Chapter 16

Exercise Solutions

E16.1

a. Driver in nonsaturation:

$$i_D = \frac{V_{DD} - v_O}{R_D} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)\left[2(v_I - V_{TN})v_O - v_O^2\right]$$

$$\frac{5 - (0.15)}{R_D} = \frac{35}{2}(5)\left[2(5 - 0.8)(0.15) - (0.15)^2\right]$$

$$\frac{4.85}{R_D} = 87.5[1.2375]$$

$$\Rightarrow \underline{R_D = 44.8\ \text{k}\Omega}$$

b. From Equation (16–10):

$$\left(\frac{0.035}{2}\right)(5)(44.8)(V_{It} - 0.8)^2 + (V_{It} - 0.8) - 5 = 0$$

$$3.920(V_{It} - 0.8)^2 + (V_{It} - 0.8) - 5 = 0$$

$$V_{It} - 0.8 = \frac{-1 \pm \sqrt{1 + 4(3.92)(5)}}{2(3.92)}$$

$$V_{It} - 0.8 = 1.0 \Rightarrow \underline{V_{It} = 1.8\ \text{V}}$$

$$\underline{V_{Ot} = 1.0\ \text{V}}$$

E16.2

a. i. $v_I = 0 \Rightarrow v_O = 4\ \text{V}$

ii. $v_I = 4\ \text{V}$, driver in nonsaturation

$$\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (v_{GSL} - V_{TNL})^2 = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_D \left[2(v_{GSD} - V_{TND})v_{DSD} - v_{DSD}^2\right]$$

$$2(5 - v_O - 1)^2 = (16)\left[2(4 - 1)v_O - v_O^2\right]$$

$$16 - 8v_O + v_O^2 = 8(6v_O - v_O^2)$$

$$9v_O^2 - 56v_O + 16 = 0$$

$$v_O = \frac{56 \pm \sqrt{(56)^2 - 4(9)(16)}}{2(9)}$$

$$v_O = 0.30\ \text{V}$$

b. $P = i_D \cdot V_{DD}$

$$i_D = \frac{35}{2}(2)(5 - 0.30 - 1)^2 = 479\ \mu\text{A}$$

$$P = (0.479)(5)$$

$$\Rightarrow \underline{P = 2.4\ \text{mW}}$$

E16.3

$$P = i_D \cdot V_{DD} \Rightarrow i_D = \frac{750}{5} = 150\ \mu\text{A}$$

$$150 = \frac{35}{2}\left(\frac{W}{L}\right)_L (5 - 0.2 - 0.8)^2$$

$$150 = 280\left(\frac{W}{L}\right)_L \Rightarrow \underline{\left(\frac{W}{L}\right)_L = 0.536}$$

$$i_D = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_D \left[2(v_I - V_{TND})v_O - v_O^2\right]$$

$$150 = \frac{35}{2}\left(\frac{W}{L}\right)_D \left[2(4.2 - 0.8)(0.2) - (0.2)^2\right]$$

$$150 = 23.1 \cdot \left(\frac{W}{L}\right)_D \Rightarrow \underline{\left(\frac{W}{L}\right)_D = 6.49}$$

E16.4

a. Load in saturation; driver in nonsaturation:

$$\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (v_{GSL} - V_{TNL})^2 = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_D \left[2(v_{GSD} - V_{TND})v_{DSD} - v_{DSD}^2\right]$$

$$2(-[-1.5])^2 = (6)\left[2(5 - 0.7)v_O - v_O^2\right]$$

$$4.5 = 6(8.6v_O - v_O^2)$$

$$6v_O^2 - 51.6v_O + 4.5 = 0$$

$$v_O = \frac{51.6 \pm \sqrt{(51.6)^2 - 4(6)(4.5)}}{2(6)}$$

$$v_O = 0.0881\ \text{V}$$

b. Load

$$v_{Ot} = V_{DD} + V_{TNL} \quad \text{Equation (16.26(b))}$$

$$= 5 - 1.5 \Rightarrow v_{Ot} = 3.5\ \text{V}$$

From Equation (16 – 28(b)):

$$\sqrt{\frac{K_D}{K_L}}(v_{It} - V_{TND}) = -V_{TNL}$$

$$\sqrt{\frac{6}{2}}(v_{It} - 0.7) = -(-1.5) = 1.5$$

Load:

$$\underline{v_{It} = 1.57\ \text{V}}$$

$$\underline{v_{Ot} = 3.5\ \text{V}}$$

Driver:

$$\underline{v_{It} = 1.57\ \text{V}}$$

$$\underline{v_{Ot} = 0.87\ \text{V}}$$

c. $i_D = \frac{35}{2} \cdot (2)(1.5)^2 = 78.75\ \mu\text{A}$

$$P = I_D \cdot V_{DD} = (78.75)(5)$$

$$\Rightarrow \underline{P = 394\ \mu\text{W}}$$

E16.5

$$P = i_D \cdot V_{DD} \Rightarrow I_D = \frac{350}{5} = 70\ \mu A$$

$$i_D = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (-V_{TNL})^2$$

$$70 = \frac{35}{2} \cdot \left(\frac{W}{L}\right)_L (2)^2 \Rightarrow \underline{\left(\frac{W}{L}\right)_L = 1}$$

$$i_D = \frac{35}{2} \cdot \left(\frac{W}{L}\right)_D [2(5 - 0.8)(0.05) - (0.05)^2]$$

$$70 = 7.31 \cdot \left(\frac{W}{L}\right)_D \Rightarrow \underline{\left(\frac{W}{L}\right)_D = 9.58}$$

E16.6

From Equation (16 – 35) :

$$V_{IH} = 0.85 + \frac{5 - 0.85}{16} \cdot \left\{\frac{1 + 2(16)}{\sqrt{1 + 3(16)}} - 1\right\}$$

$$\Rightarrow \underline{V_{IH} = 1.81\ \text{V}}$$

Then from Equation (16–34):

$$V_{OLU} = \frac{(5 - 0.85) + 16(1.81 - 0.85)}{(1 + 2(16))}$$

$$V_{OLU} = 0.591\ \text{V}$$

$$V_{IL} = 0.85$$

$$V_{OHU} = 4.15$$

So

$$NM_L = V_{IL} - V_{OLU} = 0.85 - 0.591$$

$$\Rightarrow \underline{NM_L = 0.259\ \text{V}}$$

$$NM_H = V_{OHU} - V_{IH} = 4.15 - 1.81$$

$$\Rightarrow \underline{NM_H = 2.34\ \text{V}}$$

E16.7

From Equation (16–38):

$$V_{IL} = 1 + \frac{1.7}{\sqrt{(5)(6)}} \Rightarrow \underline{V_{IL} = 1.31\ \text{V}}$$

Then from Equation (16–37):

$$V_{OHU} = (5 - 1.7) + (5)(1.31 - 1)$$
$$= 4.85\ \text{V}$$

From Equation (16–41):

$$V_{IH} = 1 + \frac{2(1.7)}{\sqrt{(3)(5)}} \Rightarrow \underline{V_{IH} = 1.88\ \text{V}}$$

Then from Equation (16–40):

$$V_{OLU} = \frac{1.88 - 1}{2} \Rightarrow V_{OLU} = 0.44\ \text{V}$$

$$NM_L = V_{IL} - V_{OLU} = 1.31 - 0.44$$

$$\Rightarrow \underline{NM_L = 0.87\ \text{V}}$$

$$NM_H = V_{OHU} - V_{IH} = 4.85 - 1.88$$

$$\Rightarrow \underline{NM_H = 2.97\ \text{V}}$$

E16.8

a. i. A = logic 1 = 10 V, B = logic 0
"A" driver in nonsaturation, "B" driver off

$$\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (-V_{TNL})^2$$
$$= \left(\frac{k'}{2}\right)\left(\frac{W}{L}\right)_D \left[2(v_I - V_{TND})V_{OL} - V_{OL}^2\right]$$

$$2(3)^2 = (10)[2(10 - 1.5)V_{OL} - V_{OL}^2]$$

$$9 = 5(17V_{OL} - V_{OL}^2)$$

$$5V_{OL}^2 - 85V_{OL} + 9 = 0$$

$$V_{OL} = \frac{85 \pm \sqrt{(85)^2 - 4(5)(9)}}{2(5)}$$

$$\Rightarrow \underline{V_{OL} = 0.107\ \text{V}}$$

ii. $A = B$ = logic 1

$$\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (-V_{TNL})^2$$
$$= 2\left(\frac{k'}{2}\right)\left(\frac{W}{L}\right)_D \left[2(v_I - V_{TND})V_{OL} - V_{OL}^2\right]$$

$$2(3)^2 = (2)(10)[2(10 - 1.5)V_{OL} - V_{OL}^2]$$

$$9 = 10(17V_{OL} - V_{OL}^2)$$

$$10V_{OL}^2 - 170V_{OL} + 9 = 0$$

$$V_{OL} = \frac{170 \pm \sqrt{(170)^2 - 4(10)(9)}}{2(10)}$$

$$\Rightarrow \underline{V_{OL} = 0.0531\ \text{V}}$$

b. Both cases.

$$i_D = \frac{35}{2} \cdot (2)(3)^2 = 315\ \mu A \Rightarrow P = i_D \cdot V_{DD}$$

$$\Rightarrow \underline{P = 3.15\ \text{mW}}$$

E16.9

$$P = i_D \cdot V_{DD} \Rightarrow i_D = \frac{800}{5} = 160\ \mu A$$

$$i_D = 160 = \frac{35}{2} \cdot \left(\frac{W}{L}\right)_L (1.4)^2 = 34.3\left(\frac{W}{L}\right)_L$$

$$\Rightarrow \underline{\left(\frac{W}{L}\right)_L = 4.66}$$

$$i_D = 160 = \frac{35}{2} \cdot \left(\frac{W}{L}\right)_D [2(5 - 0.8)(0.12) - (0.12)^2]$$

$$\Rightarrow \underline{\left(\frac{W}{L}\right)_D = 9.20}$$

E16.10

$$P = i_D \cdot V_{DD} \Rightarrow i_D = \frac{800}{5} = 160\ \mu A$$

$$i_D = 160 = \frac{35}{2} \cdot \left(\frac{W}{L}\right)_L (1.4)^2$$

$$\Rightarrow \underline{\left(\frac{W}{L}\right)_L = 4.66}$$

$i_D = 160\ \mu A$

$$= \frac{35}{2}\cdot\frac{1}{3}\cdot\left(\frac{W}{L}\right)_D [2(5-0.8)(0.12)-(0.12)^2]$$

$$\Rightarrow \left(\frac{W}{L}\right)_D = 27.6$$

E16.11

a. From the load transistor:

$$I_{DL} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L (V_{GSL}-V_{TNL})^2$$

$$= \frac{35}{2}(0.5)(5-0.15-0.7)^2$$

or

$$I_{DL} = 150.7\ \mu A$$

Maximum v_O occurs when either A or B is high and C is high. For the two NMOS in series, the effective k_N is cut in half, so

$$I_{DL} = \frac{1}{2}\left[\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_D\right]\left[2(V_{GSD}-V_{TND})V_{DS}-V_{DS}^2\right]$$

or

$$150.7 = \frac{1}{2}\left[\frac{35}{2}\cdot\left(\frac{W}{L}\right)_D\right][2(5-0.7)(0.15)-(0.15)^2]$$

which yields

$$\left(\frac{W}{L}\right)_D = 13.6$$

b. $P = i_D\cdot V_{DD} = (150.7)(5) \Rightarrow P = 753\ \mu W$

E16.12

a. $v_O(\max)$ occurs when $A=B=1$ and $C=D=0$ or $A=B=0$ and $C=D=1$

$$\left(\frac{W}{L}\right)_L(-V_{TNL})^2 = \frac{1}{2}\cdot\left(\frac{W}{L}\right)_D\left[2(v_I-V_{TND})v_O-v_O^2\right]$$

$$(0.5)(1.2)^2 = \frac{1}{2}\cdot\left(\frac{W}{L}\right)_D[2(5-0.7)(0.15)-(0.15)^2]$$

$$0.72 = (0.634)\left(\frac{W}{L}\right)_D \Rightarrow \left(\frac{W}{L}\right)_D = 1.14$$

b. $$i_D = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L(-V_{TNL})^2 = \left(\frac{35}{2}\right)(0.5)[-(-1.2)]^2$$

$i_D = 12.6\ \mu A$

$P = i_D\cdot V_{DD} = (12.6)(5) \Rightarrow P = 63\ \mu W$

E16.13

a. $K_n/K_p = 1$

$$V_{It} = \frac{10-2+(1)(2)}{1+1} \Rightarrow V_{It} = 5\ V$$

$$V_{OPt} = V_{It}+|V_{TP}| = 5+2 \Rightarrow V_{OPt} = 7\ V$$

$$V_{ONt} = V_{It}-V_{TN} = 5-2 \Rightarrow V_{ONt} = 3\ V$$

b. $K_n/K_p = 0.5$

$$\Rightarrow V_{It} = \frac{10-2+\sqrt{0.5}(2)}{1+\sqrt{0.5}} \Rightarrow V_{It} = 5.52\ V$$

