CAD of Digital VLSI Systems

Homework 4

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1. V_{IH}: PMOS (sat) NMOS (sat)

PMOS: $I_D = \frac{1}{2}\mu_p \frac{W}{L} C_{ox} (|V_{gs}| - |V_T|)^2 (1 + \lambda |V_{ds}|)$

$\mu_p C_{ox} = k_p$ $\frac{W}{L} = 40$ $V_{gs} = V_g - V_s = V_{in} - 5$ $V_{ds} = V_d - V_s = V_o - 5$ $\lambda = 0.19$

$I_D = \frac{1}{2} \times 5.4 \times 40 (|V_{in} - 5| - 0.74)^2 (1 + 0.19(|V_o - 5|))$

$= 108 (4.26 - V_{in})^2 (1.95 - 0.19 V_o)$

NMOS: $I_D = \frac{1}{2}\mu_n \frac{W}{L} C_{ox} (V_{gs} - V_T)^2 (1 + \lambda V_{ds})$

$\mu_n C_{ox} = k_n$ $\frac{W}{L} = \frac{1}{40}$ $V_{gs} = V_o - 0$ $V_{ds} = V_o$ $\lambda = 0.06$

$I_D = \frac{1}{2} \times 19.6 \times \frac{1}{40} (V_o - 0.74)^2 (1 + 0.06 V_o)$

$= 0.245 (V_o - 0.74)^2 (1 + 0.06 V_o)$

$\Rightarrow \frac{108}{0.245} (4.26 - V_{in})^2 (1.95 - 0.19 V_o) = 0.245 (V_o - 0.74)^2 (1 + 0.06 V_o)$

diff w.r.t. V_{in}

$441 \times (-2) \times (4.26 - V_{in})(1.95 \times 0.19 V_o) + (4.26 - V_{in})^2 (-0.19) \frac{dV_o}{dV_{in}}]$

$= [2(V_o - 0.74)(1 + 0.06 V_o) + 0.06 (V_o - 0.74)^2] \frac{dV_o}{dV_{in}}$

$V_{in} = 4.26$ V $= V_{IH}$

$V_{out} = 0.74$ V

V_{IL} : PMOS (linear) NMOS (sat)

PMOS: $I_D = \mu_p \frac{W}{L} C_{ox} \left[(|V_{GS}| - |V_{TH}|) |V_{DS}| - \frac{1}{2} |V_{DS}|^2 \right]$

$k_p = 54 \quad \frac{W}{L} = 40 \quad V_{GS} = V_{in} - 5 \quad V_{DS} = V_o - 5$

$I_D = 54 \times 40 \left[(4.26 - V_{in})(5 - V_o) - \frac{(5 - V_o)^2}{2} \right]$

NMOS: $I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{ds})$

$= \frac{1}{2} \times \frac{1}{40} \times 19.6 \, (V_o - 0.74)^2 (1 + 0.06 V_o)$

$= 0.245 \, (V_o - 0.74)^2 (1 + 0.06 V_o)$

$$\frac{216}{0.245} \left[(4.26 - V_{in})(5 - V_o) - \frac{(5 - V_o)^2}{2} \right] = (V_o - 0.74)^2 (1 + 0.06 V_o)$$

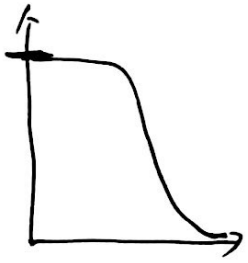
diff w.r.t V_{in}

$$\frac{216}{0.245} \left[(V_o - 5) + (-1) \frac{dv_o}{dV_{in}} (4.26 - V_{in}) - (V_o - 5) \frac{dv_o}{dV_{in}} \right] = \left[2(V_o - 0.74)(1 + 0.06 V_o) + (V_o - 0.74)^2 \times 0.06 \frac{dv_o}{dV_{in}} \right]$$

$V_{in} = 4.01 = V_{IL}$

$V_o = 4.87$

V_{OH} : when $V_{in} = 0$. P (lin) - N (Sat).



$$\frac{216}{0.245}\left[(4.26 - V_{in})(5 - V_o) - \frac{(5 - V_o)^2}{2}\right] = (V_o - 0.74)(1 + 0.06 V_o)$$

$V_{in} = 0 \qquad V_o = V_{OH} = 4.99 \approx 5\ V$

V_{OL} : Since NMOS is always in saturation. the minimum

$V_{out} = 0.74\ V = V_{OL}$.

