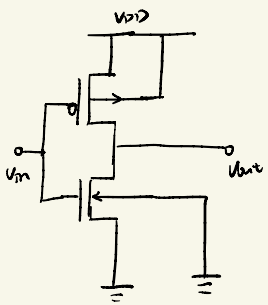
6.10

CMOS 反相器参数

$V_{T0,n} = 0.5V$ $\mu_n C_{ox} = 98\ \mu A/V^2$ $\left(\frac{W}{L}\right)_n = 20$ $L_n = 40nm$ $E_{crit,n} = 0.4$

$V_{T0,p} = -0.48V$ $\mu_p C_{ox} = 46\ \mu A/V^2$ $\left(\frac{W}{L}\right)_p = 30$ $L_p = 40nm$ $E_{crit,p} = 1.8$

$V_{DD} = 1.2V$ $C_{load} = 10fF$



a.

$$t_{rise} = \frac{C_{load} \cdot \Delta V}{I_{average,rise}}$$

(短沟道)

$$I_{average,rise} = \frac{1}{2}\left[I_1(V_{out} = 0.12V) + I_2(V_{out} = 1.08V) \right]$$

I_2 ($V_{in} = 0V$, $V_{out} = 1.08V$) (线性区)

$$= \frac{1}{2} \mu_p C_{ox} \frac{W_p}{L_p} \frac{1}{1 + \frac{V_{SD}}{E_{crit,p} L_p}} \left(2(V_{SG} + V_{T0,p}) V_{SD} - V_{SD}^2 \right)$$

$$= \frac{1}{2} \times 46 \times 10^{-6} \times 30 \times \frac{1}{1 + \frac{1.2 - 1.08}{1.8}} \left(2 \times (1.2 - 0.48) \times (1.2 - 1.08) - (1.2 - 1.08)^2 \right)$$

$$= 102.465\ \mu A$$

I_1 ($V_{in} = 0V$, $V_{out} = 0.12V$) (饱和区)

$$= \frac{1}{2} \mu_p C_{ox} \frac{W_p}{L_p} \frac{1}{1 + \frac{V_{SG} + V_{T0,p}}{E_{crit,p} L_p}} \left(V_{SG} + V_{T0,p} \right)^2$$

$$= \frac{1}{2} \times 46 \times 10^{-6} \times 30 \quad \frac{1}{1 + \frac{1.2 - 0.48}{1.8}} \left(1.2 - 0.48 \right)^2$$

$$= 255.497\ \mu A$$

$$I_{average,rise} = \frac{1}{2}\left(255.497 + 102.465 \right) = 178.981\ \mu A$$

$$t_{rise} = \frac{C_{load} \cdot \Delta V}{I_{average,rise}} = \frac{60 \times 10^{-15} \times (1.08 - 0.12)}{178.981 \times 10^{-6}} = 53.637\ ps$$

$$t_{fall} = \frac{C_{load} \cdot \Delta V}{I_{average,fall}}$$

$$I_{average,fall} = \frac{1}{2}\left(I_1 \left(V_{out} = 0.12V \right) + I_2 \left(V_{out} = 1.08V \right) \right)$$

I_1 ($V_{out} = 0.12V$, $V_{in} = 1.2V$) (线性区)

$$= \frac{1}{2} \mu_n C_{ox} \frac{W_n}{L_n} \quad \frac{1}{1 + \frac{V_{DS}}{E_{cn} L_n}} \left(2(V_{GS} - V_{Tn}) V_{DS} - V_{DS}^2 \right)$$

$$= \frac{1}{2} \times 98 \times 10^{-6} \times 20 \times \frac{1}{1 + \frac{0.12}{0.4}} \left(2(1.2 - 0.5) 0.12 - 0.12^2 \right)$$

$$= 115.79\ \mu A$$

I_2 = ($V_{out} = 1.08V$, $V_{in} = 1.2V$) (饱和区)

$$= \frac{1}{2} \mu_n C_{ox} \frac{W_n}{L_n} \quad \frac{1}{1 + \frac{V_{GS} - V_{Tn}}{E_{cn} L_n}} \left(V_{GS} - V_{Tn} \right)^2$$

$$= \frac{1}{2} \times 98 \times 10^{-6} \times 20 \times \frac{1}{1 + \frac{1.2 - 0.5}{0.4}} \left(1.2 - 0.5\right)^2$$

$$= 174.618 \text{ ps}$$

$$t_{average,fall} = \frac{1}{2}\left(174.618 + 113.79\right) = 145.204 \text{ ps}$$

$$t_{fall} = \frac{C_{load}\,\Delta V}{t_{average,fall}} = \frac{20 \times 10^{-15} \times (1.08 - 0.12)}{145.204 \times 10^{-6}} = 66.11 \text{ ps}$$

b.