$V_{OPt} = 7.52\ V$

$V_{ONt} = 3.52\ V$

c. $K_n/K_p = 2$

$$\Rightarrow V_{It} = \frac{10-2+\sqrt{2}(2)}{1+\sqrt{2}} \Rightarrow V_{It} = 4.49\ V$$

$V_{OPt} = 6.49\ V$

$V_{ONt} = 2.49\ V$

E16.14

a. $K_n = K_p = 50\ \mu A/V^2$

$V_{It} = 2.5\ V$

$$i_D(\max) = K_n(V_{It}-V_{TN})^2 = 50(2.5-0.8)^2$$

$$\Rightarrow i_D(\max) = 145\ \mu A$$

b. $K_n = K_p = 200\ \mu A/V^2$

$V_{It} = 2.5\ V$

$i_D(\max) = (200)(2.5-0.8)^2$

$$\Rightarrow i_D(\max) = 578\ \mu A$$

E16.15

$P = f\cdot C_L\cdot V_{DD}^2$

$(0.10\times 10^{-6}) = f(0.5\times 10^{-12})(3)^2$

$f = 2.22\times 10^4$ Hz $\Rightarrow f = 22.2$ kHz

E16.16

a. $K_n/K_p = 200/80 = 2.5$

$$\Rightarrow V_{It} = \frac{10-2+\sqrt{2.5}(2)}{1+\sqrt{2.5}} \Rightarrow V_{It} = 4.32\ V$$

$V_{OPt} = 6.32\ V$

$V_{ONt} = 2.32\ V$

b. $$V_{IL} = 2+\frac{10-2-2}{2.5-1}\cdot\left[2\sqrt{\frac{2.5}{2.5+3}}-1\right]$$

$$\Rightarrow V_{IL} = 3.39\ V$$

$$V_{OHU} = \frac{1}{2}\{(1+2.5)(3.39)+10-(2.5)(2)+2\}$$

$V_{OHU} = 9.43\ V$

$$V_{IH} = 2+\frac{10-2-2}{2.5-1}\cdot\left[\frac{2(2.5)}{\sqrt{3(2.5)+1}}-1\right]$$

$$\Rightarrow V_{IH} = 4.86\ V$$

$$V_{OLU} = \frac{(4.86)(1+2.5)-10-(2.5)(2)+2}{2(2.5)}$$

$V_{OLU} = 0.802\ V$

c. $NM_L = V_{IL} - V_{OLU} = 3.39 - 0.802$

$$\Rightarrow \underline{NM_L = 2.59\text{ V}}$$

$$NM_H = V_{OHU} - V_{IH} = 9.43 - 4.86$$

$$\Rightarrow \underline{NM_H = 4.57\text{ V}}$$

E16.17

a. $$V_{It} = \frac{5 - 2 + (1)(6.8)}{1 + 1}$$

$$V_{It} = 1.9\text{ V}$$
$$V_{OPt} = 3.9\text{ V}$$
$$V_{ONt} = 1.1\text{ V}$$

b. $$V_{IL} = 0.8 + \frac{3}{8}\cdot[5 - 2 - 0.8]$$

$$\Rightarrow \underline{V_{IL} = 1.63\text{ V}}$$

$$V_{OHU} = \frac{1}{2}\{2(1.63) + 5 - 0.8 + 2\}$$

$$V_{OHU} = 4.73\text{ V}$$

$$V_{IH} = 0.8 + \frac{5}{8}(5 - 2 - 0.8)$$

$$\Rightarrow \underline{V_{IH} = 2.18\text{ V}}$$

$$V_{OLU} = \frac{1}{2}\{2(2.18) - 5 - 0.8 + 2\}$$

$$V_{OLU} = 0.275\text{ V}$$

c. $NM_L = V_{IL} - V_{OLU} = 1.63 - 0.275$

$$\Rightarrow \underline{NM_L = 1.35\text{ V}}$$

$$NM_H = V_{OHU} - V_{IH} = 4.73 - 2.18$$

$$\Rightarrow \underline{NM_H = 2.55\text{ V}}$$

E16.18

a. $A = 0 \Rightarrow M_{PA}$ (assume zero resistance)

$$K_n = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_N$$

$$K_p = \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_P = \frac{1}{2}\cdot\left(\frac{k_n'}{2}\right)\cdot 8\left(\frac{W}{L}\right)_N$$

$$K_p = 2K_n \Rightarrow \frac{K_n}{K_p} = \frac{1}{2}$$

From Equation (16–55).

$$V_{It} = \frac{5 - 1 + \sqrt{0.5}(1)}{1 + \sqrt{0.5}} \Rightarrow V_{It} = 2.76\text{ V}$$

$$V_{OPt} = 3.76\text{ V}$$
$$V_{ONt} = 1.76\text{ V}$$

b. From Equation (16-58(b))

$$i_D(peak) = K_n(V_{It} - V_{TN})^2$$

$$50 = \frac{35}{2}\left(\frac{W}{L}\right)_N (2.76 - 1)^2 = 54.2\left(\frac{W}{L}\right)_N$$

$$\Rightarrow \underline{\left(\frac{W}{L}\right)_N = 0.923}$$

$$\underline{\left(\frac{W}{L}\right)_P = (8)(0.923) = 7.38}$$

E16.19

Want $K_{n,eff} = K_{p,eff}$

$$\left(\frac{k_n'}{2}\right)\cdot\frac{1}{2}\left(\frac{W}{L}\right)_N = \left(\frac{k_p'}{2}\right)\cdot 2\left(\frac{W}{L}\right)_P = \frac{1}{2}\cdot\frac{k_n'}{2}\cdot 2\left(\frac{W}{L}\right)_P$$

$$\Rightarrow \underline{\left(\frac{W}{L}\right)_N = 2\left(\frac{W}{L}\right)_P}$$

E16.20

Want $K_{n,eff} = K_{p,eff}$

$$\left(\frac{k_n'}{2}\right)\cdot 3\left(\frac{W}{L}\right)_N = \left(\frac{k_p'}{2}\right)\cdot\frac{1}{3}\left(\frac{W}{L}\right)_P = \frac{1}{2}\cdot\frac{k_n'}{2}\cdot\frac{1}{3}\left(\frac{W}{L}\right)_P$$

$$3\left(\frac{W}{L}\right)_N = \frac{1}{6}\cdot\left(\frac{W}{L}\right)_P$$

Or

$$\Rightarrow \underline{\frac{(W/L)_p}{(W/L)_N} = 18}$$

E16.21

Want $K_{n,eff} = K_{p,eff}$

$$\left(\frac{k_n'}{2}\right)\cdot\frac{1}{3}\left(\frac{W}{L}\right)_N = \left(\frac{k_p'}{2}\right)\cdot 3\left(\frac{W}{L}\right)_P = \frac{1}{2}\cdot\frac{k_n'}{2}\cdot 3\left(\frac{W}{L}\right)_P$$

$$\frac{1}{3}\left(\frac{W}{L}\right)_N = \frac{3}{2}\cdot\left(\frac{W}{L}\right)_P$$

Or

$$\Rightarrow \underline{\frac{(W/L)_p}{(W/L)_N} = \frac{2}{9}}$$

E16.22

NMOS:

M_{NA}, M_{NB} in series $\Rightarrow \left(\frac{W}{L}\right) = 2$

M_{ND}, M_{NE} in parallel $\Rightarrow \left(\frac{W}{L}\right) = 1$

M_{NC} in series with $M_{ND} \| M_{NE} \Rightarrow \left(\frac{W}{L}\right) = 2$

Effective composite $\left(\frac{W}{L}\right) = 1$ for each side.

PMOS:

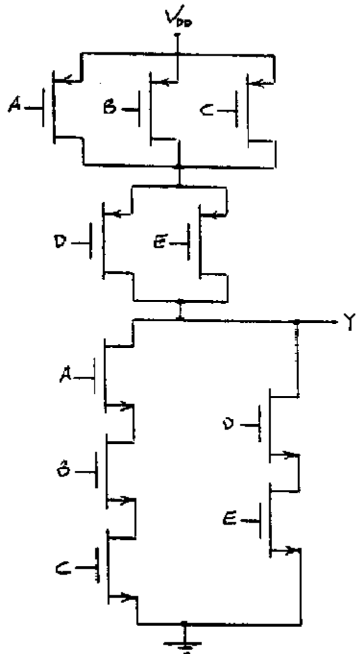
Want the effective composite $\left(\frac{W}{L}\right)$ of each side to be 2.

M_{PA}, M_{PC} in series $\Rightarrow \left(\frac{W}{L}\right) = 4$

M_{PA}, M_{PB} in parallel $\Rightarrow \left(\frac{W}{L}\right)_B = 4$

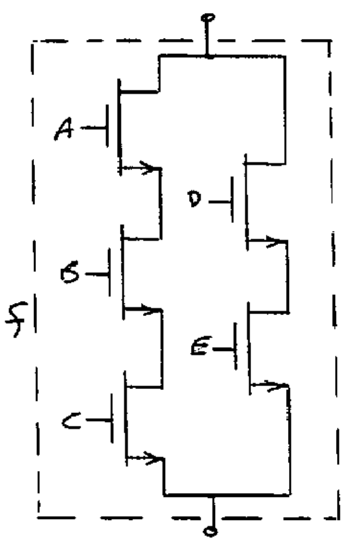
M_{PD}, M_{PE} in series $\Rightarrow \left(\frac{W}{L}\right) = 8$

E16.23



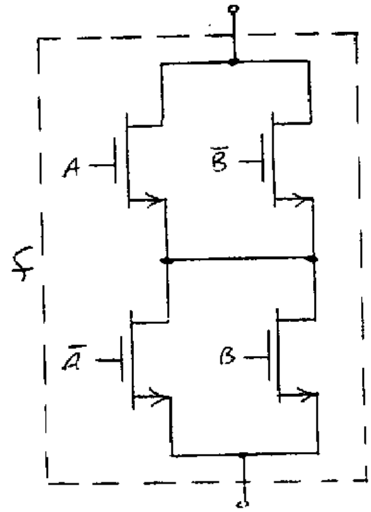
E16.24

The NMOS part of the circuit is:



E16.25

The NMOS part of the circuit is:



E16.26

a. $v_I = \phi = 5$ V $\Rightarrow$ $\underline{v_O = 4 \text{ V}}$

b. $v_I = 3$ V, $\phi = 5$ V $\Rightarrow$ $\underline{v_O = 3 \text{ V}}$

c. $v_I = 4.2$ V, $\phi = 5$ V $\Rightarrow$ $\underline{v_O = 4 \text{ V}}$

d. $v_I = 5$ V, $\phi = 3$ V $\Rightarrow$ $\underline{v_O = 2 \text{ V}}$

E16.27

(a) $v_I = 8V, \phi = 10V \Rightarrow v_{GSD} = 8V$

M_D in nonsaturation

$K_D\left[2(v_{GSD} - V_{TND})v_O - v_O^2\right]$

$K_L\left[V_{DD} - v_O - V_{TNL}\right]^2$

$$\frac{K_D}{K_L}\left[2(8-2)(0.5)-(0.5)^2\right] = [10-0.5-2]^2$$

$$\Rightarrow \underline{\frac{K_D}{K_L} = 9.78}$$

(b) $v_I = \phi = 8V \Rightarrow v_{GSD} = 6V$

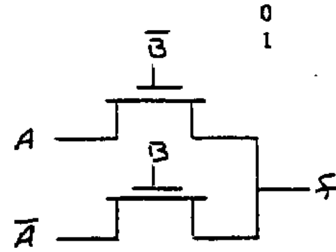
$$\frac{K_D}{K_L}\left[2(6-2)(0.5)-(0.5)^2\right] = [10-0.5-2]^2$$

$$\Rightarrow \underline{\frac{K_D}{K_L} = 15}$$

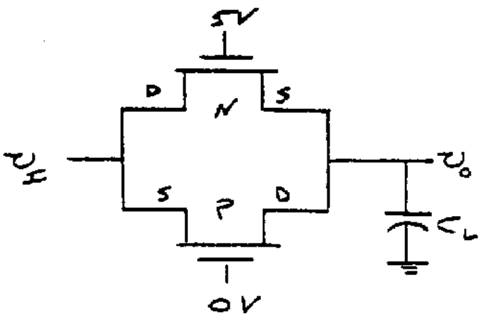
E16.28

Exclusive-OR

A	B	f
0	0	0
1	0	1
0	1	1
1	1	0



E16.29

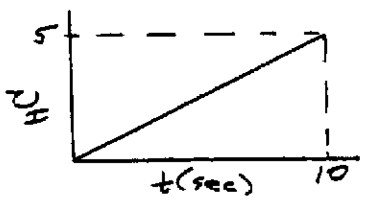


NMOS conducting for $0 \le v_I \le 4.2$ V

$\Rightarrow$NMOS Conducting: $0 \le t \le 8.4$ s
NMOS Cutoff : $8.4 \le t \le 10$ s

PMOS cutoff for $0 \le v_I \le 1.2$ V

$\Rightarrow$PMOS Cutoff : $0 \le t \le 2.4$ s
PMOS Conducting: $2.4 \le t \le 10$ s



E16.30

(a) $1K \Rightarrow 32x32$ array
Each row and column requires a 5-bit word $\Rightarrow$
6 transistors per row and column, $\Rightarrow$
$32x6 + 32x6 = 384$ transistors plus buffer transistors.
(b) $4K \Rightarrow 64x64$ array
Each row and column requires a 6-bit word$\Rightarrow$
7 transistors per row and column $\Rightarrow$
$64x7 + 64x7 = 896$ transistors plus buffer transistors.
(c) $16K \Rightarrow 128x128$ array
Each row and column requires a 7-bit word$\Rightarrow$
8 transistors per row and column $\Rightarrow$
$128x8 + 128x8 = 2048$ transistors plus buffer transistors.