V_{LT} : $V_o = V_{in}$ N(sat) P(sat)

$$\frac{\beta_p}{2}(V_{sg} - |V_{tp}|)^2 (1 + \lambda V_{sd}) = \frac{\beta_n}{2}(V_{gs} - V_{tn})^2 (1 + \lambda V_{ds})$$

$$216\ (4.26 - V_{in})^2 (1 + 0.19(5 - V_{in})) = 0.49(V_{in} - 0.74)^2 (1 + 0.06 V_{in})$$

$$V_{in} = 4.09 = V_{LT}$$

$NML = |V_{OL} - V_{IL}| = 4.01 - 0.74 = 3.27$

$NMH = |V_{OH} - V_{IH}| = 5 - 4.26 = 0.74$

T_r . T_f:

$C_{gd_1} = 2 \times 6.6 \times 10^{-12} \times 20 \times 10^{-6} = 2.64 \times 10^{-16}$. $C_{gd_2} = 0$

$C_{db_1} = 1.836 \times 10^{-17}\ F$ $C_{db_2} = 2.359 \times 10^{-17}$.

$C_{gs} = C_{g4} = 11 \times 10^{-15}$

$C_L = \Sigma = 2.2 \times 10^{-14}\ F$

$T_r = 3.48 \times 10^{-8}\ s$

$T_f = 1.264 \times 10^{-7}\ s$.

(2)

$$V_{LT} = \frac{V_{tn} + \sqrt{\beta_p/\beta_n}\,(V_{dd} - |V_{tp}|)}{1 + \sqrt{\beta_p/\beta_n}} = 1$$

$\sqrt{\beta_p/\beta_n} = A \quad V_{tn} = 0.74 \quad V_{dd} = 1.8 \quad |V_{tp}| = 0.74$

$$\frac{0.74 + A(1.8 - 0.74)}{1 + A} = 1 + H$$

$$0.74 + 1.06A = 1 + H$$

$$A = 4.33 = \sqrt{\beta_p/\beta_n}$$

$$\frac{\beta_p}{\beta_n} = 18.78 = \frac{\mu_p C_{ox} W_p/L_p}{\mu_n C_{ox} W_n/L_n} = \frac{k_p}{k_n} \times \frac{W_p/L_p}{W_n/L_n}$$

$$\frac{k_p}{k_n} = \frac{5.4}{19.6} = 0.2755$$

$$\frac{W_p/L_p}{W_n/L_n} = 68.2$$

$$T_f = t_{HL} = \frac{C_L}{\beta_n (V_H - V_{tn})} \left\{ \frac{2V_{tn}}{(V_H - V_{tn})} + \ln\left[\frac{2(V_H - V_{tn})}{V_L} - 1 \right] \right\}$$

$V_H = 1.62$
$V_L = 0.18$
$V_H - V_{tn} = 0.88$

$$= \frac{100 \times 10^{-15}}{\beta_n \times 0.88} \left[\frac{1.48}{0.88} + \ln\left(\frac{1.76}{0.18} - 1 \right) \right]$$

$$= \frac{438 \times 10^{-15}}{\beta_n} < 2 \times 10^{-9}$$

$$\beta_n > \frac{438 \times 10^{-15}}{2 \times 10^{-9}} = k_n \frac{W_n}{L_n} \Rightarrow \frac{W_n}{L_n} > \frac{219 \times 10^{-6}}{19.6 \times 10^{-6}} = 11.17$$

$$T_r = t_{LH} = \frac{C_L}{\beta_p (V_H - |V_{tp}|)} \left\{ \frac{2|V_{tp}|}{(V_H - |V_{tp}|)} + \ln\left(\frac{2(V_H - |V_{tp}|)}{V_L} - 1\right) \right\}$$