$$f_{max} = \frac{1}{2\,t_{fall}} = \frac{1}{2 \times 66.11 \times 10^{-12}} = 7.56 \times 10^{9} \text{ Hz}$$

c.

$$P_{average} = C_{load} \cdot V_{DD}^2 \cdot f_{max} = 10 \times 10^{-15} \times 1.2^2 \times 7.56 \times 10^{9}$$

$$= 1.08864 \times 10^{-4} \text{ W}$$

d.

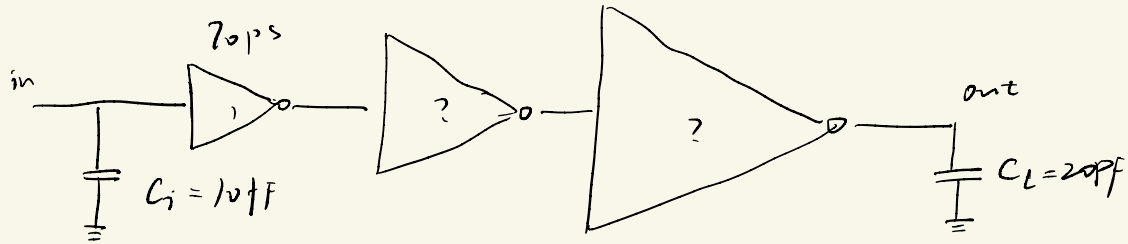
$$\left(\frac{W}{L}\right)_{p\_new} = \left(\frac{W}{L}\right)_p \times \frac{4}{3} = 40$$

$$\left(\frac{W}{L}\right)_{n\_new} = \left(\frac{W}{L}\right)_n \times \frac{4}{3} = 26.66\cdots$$

$$V_{th} = \frac{V_{T0,n} + \sqrt{k}\left(V_{DD} - |V_{T0,p}|\right)}{1 + \sqrt{k}}$$

$k \propto \left(\frac{W}{L}\right)_p \Big/ \left(\frac{W}{L}\right)_n$ ，K不变，不影响 V_{th}

1.



(1) $2p = 70ps$.

$$a^3 = \frac{C_L}{C_i} = \frac{20\times10^3}{10} = 2\times10^3$$

$$a = \sqrt[3]{2} \times 10 = 12.599$$

$$a^2 = 158.74$$

最小的门的倍数的尺寸为 12.599 和 158.74

(2) $\gamma = 1$. $a_{opt} = 3.6$

$$N+1 = \frac{\ln(20\times10^3)}{\ln 3.6} = 7.731$$

$N+1 = 7$. $a = (2\times10^3)^{\frac{1}{7}} = 2.9619$

$$t = 72p_0(1+a) = 1.941ns$$

$N+1 = 6$. $a = (2\times10^3)^{\frac{1}{6}} = 3.5495$

$$t = 62p_0(1+a) = 1.91079ns$$

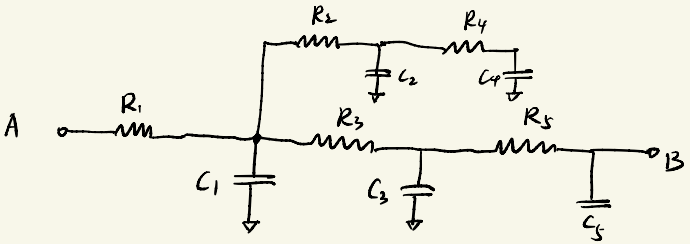
$N+1 = 5$. $a = (2\times10^3)^{\frac{1}{5}} = 4.573$

$$t = 52p(1+a) = 1.95ns$$

N+1=6，即再插入5级仅相差此时最小，为 1.9079 ns

(3) 方法二 此时更小，但是会插入较多元件，影响电路面积（增R），功耗也增加

2.



$$\tau_{AB} = C_1R_1 + R_1(C_2+C_4) + C_3(R_1+R_3) + C_5(R_1+R_3+R_5)$$

$$= 10^{-15}(2500 + 5000 + 5000 + 15000)$$

$$= 27500 \times 10^{-15} = 2.75 \times 10^{-11}\ s$$

$$= 27.5\ ps$$

$$\tau_p = 0.69\,\tau_{AB} = 18.975\ ps$$