E16.31

$16K \Rightarrow 16384$ cells
Total Power $= 125\,mW = (2.5)I_T$
$\Rightarrow I_T = 50\,mA$
Then, for each cell, $I = \dfrac{50\,mA}{16384} \Rightarrow I = 3.05\,\mu A$
Now, $I \cong \dfrac{V_{DD}}{R}$ or $R = \dfrac{V_{DD}}{I} = \dfrac{2.5}{3.05} \Rightarrow$
$\underline{R = 0.82\,M\Omega}$

E16.32

From Equation (16.93)

$$\frac{(W/L)_{nA}}{(W/L)_{n1}} = \frac{2(V_{DD}V_{TN}) - 3V_{TN}^2}{(V_{DD} - 2V_{TN})^2}$$
$$= \frac{2(2.5)(0.4) - 3(0.4)^2}{(2.5 - 2(0.4))^2} = 0.526$$

From Equation (16.95)

$$\frac{(W/L)_p}{(W/L)_{nB}} = \frac{k_n'}{k_p'} \cdot \frac{2(V_{DD}V_{TN}) - 3V_{TN}^2}{(V_{DD} + V_{TP})^2}$$
$$= (2.5)\left[\frac{2(2.5)(0.4) - 3(0.4)^2}{(2.5 - 0.4)^2}\right] = 1.31$$

So $\left(\dfrac{W}{L}\right)$ of transmission gate device must be < 0.526 times the $\left(\dfrac{W}{L}\right)$ of the NMOS transistors in the inverter cell. The $\left(\dfrac{W}{L}\right)$ of the PMOS transistors must be < 1.31 times the $\left(\dfrac{W}{L}\right)$ of the transmission gate devices. Then the $\left(\dfrac{W}{L}\right)$ of the PMOS devices must be < 0.689 times $\left(\dfrac{W}{L}\right)$ of NMOS devices in cell.

E16.33

Initial voltage across the storage capacitor
$= V_{DD} - V_{TN} = 3 - 0.5 = 2.5V$.
Now
$-I = C\dfrac{dV}{dt}$ or $V = -\dfrac{I}{C} \cdot t + K$
where $K = 2.5V$, $t = 1.5\,ms$, $V = \dfrac{2.5}{2} = 1.25V$, and
$C = 0.05\,pF$. Then

$$1.25 = 2.5 - \frac{I(1.5x10^{-3})}{(0.05x10^{-12})} \Rightarrow$$

$\underline{I = 4.17x10^{-11}\,A \Rightarrow I = 41.7\,pA}$

Chapter 16

Problem Solutions

16.1

(a) $\Delta V_{TN} = \frac{\sqrt{2e \in_s N_a}}{C_{ox}}\left[\sqrt{2\phi_{fp} + V_{SB}} - \sqrt{2\phi_{fp}}\right]$

$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{(3.9)(8.85x10^{-14})}{450x10^{-8}} = 7.67x10^{-8}$

$\sqrt{2e \in_s N_a}$

$= \left[2(1.6x10^{-19})(11.7)(8.85x10^{-14})(8x10^{15})\right]^{1/2}$

$= 5.15x10^{-8}$

Then

$\Delta V_{TN} = \frac{5.15x10^{-8}}{7.67x10^{-8}} \cdot \left[\sqrt{2(0.343) + V_{SB}} - \sqrt{2(0.343)}\right]$

For $V_{SB} = 1\,V$:

$\Delta V_{TN} = 0.671\left[\sqrt{1.686} - \sqrt{0.686}\right] \Rightarrow \underline{\Delta V_{TN} = 0.316\,V}$

For $V_{SB} = 2\,V$:

$\Delta V_{TN} = 0.671\left[\sqrt{2.686} - \sqrt{0.686}\right] \Rightarrow \underline{\Delta V_{TN} = 0.544\,V}$

(b) For $V_{GS} = 2.5$ V, $V_{DS} = 5$ V, transistor biased in the saturation region.

$I_D = K_n(V_{GS} - V_{TN})^2$

For $V_{SB} = 0$,

$I_D = 0.2(2.5 - 0.8)^2 = 0.578$ mA

For $V_{SB} = 1$,

$I_D = 0.2(2.5 - [0.8 + 0.316])^2 = 0.383$ mA

For $V_{SB} = 2$,

$I_D = 0.2(2.5 - [0.8 + 0.544])^2 = 0.267$ mA

16.2

(a) $I_D = \frac{V_{DD} - v_O}{R_D} = K_n\left[2(V_{GS} - V_{TN})v_O - v_O^2\right]$

$\frac{5-(0.1)}{40x10^3} = K_n\left[2(5-0.8)(0.1) - (0.1)^2\right]$

or $K_n = 1.476x10^{-4}\ A/V^2 = \frac{8x10^{-5}}{2}\left(\frac{W}{L}\right)$

So that $\underline{\left(\frac{W}{L}\right) = 3.69}$

b. From Equation (16.10),

$K_nR_D[V_{It} - V_{TN}]^2 + [V_{It} - V_{TN}] - V_{DD} = 0$

$(0.1476)(40)[V_{It} - 0.8]^2 + [V_{It} - 0.8] - 5 = 0$

or $[V_{It} - 0.8] = \frac{-1 \pm \sqrt{(1)^2 + 4(0.1476)(40)(5)}}{2(0.1476)(40)}$

or $[V_{It} - 0.8] = 0.839$

So that $\underline{V_{It} = 1.64\ \text{V}}$

$P = I_D(\max) \cdot V_{DD}$

and $I_D(\max) = \frac{5 - (0.1)}{40} = 0.1225$ mA

or $\underline{P = 0.6125\ \text{mW}}$

16.3

a. From Equation (16.10), the transistor point is found from

$K_nR_D(V_{It} - V_{TN})^2 + (V_{It} - V_{TN}) - V_{DD} = 0$

$K_n = 50\ \mu A/V^2$, $R_D = 20\ k\Omega$, $V_{TN} = 0.8\,V$

$(0.05)(20)(V_{It} - V_{TN})^2 + (V_{It} - V_{TN}) - 5 = 0$

$V_{It} - V_{TN} = \frac{-1 \pm \sqrt{1 + 4(0.05)(20)(5)}}{2(0.05)(20)}$

$= 1.79$ V So $V_{It} = 2.59$ V

$V_{Ot} = 1.79$ V

Output voltage for $v_I = 5$ V is determined from Equation (16.12):

$v_O = 5 - (0.05)(20)[2(5 - 0.8)v_O - v_O^2]$

$v_O^2 - 9.4v_O + 5 = 0$

So $v_O = \frac{9.4 \pm \sqrt{(9.4)^2 - 4(1)(5)}}{2(1)} = 0.566$ V

b. For $R_D = 200$ kΩ,

$(V_{It} - V_{TN}) = \frac{-1 \pm \sqrt{1 + 4(0.05)(200)(5)}}{2(0.05)(200)}$

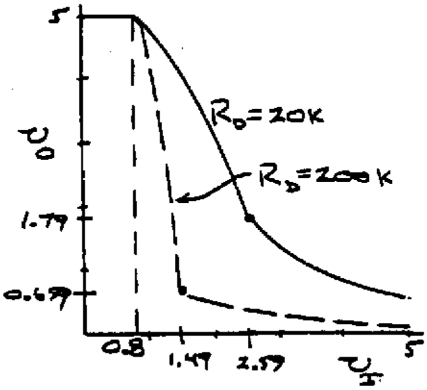
$= 0.659$ V So $V_{It} = 1.46$ V

$V_{Ot} = 0.659$ V

$v_O = 5 - (0.05)(200)[2(5 - 0.8)v_O - v_O^2]$

or $10v_O^2 - 85v_O + 5 = 0$

$v_O = \frac{85 \pm \sqrt{(85)^2 - 4(10)(5)}}{2(10)} = 0.0592$ V



16.4

$P = i_D \cdot V_{DD}$

$1 = i_D(5) \Rightarrow i_D = 0.2\ mA$

Now

$i_D = K_n\left[2(v_I - V_{TN})v_O - v_O^2\right]$

$0.2 = K_n\left[2(5-0.8)(0.2) - (0.2)^2\right]$

or $K_n = 0.122\ mA/V^2 = \left(\frac{0.080}{2}\right)\left(\frac{W}{L}\right) \Rightarrow$

$\underline{\left(\frac{W}{L}\right) = 3.05}$

Also

$v_O = V_{DD} - K_n R_D\left[2(v_I - V_{TN})v_O - v_O^2\right]$

$0.2 = 5 - (0.122)R_D\left[2(5-0.8)(0.2) - (0.2)^2\right] \Rightarrow$

$\underline{R_D = 24\ k\Omega}$

16.5

From Equation (16.21) :

$$V_{It} = \frac{10 - 2 + 2\left(1 + \sqrt{\frac{200}{50}}\right)}{1 + \sqrt{\frac{200}{50}}}$$

or $\underline{V_{It} = 4.67\ V}$

$V_{Ot} = V_{It} - V_{TND} = 4.67 - 2 \Rightarrow \underline{V_{Ot} = 2.67\ V}$

From Equation (16.23):

$$200\left[2(8-2)v_0 - v_0^2\right] = 50[10 - v_0 - 2]^2$$

$$4\left[12v_0 - v_0^2\right] = [8 - v_0]^2 = \left[64 - 16v_0 + v_0^2\right]$$

$$5v_0^2 - 64v_0 + 64 = 0$$

$$v_0 = \frac{64 \pm \sqrt{(64)^2 - 4(5)(64)}}{2(5)}$$

or $\underline{v_0 = 1.09\ V}$

16.6

(a) From Equation (16.23)

$\frac{K_D}{K_L}\left[2(3-0.5)(0.25) - (0.25)^2\right] = (3 - 0.25 - 0.5)^2$

$\Rightarrow \underline{\frac{K_D}{K_L} = 4.26}$

(b) $\frac{K_D}{K_L}\left[2(2.5-0.5)(0.25) - (0.25)^2\right] = (3 - 0.25 - 0.5)^2$

$\Rightarrow \underline{\frac{K_D}{K_L} = 5.06}$

(c) $i_D = K_L(V_{GSL} - V_{TNL})^2 = K_L(V_{DD} - v_O - V_{TNL})^2$

$= \left(\frac{0.080}{2}\right)(1)(3 - 0.25 - 0.5)^2 \Rightarrow$

$\underline{i_D = 0.203\ mA}$

$P = i_D \cdot V_{DD} = (0.203)(3) \Rightarrow \underline{P = 0.608\ mW}$

for both parts (a) and (b).

