V_t$ Saturation: $V_{ds} \geq V_{DD} - V_t$ ← this one

$I_{dsp} = \frac{\beta}{2}(V_{gs} - V_t)^2$ $I_{ds} = \frac{\beta}{2}(-V_{out} - V_{tp})^2$ $I_{ds} < \frac{\beta}{2}(-2V_t)^2 = \frac{\beta}{2}4V_t^2 < 2\beta V_t$

NMOS $V_{gs} > V_t$ $-V_{tp} < V_{gs} - V_t \rightarrow$ linear

$I_{dsn} = \beta\left[V_{gs} - V_t - V_{ds}/2\right]V_{ds} = \beta\left[V_{DD} - V_{tn} - V_{out}/2\right]V_{out}$ $I_{dsp} = I_{dsn}$

$\frac{\cancel{\beta}}{2}(-V_{out} - V_{tp})^2 = \cancel{\beta}\left[V_{DD} - V_{tn} - V_{out}/2\right]V_{out}$

$V_{out}^2 + 2V_{out}V_{tp} + V_{tp}^2 = 2V_{DD}V_{out} - 2V_{tn}V_{out} - V_{out}^2$

$2V_{out}^2 + V_{out}(2V_{tp} - 2V_{DD} - 2V_{tn}) + V_{tp}^2 = V_{out}^2 + V_{out}(V_{tp} - V_{DD} - V_{tn}) + V_{tp}^2 = 0$