16.7

(a) $P = 0.4\ mW = i_D \cdot V_{DD} = i_D(3) \Rightarrow$

$i_D = 0.133\ mA$

$i_D = K_L(V_{DD} - v_O - V_{TNL})^2$

$0.133 = \left(\frac{0.080}{2}\right)\left(\frac{W}{L}\right)_L (3 - 0.1 - 0.5)^2 = (0.2304)\left(\frac{W}{L}\right)_L$

So $\underline{\left(\frac{W}{L}\right)_L = 0.577}$

$\frac{K_D}{K_L}\left[2(2.5-0.5)(0.1) - (0.1)^2\right] = (3 - 0.1 - 0.5)^2$

$\Rightarrow \frac{K_D}{K_L} = 14.8$ so that $\underline{\left(\frac{W}{L}\right)_D = 8.54}$

$V_{It} = \frac{3 - 0.5 + 0.5\left(1 + \sqrt{14.8}\right)}{1 + \sqrt{14.8}}$

or

$\underline{V_{It} = 1.02\ V}$, $\underline{V_{Ot} = 0.52\ V}$

(b) $NM_L = V_{IL} - V_{OLU}$

$NM_H = V_{OHU} - V_{IH}$

From Equation (16.35)

$V_{IH} = 0.5 + \frac{(3-0.5)}{14.8}\left\{\frac{(1 + 2(14.8))}{\sqrt{1 + 3(14.8)}} - 1\right\} \Rightarrow$

$V_{IH} = 1.10\ V$

$V_{OHU} = 3.0 - 0.5 = 2.5\ V$

$NM_H = V_{OHU} - V_{IH} = 2.5 - 1.10 \Rightarrow \underline{NM_H = 1.40\ V}$

$V_{IL} = V_{TND} = 0.5\ V$

$$V_{OLU} = \frac{(V_{DD} - V_{TNL}) + \frac{K_D}{K_L}(V_I - V_{TND})}{1 + 2\left(\frac{K_D}{K_L}\right)}$$

$$= \frac{(3-0.5) + 14.8(1.1-0.5)}{1+2(14.8)} \Rightarrow$$

$V_{OLU} = 0.372\,V$

Then $NM_L = V_{IL} - V_{OLU} = 0.5 - 0.372 \Rightarrow$

$\underline{NM_L = 0.128\,V}$

16.8

We have

$$\frac{K_D}{K_L}\left[2(v_I - V_{TND})v_O - v_O^2\right] = (V_{DD} - v_O - V_{TNL})^2$$

$$\frac{(W/L)_D}{(W/L)_L}\left[2(V_{DD} - V_{TN} - V_{TN})(0.08V_{DD}) - (0.08V_{DD})^2\right]$$

$$= (V_{DD} - 0.08V_{DD} - V_{TN})^2$$

$$\frac{(W/L)_D}{(W/L)_L}\left[2(V_{DD} - 2(0.2)V_{DD})(0.08V_{DD}) - 0.0064V_{DD}^2\right]$$

$$= \left[(0.92 - 0.2)V_{DD}\right]^2 = 0.5184V_{DD}^2$$

$$\frac{(W/L)_D}{(W/L)_L}[0.096] = 0.5184 \Rightarrow \underline{\frac{(W/L)_D}{(W/L)_L} = 5.4}$$

16.9

$V_{OH} = V_B - V_{GS} = \text{Logic } 1$

So

(a) $V_B = 4\,V \Rightarrow V_{OH} = 3\,V$

(b) $V_B = 5\,V \Rightarrow V_{OH} = 4\,V$

(c) $V_B = 6\,V \Rightarrow V_{OH} = 5\,V$

(d) $V_B = 7\,V \Rightarrow V_{OH} = 6\,V$

For $v_I = V_{OH}$

$$K_D\left[2(v_I - V_T)v_O - v_O^2\right] = K_L\left[V_B - v_O - V_T\right]^2$$

Then

(a) $(1)\left[2(3-1)V_{OL} - V_{OL}^2\right] = (0.4)\left[4 - V_{OL} - 1\right]^2 \Rightarrow$

$\underline{V_{OL} = 0.657\,V}$

(b) $(1)\left[2(4-1)V_{OL} - V_{OL}^2\right] = (0.4)\left[5 - V_{OL} - 1\right]^2 \Rightarrow$

$\underline{V_{OL} = 0.791\,V}$

(c) $(1)\left[2(5-1)V_{OL} - V_{OL}^2\right] = (0.4)\left[6 - V_{OL} - 1\right]^2 \Rightarrow$

$\underline{V_{OL} = 0.935\,V}$

(d) $(1)\left[2(6-1)V_{OL} - V_{OL}^2\right] = (0.4)\left[7 - V_{OL} - 1\right]^2 \Rightarrow$

$\underline{V_{OL} = 1.08\,V}$

16.10

a. For load $V_{Ot} = V_{DD} + V_{TNL} = 5 - 2 = 3\,V$

$$\sqrt{\frac{K_D}{K_L}} \cdot (V_{It} - V_{TND}) = -V_{TNL}$$

$$\sqrt{\frac{500}{100}}(V_{It} - 0.8) = -(-2)$$

$$\left.\begin{aligned} &\Rightarrow V_{It} = 1.69\,V \\ &V_{Ot} = 3\text{ V} \end{aligned}\right\}\text{ Load}$$

Driver: $V_{Ot} = V_{It} - V_{TND} = 1.69 - 0.8 = 0.89\,V$

$$\left.\begin{aligned} V_{It} &= 1.69\text{ V} \\ V_{Ot} &= 0.89\text{ V} \end{aligned}\right\}\text{ Driver}$$

b. From Equation (16.29(b)):

$$\frac{500}{100} \cdot \left[2(5 - 0.8)v_0 - v_0^2\right] = [-(-2)]^2$$

$$5v_0^2 - 42v_0 + 4 = 0$$

$$v_0 = \frac{42 \pm \sqrt{(42)^2 - 4(5)(4)}}{2(5)} \Rightarrow \underline{v_0 = 0.0963\text{ V}}$$

c. $i_D = K_L(-V_{TNL})^2 = 100[-(-2)]^2 \Rightarrow$

$i_D = 400\,\mu A$

16.11

$$\left(\frac{500}{50}\right)\left[2(3-0.5)(0.1) - (0.1)^2\right] = (-V_{TNL})^2$$

So

$(-V_{TNL})^2 = 4.9 \Rightarrow \underline{V_{TNL} = -2.21\,V}$

16.12

(a) $P = i_D \cdot V_{DD}$

$150 = i_D \cdot (3) \Rightarrow i_D = 50\,\mu A$

$i_D = K_L(-V_{TNL})^2$

$$50 = \left(\frac{80}{2}\right)\left(\frac{W}{L}\right)_L\left[-(-1)\right]^2 \Rightarrow \underline{\left(\frac{W}{L}\right)_L = 1.25}$$

$$\frac{K_D}{K_L}\left[2(3-0.5)(0.1) - (0.1)^2\right] = \left[-(-1)\right]^2$$

$$\frac{K_D}{K_L} = \frac{(W/L)_D}{(W/L)_L} = 2.04 \Rightarrow \underline{\left(\frac{W}{L}\right)_D = 2.55}$$

For the Load:

$V_{Ot} = V_{DD} + V_{TNL} = 3 - 1 \Rightarrow \underline{V_{Ot} = 2\,V}$

$\sqrt{2.04}(V_{It} - 0.5) = \left[-(-1)\right] \Rightarrow \underline{V_{It} = 1.20\,V}$

For the Driver:

$V_{Ot} = V_{It} - V_{TND} = 1.20 - 0.5 \Rightarrow \underline{V_{Ot} = 0.70\,V}$

$\underline{V_{It} = 1.20\,V}$

(b) $NM_L = V_{IL} - V_{OLU}$

$NM_H = V_{OHU} - V_{IH}$

$$V_{IL} = 0.5 + \frac{[-(-1)]}{\sqrt{(2.04)(1+2.04)}} = 0.902\,V$$

$$V_{IH} = 0.5 + \frac{2[-(-1)]}{\sqrt{3(2.04)}} = 1.31\,V$$

Then $V_{OHU} = (3-1) + (2.04)(0.902-0.5) = 2.82\,V$

$$V_{OLU} = \frac{(1.31-0.5)}{2} = 0.405\,V$$

$NM_L = 0.902 - 0.405 \Rightarrow \underline{NM_L = 0.497\,V}$

$NM_H = 2.82 - 1.31 \Rightarrow \underline{NM_H = 1.51\,V}$

16.13

a. From Equation (16.29(b)):

$$\left(\frac{W}{L}\right)_D [2(2.5-0.5)(0.05)-(0.05)^2] = \left(\frac{W}{L}\right)_L [-(-1)]^2$$

$$\left(\frac{W}{L}\right)_L = 1$$

Then $\underline{\left(\frac{W}{L}\right)_D = 5.06}$

b. $i_D = \left(\frac{80}{2}\right)(1)[-(-1)]^2$

or $\underline{i_D = 40\ \mu A}$

$P = i_D \cdot V_{DD} = (40)(2.5)$

$\Rightarrow \underline{P = 100\ \mu W}$

16.14

a. i. $v_I = 0.5\ V \Rightarrow i_D = 0 \Rightarrow \underline{P = 0}$

ii. $v_I = 5\ V$, From Equation (16.12),

$$v_0 = 5 - (0.1)(20)[2(5-1.5)v_0 - v_0^2]$$

$$2v_0^2 - 15v_0 + 5 = 0$$

$$v_0 = \frac{15 \pm \sqrt{(15)^2 - 4(2)(5)}}{2(2)} \Rightarrow \underline{v_0 = 0.35\ V}$$

$$i_D = \frac{5-0.35}{20} = 0.2325\ mA$$

$P = i_D \cdot V_{DD} = (0.2325)(5) \Rightarrow \underline{P = 1.16\ mW}$

b. i. $v_I = 0.25\ V \Rightarrow i_D = 0 \Rightarrow \underline{P = 0}$

ii. $v_I = 4.3\ V$, From Equation (16.23),

$$100[2(4.3-0.7)v_0 - v_0^2] = 10[5 - v_0 - 0.7]^2$$

$$10[7.2v_0 - v_0^2] = 18.49 - 8.6v_0 + v_0^2$$

Then

$$11v_0^2 - 80.6v_0 + 18.49 = 0$$

$$v_0 = \frac{80.6 \pm \sqrt{(80.6)^2 - 4(11)(18.49)}}{2(11)}$$

$\Rightarrow \underline{v_0 = 0.237\ V}$

Then

$$i_D = 10[5 - 0.237 - 0.7]^2 = 165\ \mu A$$

$P = i_D \cdot V_{DD} = (165)(5) \Rightarrow \underline{P = 825\ \mu W}$

c. i. $v_I = 0.03\ V \Rightarrow i_D = 0 \Rightarrow \underline{P = 0}$

ii. $v_I = 5\ V$

$$i_D = K_L(-V_{TNL})^2 = (10)[-(-2)]^2 = 40\ \mu A$$

$P = i_D \cdot V_{DD} = (40)(5) \Rightarrow \underline{P = 200\ \mu W}$

16.15

From Equation (16.35)

$$V_{IH} = 0.8 + \frac{5-(0.8)}{10} \cdot \left\{\frac{1+2(10)}{\sqrt{1+3(10)}} - 1\right\}$$

$$V_{IH} = 0.8 + 0.42 \cdot \left\{\frac{21}{5.57} - 1\right\}$$

or

$\underline{V_{IH} = 1.96\ V}$

M_{D2} in non-saturation region. Then

$$K_D[2(v_{GS2} - V_{TN})v_{DS2} - v_{DS2}^2] = K_L[V_{DD} - v_{O2} - V_{TN}]^2$$

$v_{DS2} = v_{02}$ and $v_{GS2} = V_{IH} = 1.96$

$$10[2(1.96-0.8)v_{02} - v_{02}^2] = [5 - v_{02} - 0.8]^2$$

$$23.2v_{02} - 10v_{02}^2 = 17.64 - 8.4v_{02} + v_{02}^2$$

or

$$11v_{02}^2 - 31.6v_{02} + 17.64 = 0$$

$$v_{02} = \frac{31.6 \pm \sqrt{(31.6)^2 - 4(11)(17.64)}}{2(11)}$$

$\Rightarrow \underline{v_{02} = 0.758\ V}$

Now M_{D1} in saturation region. Then

$$K_D[v_I - V_{TN}]^2 = K_L[V_{DD} - v_{O1} - V_{TN}]^2$$

$$\sqrt{10}\cdot(v_I - 0.8) = 5 - 1.96 - 0.8 = 2.24$$

Then $\underline{v_I = 1.51\text{ V}}$

16.16

a. From Equation (16.41),

$$V_{IH} = 0.8 + \frac{2[-(-2)]}{\sqrt{3(4)}} \Rightarrow \underline{V_{IH} = 1.95\text{ V} = v_{01}}$$

M_{D2} in non-saturation and M_{L2} in saturation.

$$K_D\left[2(v_{O1} - V_{TND})v_{O2} - v_{O2}^2\right] = K_L(-V_{TNL})^2$$

$$4[2(1.95 - 0.8)v_{02} - v_{02}^2] = (1)[-(-2)]^2$$

$$4v_{02}^2 - 9.2v_{02} + 4 = 0$$

$$v_{02} = \frac{9.2 \pm \sqrt{(9.2)^2 - 4(4)(4)}}{2(4)} \Rightarrow \underline{v_{02} = 0.582\text{ V}}$$

Both M_{D1} and M_{L1} in saturation region. From Equation (16.28(b)),

$$\sqrt{4}\cdot(v_I - 0.8) = -(-2)$$

or $\underline{v_I = 1.8\text{ V}}$

b. $V_{IL} = 0.8 + \dfrac{(+2)}{\sqrt{4(1+4)}} = 1.25\text{ V} = v_{01}$

M_{D2} in saturation, M_{L2} in non-saturation

$$K_D[v_{O1} - V_{TND}]^2$$
$$= K_L\left[2(-V_{TNL})(5 - v_{O2}) - (5 - v_{O2})^2\right]$$

$$4(1.25 - 0.8)^2 = 2(2)(5 - v_{02}) - (5 - v_{02})^2$$

$$(5 - v_{02})^2 - 4(5 - v_{02}) + 0.81 = 0$$

$$5 - v_{02} = \frac{4 \pm \sqrt{(4)^2 - 4(1)(0.81)}}{2(1)} = 0.214\text{ V}$$

so

$$v_{02} = 4.786\text{ V}$$

To find v_I:

$$4(v_{01} - 0.8)^2 = (1)(-(-2))^2$$

$$v_{01} - 0.8 = 1$$

$$v_{01} = 1.8\text{ V}$$

c. $V_{IH} = 1.95\text{ V},\quad V_{IL} = 1.25\text{ V}$

16.17

a. i. Neglecting the body effect,

$$v_0 = V_{DD} - V_{Th}$$

Assume $V_{DD} = 5$ V, then $\underline{v_0 = 4.2\text{ V}}$

ii. Taking the body effect into account: From Problem 16.1,

$$V_{TN} = V_{TN0} + 0.671\left[\sqrt{0.686 + V_{SB}} - \sqrt{0.686}\right]$$

and $V_{SB} = v_0$

Then

$$v_0 = 5 - \left[0.8 + 0.671\left(\sqrt{0.686 + v_0} - \sqrt{0.686}\right)\right]$$

$$v_0 = 4.756 - 0.671\sqrt{0.686 + v_0}$$

$$0.671\sqrt{0.686 + v_0} = 4.756 - v_0$$

$$0.450(0.686 + v_0) = 22.62 - 9.51v_0 + v_0^2$$

$$v_0^2 - 9.96v_0 + 22.3 = 0$$

$$v_0 = \frac{9.96 \pm \sqrt{(9.96)^2 - 4(22.3)}}{2} \Rightarrow \underline{v_0 = 3.40\text{ V}}$$

b. PSpice results similar to Figure 16.18(a).

16.18

Results similar to Figure 16.18(b).

16.19

a. M_X on, M_Y cutoff.
From Equation (16.29(b)):

$$\frac{K_D}{K_L}\left[2(5 - 0.8)(0.2) - (0.2)^2\right] = \left[-(-2)\right]^2$$

or $\underline{\dfrac{K_D}{K_L} = 2.44}$

b. For $v_X = v_Y = 5$ V

$$2(2.44)[2(5 - 0.8)v_0 - v_0^2] = [-(-2)]^2$$

$$4.88v_0^2 - 41.0v_0 + 4 = 0$$

$$v_0 = \frac{41 \pm \sqrt{(41)^2 - 4(4.88)(4)}}{2(4.88)}$$

or

$$\underline{v_0 = 0.0987\text{ V}}$$

c. $i_D = \left(\dfrac{80}{2}\right)(1)[-(-2)]^2 = 160\ \mu\text{A}$

$P = (160)(5) \Rightarrow \underline{P = 800\ \mu\text{W}}$

for both parts (a) and (b).

16.20

(a) Maximum value of v_O in low state- when only one input is high, then,

$$\frac{K_D}{K_L}\left[2(3-0.5)(0.1)-(0.1)^2\right]=\left[-(-1)\right]^2$$

$$\frac{K_D}{K_L}=2.04$$

(b) $P=i_D\cdot V_{DD}$

$0.1=i_D(3)\Rightarrow i_D=33.3\ \mu A$

$$i_D=\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_L(-V_{TNL})^2$$

$$33.3=\left(\frac{80}{2}\right)\left(\frac{W}{L}\right)_L\left[-(-1)\right]^2\Rightarrow\ \left(\frac{W}{L}\right)_L=0.8325$$

Then $\left(\frac{W}{L}\right)_D=1.70$

(c) $3(2.04)\left[2(3-0.5)v_O-v_O^2\right]=\left[-(-1)\right]^2\Rightarrow$

$\underline{v_O=0.0329\ V}$

16.21

a. $P=i_D\cdot V_{DD}$

$250=i_D(5)\Rightarrow i_D=50\ \mu\text{A}$

$$i_D=\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_{ML1}\left[-V_{TNL1}\right]^2$$

$$50=\left(\frac{60}{2}\right)\left(\frac{W}{L}\right)_{ML1}\left[-(-2)\right]^2$$

So that $\left(\frac{W}{L}\right)_{ML1}=0.417$

$$\frac{K_D}{K_L}\left[2(v_I-V_{TND})v_O-v_O^2\right]=\left[-V_{TNL}\right]^2$$

$$\frac{K_D}{K_L}\left[2(5-0.8)(0.15)-(0.15)^2\right]=\left[-(-2)\right]^2$$

or $\frac{K_D}{K_L}=3.23\Rightarrow\ \left(\frac{W}{L}\right)_{MD1}=1.35$

b. For $v_X=v_Y=0\Rightarrow v_{O1}=5$ and $v_{O3}=4.2$

Then

$$K_{D2}\left[2(v_{O1}-V_{TND})v_{O2}-v_{O2}^2\right]$$
$$+K_{D3}\left[2(v_{O3}-V_{TND})v_{O2}-v_{O2}^2\right]=K_{L2}\left[-V_{TNL2}\right]^2$$

$$K_{D2}\propto 8,\ K_{D3}\propto 8,\ K_{L2}\propto 1$$

$$8\left[2(5-0.8)v_{O2}-v_{O2}^2\right]+8\left[2(4.2-0.8)v_{O2}-v_{O2}^2\right]=(1)\left[-(-2)\right]^2$$

$$67.2v_{O2}-8v_{O2}^2+54.4v_{O2}-8v_{O2}^2=4$$

Then

$$16v_0^2-121.6v_0+4=0$$

$$v_{O2}=\frac{121.6\pm\sqrt{(121.6)^2-4(16)(4)}}{2(16)}$$

So $\underline{v_{O2}=0.0330\ \text{V}}$

16.22

a. We can write

$$K_x\left[2(v_X-V_{TN})v_{DSX}-v_{DSX}^2\right]$$
$$=K_y\left[2(v_Y-v_{DSX}-V_{TN})v_{DSY}-v_{DSY}^2\right]$$
$$=K_L\left[V_{DD}-v_O-V_{TN}\right]^2$$

where $v_0=v_{DSX}+v_{DSY}$

We have

$v_X=v_Y=9.2\ V,\ V_{DD}=10\ V,\ V_{TN}=0.8\ V$

As a good first approximation, neglect the v_{DSX}^2 and v_{DSY}^2 terms. Let $v_0\approx 2v_{DSX}$. Then from the first and third terms in the above equation,

$$9[2(9.2-0.8)v_{DSX}]\cong(1)(10-2v_{DSX}-0.8)^2$$
$$(151.2)v_{DSX}\cong 84.64-36.8v_{DSX}$$

So that $\underline{v_{DSX}=0.450\ \text{V}}$

From the first and second terms of the above equation,

$$9[2(9.2-0.8)v_{DSX}]\cong 9[2(9.2-v_{DSX}-0.8)v_{DSY}]$$

or

$$(16.8)(0.45)=2(9.2-0.45-0.8)v_{DSY}$$

which yields $\underline{v_{DSY}=0.475\ \text{V}}$

Then $v_0=v_{DSX}+v_{DSY}=0.450+0.475$

or $\underline{v_0=0.925\ \text{V}}$

We have $\underline{v_{GSX}=9.2\ \text{V}}$

and $v_{GSY}=9.2-v_{DSX}=9.2-0.45$

or $\underline{v_{GSY}=8.75\ \text{V}}$

b. Since v_0 is close to ground potential, the body effect will have minimal effect on the results.
From a PSpice analysis:

For part (a) :

$v_{DSX}=0.462$ V, $v_{DSY}=0.491$ V, $v_0=0.9536$ V,

$v_{GSX}=9.2$ V, and $v_{GSY}=8.738$ V

For part (b) :

$v_{DSX}=0.441$ V, $v_{DSY}=0.475$ V, $v_0=0.9154$ V,

$v_{GSX}=9.2$ V, and $v_{GSY}=8.759$ V

16.23

a. We can write

$$K_x\left[2(v_X - V_{TNX})v_{DSX} - v_{DSX}^2\right]$$
$$= K_y\left[2(v_Y - v_{DSX} - V_{TNY})v_{DSY} - v_{DSY}^2\right]$$
$$= K_L\left[-V_{TNL}\right]^2$$

From the first and third terms, (neglect v_{DSX}^2).

$$4[2(5-0.8)v_{DSX}] = (1)[-(-1.5)]^2$$

or $\underline{v_{DSX} = 0.067\text{ V}}$

From the second and third terms, (neglect v_{DSY}^2).

$$4[2(5-0.067-0.8)v_{DSY}] = (1)[-(-1.5)]^2$$

or $\underline{v_{DSY} = 0.068\text{ V}}$

Now

$v_{GSX} = 5,\ v_{GSY} = 5 - 0.067 \Rightarrow v_{GSY} = 4.933\text{ V}$

and $v_0 = v_{DSX} + v_{DSY} \Rightarrow \underline{v_0 = 0.135\text{ V}}$

Since v_0 is close to ground potential, the body-effect has little effect on the results.

16.24

Complement of (B AND C) OR $A \Rightarrow \overline{(B \cdot C) + A}$

16.25

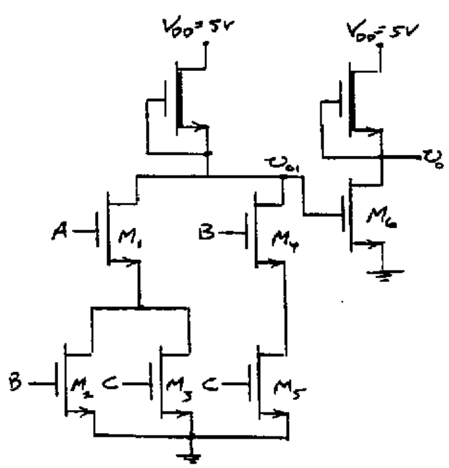
Considering a truth table, we find

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

which shows that the circuit performs the exclusive-OR function.

16.26

(a) Carry-out $= A \bullet (B + C) + B \bullet C$



(b) For $v_{O1} = Low = 0.2\,V$

$$\frac{K_D}{K_L}\left[2(5-0.8)(0.2)-(0.2)^2\right] = \left[-(-1.5)\right]^2 \Rightarrow$$

For $\left(\frac{W}{L}\right)_L = 1$, then $\left(\frac{W}{L}\right)_D = 1.37$

So, for M_6: $\underline{\left(\frac{W}{L}\right)_6 = 1.37}$

To achieve the required composite conduction parameter,

For $M_1 - M_5$: $\underline{\left(\frac{W}{L}\right)_{1-5} = 2.74}$

16.28

a. From Equation (16.55),

$$v_I = V_{It} = \frac{5 - 0.8 + 0.8}{1+1} = \underline{V_{It} = 2.5\text{ V}}$$

p – channel, $V_{0Pt} = 2.5 - (-0.8) \Rightarrow \underline{V_{0Pt} = 3.3\text{ V}}$

n – channel, $V_{0Nt} = 2.5 - 0.8 \Rightarrow \underline{V_{0Nt} = 1.7\text{ V}}$

c For $v_I = 2$ V, NMOS in saturation and PMOS in nonsaturation. From Equation (16.49),

$$(2-0.8)^2 = \left[2(5-2-0.8)(5-v_0) - (5-v_0)^2\right]$$
$$1.44 = 4.4(5-v_0) - (5-v_0)^2$$

So $(5-v_0)^2 - 4.4(5-v_0) + 1.44 = 0$

$$(5 - v_0) = \frac{4.4 \pm \sqrt{(4.4)^2 - 4(1)(1.44)}}{2}$$

or

$$5 - v_0 = 0.356 \Rightarrow \underline{v_0 = 4.64\text{ V}}$$

By symmetry, for $v_I = 3$ V, $\underline{v_0 = 0.356\text{ V}}$

16.29

(a) $K_n = \left(\frac{80}{2}\right)(2) = 80\ \mu A/V^2$

$K_p = \left(\frac{40}{2}\right)(4) = 80\ \mu A/V^2$

(i) $$V_{It} = \frac{V_{DD} + V_{TP} + \sqrt{\frac{K_n}{K_p}}\cdot V_{TN}}{1 + \sqrt{\frac{K_n}{K_p}}} = \frac{3.3 - 0.4 + (1)(0.4)}{1+1}$$

$\underline{V_{It} = 1.65\,V}$

PMOS:

$V_{Ot} = V_{It} - V_{TP} = 1.65 - (-0.4) \Rightarrow \underline{V_{Ot} = 2.05\,V}$

NMOS:

$V_{Ot} = V_{It} - V_{TN} = 1.65 - (0.4) \Rightarrow \underline{V_{Ot} = 1.25\,V}$

(iii) For $v_O = 0.4\,V$: NMOS: Non-sat: PMOS:Sat

$K_n\left[2(V_{GSN} - V_{TN})V_{DS} - V_{DS}^2\right] = K_p\left[V_{SGP} + V_{TP}\right]^2$

$2(v_I - 0.4)(0.4) - (0.4)^2 = (3.3 - v_I - 0.4)^2 \Rightarrow$

$\underline{v_I = 1.89\,V}$

For $v_O = 2.9\,V$, By symmetry

$v_I = 1.65 - (1.89 - 1.65) \Rightarrow \underline{v_I = 1.41\,V}$

(b) $K_n = \left(\frac{80}{2}\right)(2) = 80\,\mu A/V^2$

$K_p = \left(\frac{40}{2}\right)(2) = 40\,\mu A/V^2$

(i) $$V_{it} = \frac{3.3 - 0.4 + \sqrt{\frac{80}{40}}\cdot(0.4)}{1 + \sqrt{\frac{80}{40}}} \Rightarrow \underline{V_{it} = 1.44\,V}$$

PMOS:

$V_{Ot} = 1.44 - (-0.4) \Rightarrow \underline{V_{Ot} = 1.84\,V}$

NMOS:

$V_{Ot} = 1.44 - 0.4 \Rightarrow \underline{V_{Ot} = 1.04\,V}$

(iii) For $v_O = 0.4\,V$

$(80)\left[2(v_I - 0.4)(0.4) - (0.4)^2\right] = (40)\left[3.3 - v_I - 0.4\right]^2$

$\Rightarrow \underline{v_I = 1.62\,V}$

For $v_O = 2.9\,V$: NMOS:Sat, PMOS:Non-sat

$(80)\left[v_I - 0.4\right]^2 = (40)\left[2(3.3 - v_I - 0.4)(0.4) - (0.4)^2\right]$

$\Rightarrow \underline{v_I = 1.16\,V}$

16.30

a. For $v_{O1} = 0.6 < V_{TN} \Rightarrow \underline{v_{O2} = 5\,V}$

N_1 in nonsaturation and P_1 in saturation. From Equation (16.57),

$[2(v_I - 0.8)(0.6) - (0.6)^2] = [5 - v_I - 0.8]^2$

$1.2v_I - 1.32 = 17.64 - 8.4v_I + v_I^2$

or

$v_I^2 - 9.6v_I + 18.96 = 0$

$$v_I = \frac{9.6 \pm \sqrt{(9.6)^2 - 4(1)(18.96)}}{2}$$

or

$\underline{v_I = 2.78\ \text{V}}$

b. $V_{ONt} \le v_{O2} \le V_{OPt}$

From symmetry, $V_{It} = 2.5$ V

$V_{OPt} = 2.5 + 0.8 = 3.3$ V

and $V_{ONt} = 2.5 - 0.8 = 1.7$ V

So $\underline{1.7 \le v_{O2} \le 3.3\ \text{V}}$

16.31

a. $V_{ONt} \le v_{O1} \le V_{OPt}$

By symmetry, $V_{It} = 2.5$ V

$V_{OPt} = 2.5 + 0.8 = 3.3$ V

and $V_{ONt} = 2.5 - 0.8 = 1.7$ V

So $\underline{1.7 \le v_{O1} \le 3.3\ \text{V}}$

b. For $v_{O2} = 0.6 < V_{TN} \Rightarrow \underline{v_{O3} = 5\,V}$

N_2 in nonsaturation and P_2 in saturation. From Equation (16.57),

$[2(v_{I2} - 0.8)(0.6) - (0.6)^2] = [5 - v_{I2} - 0.8]^2$

$1.2v_{I2} - 1.32 = 17.64 - 8.4v_{I2} + v_{I2}^2$

or

$v_{I2}^2 - 9.6v_{I2} + 18.96 = 0$

So $v_{I2} = \underline{v_{O1} = 2.78\ \text{V}}$

For $v_{O1} = 2.78$, both N_1 and P_1 in saturation. Then

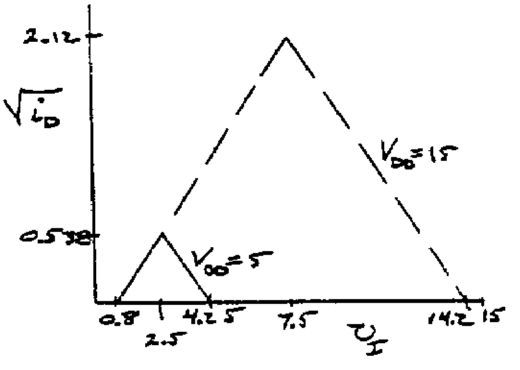
$\underline{v_I = 2.5\ \text{V}}$

16.32

a. $\sqrt{i_{peak}} = \sqrt{K_n}(v_I - V_{TN})$

$\sqrt{i_{peak}} = \sqrt{0.1}\cdot(2.5 - 0.8) = 0.538\ (\text{mA})^{1/2}$

b. $\sqrt{i_{peak}} = \sqrt{0.1}\cdot(7.5 - 0.8) = 2.12\ (\text{mA})^{1/2}$



16.33

(a) $K_n = \left(\frac{50}{2}\right)(2) = 50\,\mu A/V^2$

$K_p = \left(\frac{25}{2}\right)(4) = 50\,\mu A/V^2$

$I_{D,peak} = K_n(v_I - V_{TN})^2 = 50(2.5 - 0.8)^2$

or $\underline{I_{D,peak} = 144.5\,\mu A}$

(b) $K_n = 50\ \mu A/V^2$, $K_p = 25\ \mu A/V^2$

From Equation (16.55),

$$V_{It} = \frac{5-0.8+\sqrt{\frac{50}{25}}(0.8)}{1+\sqrt{\frac{50}{25}}} = 2.21\,V$$

Then

$$I_{D,peak} = K_n(V_{It}-V_{TN})^2 = 50(2.21-0.8)^2$$

or $I_{D,peak} = 99.4\ \mu A$

16.34

a. $P = fC_L V_{DD}^2$

For $V_{DD} = 5$ V, $P = (10\times10^6)(0.2\times10^{-12})(5)^2$

or $\underline{P = 50\ \mu\text{W}}$

For $V_{DD} = 15$ V, $P = (10\times10^6)(0.2\times10^{-12})(15)^2$

or $\underline{P = 450\ \mu\text{W}}$

b. For $V_{DD} = 5$ V, $P = (10\times10^6)(0.2\times10^{-12})(5)^2$

or $\underline{P = 50\ \mu\text{W}}$

16.35

(a) $P = f\,C_L V_{DD}^2 = (150x10^6)(0.4x10^{-12})(5)^2$

$= 1.5x10^{-3}$ W/inverter

Total power: $P_T = (2x10^6)(1.5x10^{-3}) \Rightarrow$

$P_T = 3000\,W$!!!!

(b) For $f = 300\ MHz$

$1.5x10^{-3} = (300x10^6)(0.4x10^{-12})V_{DD}^2 \Rightarrow$

$\underline{V_{DD} = 3.54\,V}$

16.36

(a) For $v_I \cong V_{DD}$, NMOS in nonsaturation

$i_D = K_n\left[2(v_I - V_{TN})v_{DS} - v_{DS}^2\right]$ and $v_{DS} \cong 0$

So $\dfrac{1}{r_{ds}} = \dfrac{di_D}{dv_{DS}} \cong K_n\left[2(V_{DD}-V_{TN})\right]$

Or

$$r_{ds} = \frac{1}{\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_n \cdot 2(V_{DD}-V_{TN})}$$

or

$$r_{ds} = \frac{1}{k_n'\left(\frac{W}{L}\right)_n \cdot (V_{DD}-V_{TN})}$$

For $v_I \cong 0$, PMOS in nonsaturation

$i_D = K_p\left[2(V_{DD} - v_I + V_{TP})v_{SD} - v_{SD}^2\right]$

and $v_{SD} \cong 0$ for $v_I \cong 0$.

So

$$\frac{1}{r_{sd}} = \frac{di_D}{dv_{SD}} \cong \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_p \cdot 2(V_{DD}+V_{TP})$$

or

$$r_{sd} = \frac{1}{k_p'\left(\frac{W}{L_p}\right)\cdot(V_{DD}+V_{TP})}$$

(b) For $\left(\frac{W}{L}\right)_n = 2$, $\left(\frac{W}{L}\right)_p = 4$

$$r_{ds} = \frac{1}{(50)(2)(5-0.8)} \Rightarrow r_{ds} = 2.38\ k\Omega$$

$$r_{sd} = \frac{1}{(25)(4)(5-0.8)} \Rightarrow r_{sd} = 2.38\ k\Omega$$

For $\left(\frac{W}{L}\right)_p = 2$,.

$$r_{sd} = \frac{1}{(25)(2)(5-0.8)} \Rightarrow r_{sd} = 4.76\ k\Omega$$

Now, for NMOS:

$v_{ds} = i_d r_{ds}$ or $i_d = \dfrac{v_{ds}}{r_{ds}} = \dfrac{0.5}{2.38} \Rightarrow$ $\underline{i_d = 0.21\ mA}$

For PMOS:

For $r_{sd} = 2.38\ k\Omega$,

$i_d = \dfrac{v_{sd}}{r_{sd}} = \dfrac{0.5}{2.38} \Rightarrow$ $\underline{i_d = 0.21\ mA}$

For $r_{sd} = 4.76\ k\Omega$,

$i_d = \dfrac{v_{sd}}{r_{sd}} = \dfrac{0.5}{4.76} \Rightarrow$ $\underline{i_d = 0.105\ mA}$

16.37

From Equation (16.73)

$V_{IL} = 1.5 + \frac{3}{8}\cdot(10-1.5-1.5) \Rightarrow \underline{V_{IL} = 4.125\text{ V}}$

and Equation (16.72)

$$V_{OHU} = \frac{1}{2}\cdot[2(4.125)+10-1.5+1.5]$$

or $\underline{V_{OHU} = 9.125\text{ V}}$

From Equation (16.79)

$V_{IH} = 1.5 + \frac{5}{8}\cdot(10-1.5-1.5) \Rightarrow \underline{V_{IH} = 5.875\text{ V}}$

and Equation (16.78)

$$V_{OLU} = \frac{1}{2}\cdot[2(5.875)-10-1.5+1.5]$$

or $\underline{V_{OLU} = 0.875\text{ V}}$

Now

$$NM_L = V_{IL} - V_{OLU} = 4.125 - 0.875$$

$$\Rightarrow \underline{NM_L = 3.25\ \text{V}}$$

$$NM_H = V_{OHU} - V_{IH} = 9.125 - 5.875$$

$$\Rightarrow \underline{NM_H = 3.25\ \text{V}}$$

16.38

From Equation (16.71)

$$V_{IL} = 1.5 + \frac{(10 - 1.5 - 1.5)}{\left(\frac{100}{50} - 1\right)}\left[2\sqrt{\frac{\frac{100}{50}}{\frac{100}{50} + 3}} - 1\right]$$

$$= 1.5 + 7[2(0.632) - 1]$$

or

$$\underline{V_{IL} = 3.348\ \text{V}}$$

From Equation (16.70)

$$V_{OHU} = \frac{1}{2}\cdot\left\{\left(1 + \frac{100}{50}\right)(3.348) + 10 - \left(\frac{100}{50}\right)(1.5) + 1.5\right\}$$

or $\underline{V_{OHU} = 9.272\ \text{V}}$

From Equation (16.77)

$$V_{IH} = 1.5 + \frac{(10 - 1.5 - 1.5)}{\left(\frac{100}{50} - 1\right)}\left[\frac{2\left(\frac{100}{50}\right)}{\sqrt{3\left(\frac{100}{50}\right) + 1}} - 1\right]$$

$$= 1.5 + 7[1.51 - 1]$$

or

$$\underline{V_{IH} = 5.07\ \text{V}}$$

From Equation (16.76)

$$V_{OLU} = \frac{(5.07)\left(1 + \frac{100}{50}\right) - 10 - \left(\frac{100}{50}\right)(1.5) + 1.5}{2\left(\frac{100}{50}\right)}$$

or $\underline{V_{OLU} = 0.9275\ \text{V}}$

Now $NM_L = V_{IL} - V_{OLU} = 3.348 - 0.9275$

or $\underline{NM_L = 2.42\ \text{V}}$

$NM_H = V_{OHU} - V_{IH} = 9.272 - 5.07$

or $\underline{NM_H = 4.20\ \text{V}}$

16.39

a. $v_A = v_B = 5$ V

N_1 and N_2 on, so $v_{DS1} \approx v_{DS2} \approx 0$ V

P_1 and P_2 off

So we have a $P_3 - N_3$ CMOS inverter. By symmetry, $v_C = 2.5$ V (Transition Point).

b. For $v_A = v_B = v_C \equiv v_I$

Want $K_{n,eff} = K_{p,eff}$

$$\frac{k_n'}{2}\cdot\left(\frac{W}{3L}\right)_n = \frac{k_P'}{2}\cdot\left(\frac{3W}{L}\right)_P$$

With $k_n' = 2k_P'$, then

$$\frac{2}{2}\cdot\frac{1}{3}\cdot\left(\frac{W}{L}\right)_n = \frac{1}{2}\cdot 3\cdot\left(\frac{W}{L}\right)_P$$

$$\text{Or } \underline{\left(\frac{W}{L}\right)_n = \frac{9}{2}\cdot\left(\frac{W}{L}\right)_P}$$

c. We have

$$K_n = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_n = \left(\frac{2k_p'}{2}\right)\left(\frac{9}{2}\right)\left(\frac{W}{L}\right)_p$$

$$K_p = \left(\frac{k_p'}{2}\right)\left(\frac{W}{L}\right)_p$$

Then from Equation (16.55)

$$V_{It} = \frac{5 + (-0.8) + \sqrt{\frac{K_n}{K_p}}\cdot(0.8)}{1 + \sqrt{\frac{K_n}{K_p}}}$$

Now

$$\frac{K_n}{K_p} = (2)\left(\frac{9}{2}\right) = 9$$

Then

$$V_{It} = \frac{5 + (-0.8) + 3(0.8)}{1 + 3} \Rightarrow \underline{V_{It} = 1.65\,V}$$

16.40

By definition, NMOS is on if gate voltage is 5 V and is off if gate voltage is 0 V.

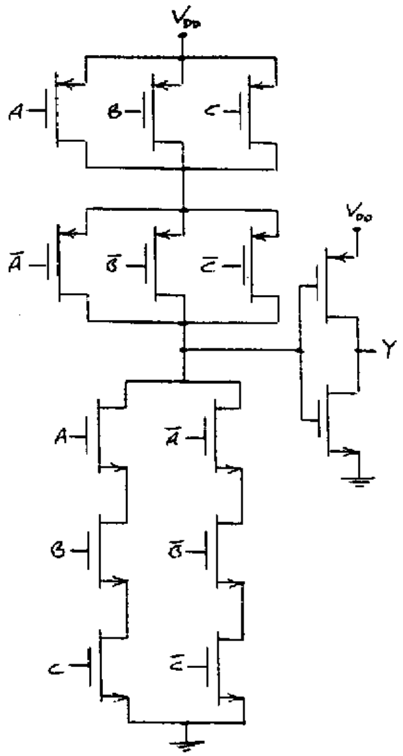
State	N_1	N_2	N_3	N_4	N_5	v_0
1	off	on	off	on	on	0
2	off	off	on	on	off	0
3	on	on	off	off	on	5
4	on	on	off	on	on	0

Logic function $(v_X \text{ OR } v_Y) \otimes (v_X \text{ AND } v_Z)$

Exclusive OR of $(v_X \text{ OR } v_Y)$ with $(v_X \text{ AND } v_Z)$

16.41

(a) A classic design is shown:



$\bar{A}, \bar{B}, \bar{C}$ signals supplied through inverters.

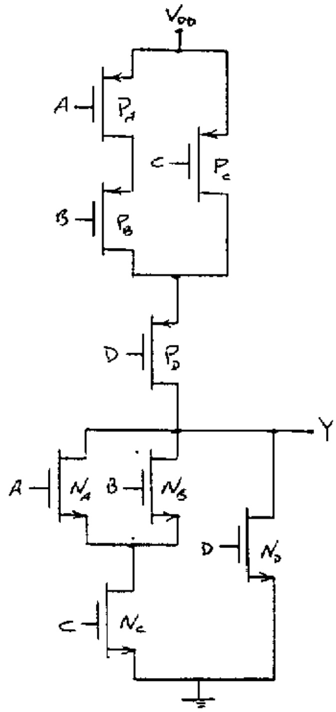
(b) For Inverters, $\left(\frac{W}{L}\right)_n = 1$ and $\left(\frac{W}{L}\right)_p = 2$

For PMOS in Logic function, let $\left(\frac{W}{L}\right)_p = 1$, then

for NMOS in Logic function, $\left(\frac{W}{L}\right)_n = 2.25$

16.42

(a) A classic design is shown:



(b) $\left(\frac{W}{L}\right)_{ND} = 1$, $\left(\frac{W}{L}\right)_{NA,NB,NC} = 2$

$\left(\frac{W}{L}\right)_{PA,PB} = 8$, $\left(\frac{W}{L}\right)_{PC,PD} = 4$

16.43

$\overline{(A \text{ OR } B) \text{ AND } C}$

16.44

Let $\left(\frac{W}{L}\right)_p = 1$ for each PMOS: Composite PMOS

$\left(\frac{W}{L}\right) = 5$. Want composite $\left(\frac{W}{L}\right) = 2.5$ for NMOS,

So that $\left(\frac{W}{L}\right)_n = 5(2.5) = 12.5$ for each NMOS.

16.45

(a)Let $\left(\frac{W}{L}\right)_n = 1$ for each NMOS. Composite $\left(\frac{W}{L}\right)$ of NMOS = 6. Want composite $\left(\frac{W}{L}\right)$ of PMOS = 12. Then $\left(\frac{W}{L}\right)_p = 6(12) = 72$ for each PMOS. Let $\left(\frac{W}{L}\right)_n = 1$ and $\left(\frac{W}{L}\right)_p = 2$ for each transistor in inverter.

(a) For 3-input NOR:
Let $\left(\frac{W}{L}\right)_n = 1$ for each NMOS. Composite $\left(\frac{W}{L}\right)$ of NMOS = 3. Want composite $\left(\frac{W}{L}\right)$ of PMOS = 6.
Then $\left(\frac{W}{L}\right)_p = 3(6) = 18$ for each PMOS.
For 2-input NAND:
Let $\left(\frac{W}{L}\right)_p = 1$ for each PMOS. Composite $\left(\frac{W}{L}\right)$ of PMOS = 2. Want composite $\left(\frac{W}{L}\right)$ of NMOS = 1.
Then $\left(\frac{W}{L}\right)_n = 2$ for each NMOS.
Sizes of PMOS transistors in (b) are substantially less than those in (a).

16.46

By definition:

NMOS off if gate voltage = 0
NMOS on if gate voltage = 5 V
PMOS off if gate voltage = 5 V
PMOS on if gate voltage = 0

State	N_1	P_1	N_A	N_B	N_C	v_{01}	N_2	P_2	v_{02}
1	off	on	off	off	off	5	on	off	0
2	on	off	on	off	off	5	on	off	0
3	off	on	off	off	off	5	on	off	0
4	on	off	off	off	on	5	on	off	0
5	off	on	off	off	off	5	on	off	0
6	on	off	off	on	on	0	off	on	5

Logic function is

$$v_{02} = (v_A \text{ OR } v_B) \text{ AND } v_C$$

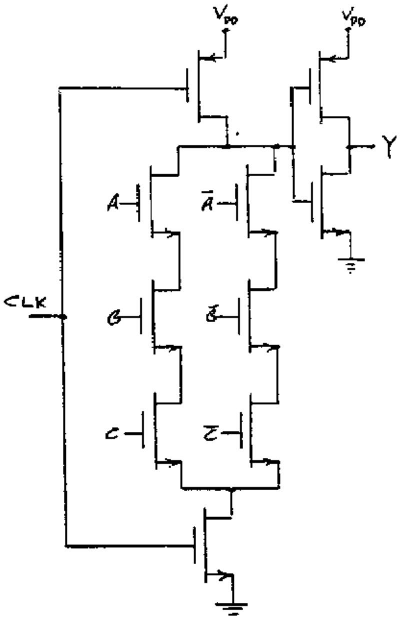
16.47

State	v_{01}	v_{02}	v_{03}
1	5	5	0
2	0	0	5
3	5	5	0
4	5	0	5
5	5	5	0
6	0	5	0

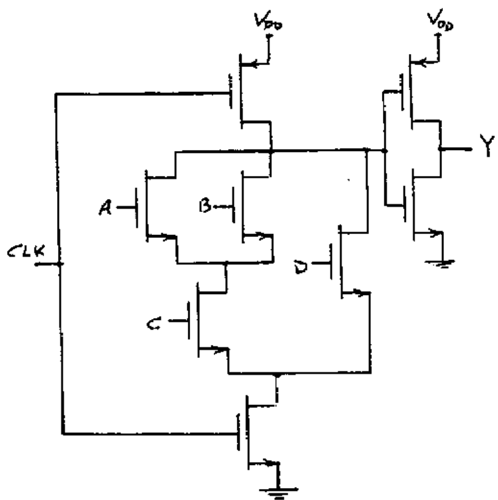
Logic function:

$$v_{03} = (v_X \text{ OR } v_Z) \text{ AND } v_Y$$

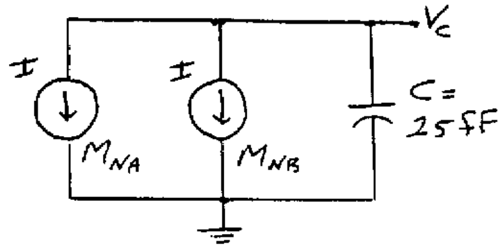
16.48



16.49



16.50



$$2I = -C\frac{dV_C}{dt}$$

So

$$\Delta V_C = -\frac{1}{C}(2I)\cdot t$$

For $\Delta V_C = -0.5\,V$

$$-0.5 = -\frac{2(2\times10^{-12})\cdot t}{25\times10^{-15}} \Rightarrow \underline{t = 3.125\,ms}$$

16.51

(a)

(i) $v_O = 0$

(ii) $v_O = 4.2\,V$

(iii) $v_O = 2.5\,V$

(b)

(i) $v_O = 0$

(ii) $v_O = 3.2\,V$

(iii) $v_O = 2.5\,V$

16.52

Neglect the body effect.

a. $v_{O1}(\text{logic }1) = 4.2$ V, $v_{O2}(\text{logic }1) = 5$ V

b. $v_I = 5\text{ V} \Rightarrow v_{GS1} = 4.2$ V

M_1 in nonsaturation and M_2 in saturation. From Equation (16.23)

$$\left(\frac{W}{L}\right)_D\left[2(v_{GS1} - V_{TND})v_{O1} - v_{O1}^2\right]$$

$$= \left(\frac{W}{L}\right)_L(V_{DD} - v_{O1} - V_{TNL})^2$$

$$\left(\frac{W}{L}\right)_D[2(4.2 - 0.8)(0.1) - (0.1)^2]$$

$$= (1)[5 - 0.1 - 0.8]^2$$

Or

$$\left(\frac{W}{L}\right)_D(0.67) = 16.81 \Rightarrow \underline{\left(\frac{W}{L}\right)_D = 25.1}$$

Now

$$v_{O1} = 4.2\text{ V} \Rightarrow v_{GS3} = 4.2\text{ V}$$

M_3 in nonsaturation and M_4 in saturation. From Equation (16.29(b)).

$$\left(\frac{W}{L}\right)_D\left[2(v_{GS3} - V_{TND})v_{O2} - v_{O2}^2\right] = \left(\frac{W}{L}\right)_L\left[-V_{TNL}\right]^2$$

$$\left(\frac{W}{L}\right)_D[2(4.2 - 0.8)(0.1) - (0.1)^2] = (2)[-(-1.5)]^2$$

$$\left(\frac{W}{L}\right)_D(0.67) = 2.25$$

Or $\underline{\left(\frac{W}{L}\right)_D = 3.36}$

16.53

For $\phi = 1$, $\bar{\phi} = 0$, then $Y = B$. And for $\phi = 0$, $\bar{\phi} = 1$, then $Y = A$.

A multiplexer.

16.54

A	B	Y	
0	0	1	
0	1	0	
1	0	0	
1	1	0, 1	⇒indeterminate

Without the top transistor, the circuit performs the exclusive-NOR function.

16.55

A	B	Y
0	0	0
1	0	1
0	1	1
1	1	0

Exclusive-OR function.

16.56

This circuit is referred to as a ratioless circuit. Identical minimum-sized transistors can be used throughout.

When ϕ_1 is low, C_3 is charged to V_{DD}. Then when ϕ_1 is high and ϕ_2 is low, M_8 turns on. If $A = B = 0$, then M_3 and M_4 are off so C_3 remains charged and v_{O1} = high. When ϕ_2 goes high, then v_{O1} is applied to the gates of M_9 and M_{10}. The circuit performs the OR logic function.

16.57

This circuit is referred to as a two-phase ratioed circuit. The same width-to-length ratios between the driver and load transistors must be maintained as discussed previously with the enhancement load inverter.

When ϕ_1 is high, v_{O1} becomes the complement of v_I. When ϕ_2 goes high, then v_O becomes the complement of v_{O1} or is the same as v_I. The circuit is a shift register.

16.58

Let $Q = 0$ and $\overline{Q} = 1$; as S increases, $\overline{Q}$ decreases. When $\overline{Q}$ reaches the transition point of the $M_5 - M_6$ inverter, the flip-flop with change state. From Equation (16.28(b)),

$$V_{II} = \sqrt{\frac{K_L}{K_D}} \cdot (-V_{TNL}) + V_{TND}$$

where $K_L = K_6$ and $K_D = K_5$.

Then

$$V_{II} = \sqrt{\frac{30}{100}} \cdot [-(-2)] + 1 \Rightarrow V_{II} = \overline{Q} = 2.095\,V$$

This is the region where both M_1 and M_3 are biased in the saturation region. Then

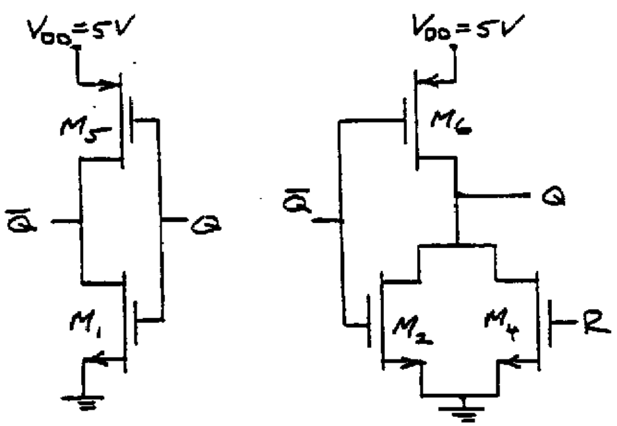
$$S = \sqrt{\frac{K_3}{K_1}} \cdot (-V_{TNL}) + V_{TND} = \sqrt{\frac{30}{200}} \cdot [-(-2)] + 1$$

or $\underline{S = 1.77\,V}$

This analysis neglects the effect of M_2 starting to turn on at the same time.

16.59

Let $v_Y = R$, $v_X = S$, $v_{O2} = Q$, and $v_{O1} = \overline{Q}$. Assume $V_{TAN} = 0.5$ V and $V_{TAP} = -0.5$ V. For $S = 0$, we have the following:



If we want the switching to occur for $R = 2.5$ V, then because of the nonsymmetry between the two circuits, we cannot have Q and $\overline{Q}$ both equal to 2.5 V.

Set $R = Q = 2.5$ V and assume $\overline{Q}$ goes low.

For the $M_1 - M_5$ inverter, M_1 in nonsaturation and M_5 in saturation. Then

$$K_n\left[2(2.5-0.5)\overline{Q} - \overline{Q}^2\right] = K_p[2.5-0.5]^2$$

Or

$$4\overline{Q} - \overline{Q}^2 = 4\left(\frac{K_p}{K_n}\right)$$

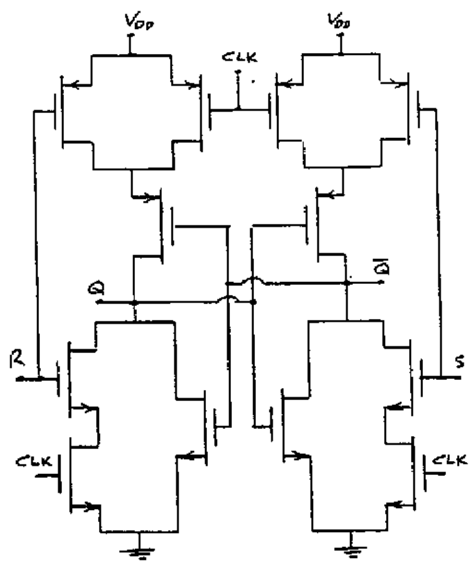
For the other circuit, $M_2 - M_4$ in saturation and M_6 in nonsaturation. Then

$$K_n(2.5-0.5)^2 + K_n(\overline{Q}-0.5)^2$$
$$= K_p\left[2(5-\overline{Q}-0.5)(2.5)-(2.5^2)\right]$$

Combining these equations and neglecting the $\overline{Q}^3$ term, we find

$\underline{\overline{Q} = 1.4\,V}$ and $\underline{\dfrac{K_p}{K_n} = 0.9}$

16.60



16.61

a. Positive edge triggered flip-flop when CLK = 1, output of first inverter is $\overline{D}$ and then $Q = \overline{\overline{D}} = D$.

b. For example, put a CMOS transmission gate between the output and the gate of M_1 driven by a $\overline{\text{CLK}}$ pulse.

16.62

For $J = 1$, $K = 0$, and CLK = 1; this makes $Q = 1$ and $\overline{Q} = 0$.

For $J = 0$, $K = 1$, and CLK = 1, and if $Q = 1$, then the circuit is driven so that $Q = 0$ and $\overline{Q} = 1$.

If initially, $Q = 0$, then the circuit is driven so that there is no change and $Q = 0$ and $\overline{Q} = 1$.

$J = 1$, $K = 1$, and CLK = 1, and if $Q = 1$, then the circuit is driven so that $Q = 0$.

If initially, $Q = 0$, then the circuit is driven so that $Q = 1$.

So if $J = K = 1$, the output changes state.

16.63

For $J = v_X = 1$, $K = v_Y = 0$, and CLK $= v_Z = 1$, then $v_0 = 0$.

For $J = v_X = 0$, $K = v_Y = 1$, and CLK $= v_Z = 1$, then $v_0 = 1$.

Now consider $J = K =$ CLK $= 1$. With $v_X = v_Z = 1$, the output is always $v_0 = 0$. So the output does not change state when $J = K =$ CLK $= 1$. This is not actually a $J - K$ flip-flop.

16.64

$64\ K \Rightarrow 65{,}536$ transistors arranged in a $256x256$ array.

(a) Each column and row decoder required 8 inputs.

(b)

(i) Address = 01011110 so input $= a_7\bar{a}_6 a_5\bar{a}_4\bar{a}_3\bar{a}_2\bar{a}_1 a_0$

(ii) Address = 11101111 so input $= \bar{a}_7\bar{a}_6\bar{a}_5 a_4\bar{a}_3\bar{a}_2\bar{a}_1\bar{a}_0$

(c)

(i) Address = 00100111 so input $= a_7 a_6\bar{a}_5 a_4 a_3\bar{a}_2\bar{a}_1\bar{a}_0$

(ii) Address = 01111011 so input $= a_7\bar{a}_6\bar{a}_5\bar{a}_4\bar{a}_3 a_2\bar{a}_1\bar{a}_0$

16.65

Put 128 words in a $8x16$ array, which means 8 row (or column) address lines and 16 column (or row) address lines.

16.66

Assume the address line is initially uncharged, then

$$I = C\frac{dV_C}{dt} \text{ or } V_C = \frac{1}{C}\int I dt = \frac{I}{C}\cdot t$$

$$\text{Then } t = \frac{V_C \cdot C}{I} = \frac{(2.7)(5.8x10^{-12})}{250x10^{-6}} \Rightarrow$$

$$\underline{t = 6.26x10^{-8}\ s \Rightarrow 62.6\ ns}$$

16.67

(a) $$\frac{5-0.1}{1} = \left(\frac{35}{2}\right)\left(\frac{W}{L}\right)\left[2(5-0.7)(0.1)-(0.1)^2\right]$$

$$\text{or } \underline{\left(\frac{W}{L}\right) = 0.329}$$

(b) $16\ K \Rightarrow 16{,}384$ cells

$$i_D \cong \frac{2}{1} = 2\ \mu A$$

Power per cell $= (2\ \mu A)(2\ V) = 4\ \mu W$

Total Power $= P_T = (4\ \mu W)(16{,}384) \Rightarrow$

$\underline{P_T = 65.5\ mW}$

Standby current $= (2\ \mu A)(16{,}384) \Rightarrow \underline{I_T = 32.8\ mA}$

16.68

$16\ K \Rightarrow 16{,}384$ cells

$P_T = 200\ mW \Rightarrow$ Power per cell

$$= \frac{200}{16{,}384} \Rightarrow 12.2\ \mu W$$

$$i_D = \frac{P}{V_{DD}} = \frac{12.2}{2.5} = 4.88\ \mu A \cong \frac{V_{DD}}{R} = \frac{2.5}{R} \Rightarrow$$

$\underline{R = 0.512\ M\Omega}$

If we want $v_O = 0.1\ V$ for a logic 0, then

$$i_D = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)\left[2(V_{DD}-V_{TN})v_O - v_O^2\right]$$

$$4.88 = \left(\frac{35}{2}\right)\left(\frac{W}{L}\right)\left[2(2.5-0.7)(0.1)-(0.1)^2\right]$$

$$\text{So } \underline{\left(\frac{W}{L}\right) = 0.797}$$

16.69

$Q = 0, \overline{Q} = 1$

So $\underline{\overline{D} = Logic\ 1 = 5\ V}$

A very short time after the row has been addressed, D remains charged at $V_{DD} = 5\ V$. Then M_{P3}, M_A, and M_{N1} begin to conduct and D decreases. In steady-state, all three transistors are biased in the nonsaturation region. Then

$$K_{p3}\left[2(V_{SG3}+V_{TP3})V_{SD3} - V_{SD3}^2\right]$$
$$= K_{nA}\left[2(V_{GSA}-V_{TNA})V_{DSA} - V_{DSA}^2\right]$$
$$= K_{n1}\left[2(V_{GS1}-V_{TN1})V_{DS1} - V_{DS1}^2\right]$$

Or

$$K_{p3}\left[2(V_{DD}+V_{TP3})(V_{DD}-D)-(V_{DD}-D)^2\right]$$
$$= K_{nA}\left[2(V_{DD}-Q-V_{TNA})(D-Q)-(D-Q)^2\right]$$
$$= K_{n1}\left[2(V_{DD}-V_{TN1})Q-Q^2\right] \qquad (1)$$

Equating the first and third terms:

$$\left(\frac{20}{2}\right)(1)\left[2(5-0.8)(5-D)-(5-D)^2\right]$$
$$=\left(\frac{40}{2}\right)(2)\left[2(5-0.8)Q-Q^2\right] \qquad (2)$$

As a first approximation, neglect the $(5-D)^2$ and Q^2 terms. We find

$$Q=1.25-0.25D \qquad (3)$$

Then, equating the first and second terms of Equation (1):

$$\left(\frac{20}{2}\right)(1)\left[2(5-0.8)(5-D)-(5-D)^2\right]$$
$$=\left(\frac{40}{2}\right)(1)\left[2(5-Q-0.8)(D-Q)-(D-Q)^2\right]$$

Substituting Equation (3), we find as a first approximation: $D=2.14\,V$

Substituting this value of D into equation (2), we find

$$8.4(5-2.14)-(5-2.14)^2=4\left[8.4Q-Q^2\right]$$

We find $\underline{Q=0.50\,V}$

Using this value of Q, we can find a second approximation for D by equating the second and third terms of equation (1). We have

$$20\left[2(4.2-Q)(D-Q)-(D-Q)^2\right]$$
$$=40\left[2(4.2Q)-Q^2\right]$$

Using $Q=0.50\,V$, we find $\underline{D=1.79\,V}$

16.70

Initially M_{N1} and M_A turn on.

M_{N1}, Nonsat; M_A, sat.

$$K_{nA}\left[V_{DD}-Q-V_{TN}\right]^2=K_{n1}\left[2(V_{DD}-V_{TN1})Q-Q^2\right]$$

$$\left(\frac{40}{2}\right)(1)\left[5-Q-0.8\right]^2=\left(\frac{40}{2}\right)(2)\left[2(5-0.8)Q-Q^2\right]$$

which yields

$$\underline{Q=0.771\,V}$$

Initially M_{P2} and M_B turn on

Both biased in nonsaturation reagion

$$K_{p2}\left[2(V_{DD}+V_{TP3})(V_{DD}-\overline{Q})-(V_{DD}-\overline{Q})^2\right]$$
$$=K_{nB}\left[2(V_{DD}-V_{TNB})\overline{Q}-\overline{Q}^2\right]$$

$$\left(\frac{20}{2}\right)(4)\left[2(5-0.8)(5-\overline{Q})-(5-\overline{Q})^2\right]$$
$$=\left(\frac{40}{2}\right)(1)\left[2(5-0.8)\overline{Q}-\overline{Q}^2\right]$$

which yields $\underline{\overline{Q}=3.78\,V}$

Note: (W/L) ratios do not satisfy Equation (16.95)

16.71

For Logic 1, v_1:

$$(5)(0.05)+(4)(1)=(1+0.05)v_1 \Rightarrow \underline{v_1=4.0476\,V}$$

v_2:

$$(5)(0.025)+(4)(1)=(1+1.025)v_2 \Rightarrow \underline{v_2=4.0244\,V}$$

For Logic 0, v_1:

$$(0)(0.05)+(4)(1)=(1+0.05)v_1 \Rightarrow \underline{v_1=3.8095\,V}$$

v_2:

$$(0)(0.025)+(4)(1)=(1+0.025)v_2 \Rightarrow \underline{v_2=3.9024\,V}$$