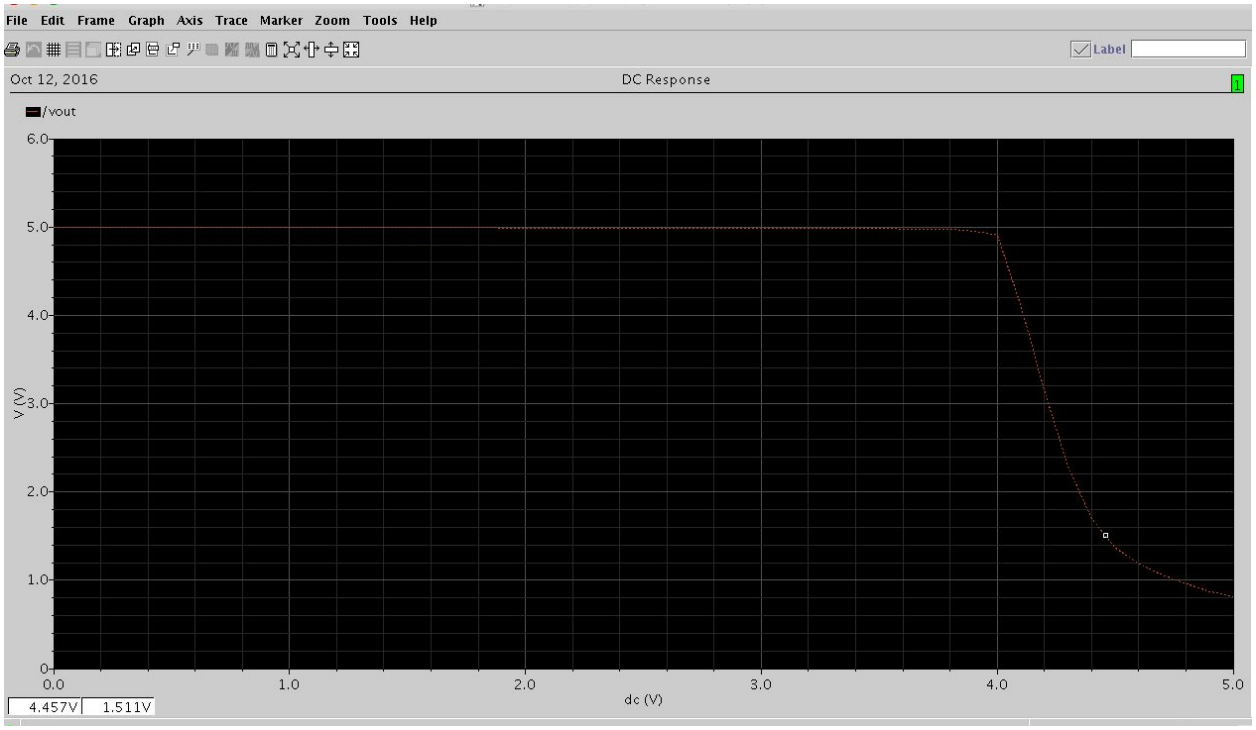
$$= \frac{100 \times 10^{-15}}{\beta_p \times 0.88} \left[\frac{1.48}{0.88} + \ln\left(\frac{1.76}{0.18} - 1\right) \right]$$

$$= \frac{438 \times 10^{-15}}{\beta_p} < 2 \times 10^{-9}$$

$$\beta_p > 219 \times 10^{-6} = k_p \frac{W_p}{L_p} \qquad \frac{W_p}{L_p} > \frac{219 \times 10^{-6}}{5.4 \times 10^{-6}} = 40.56 \;//$$

set $\frac{W_n}{L_n}$ be minimum $\frac{W_n}{L_n} = 12$ $\frac{W_p/L_p}{W_n/L_n} = 68.2$ • $\frac{W_p}{L_p} = 818.4 > 40.56$ //

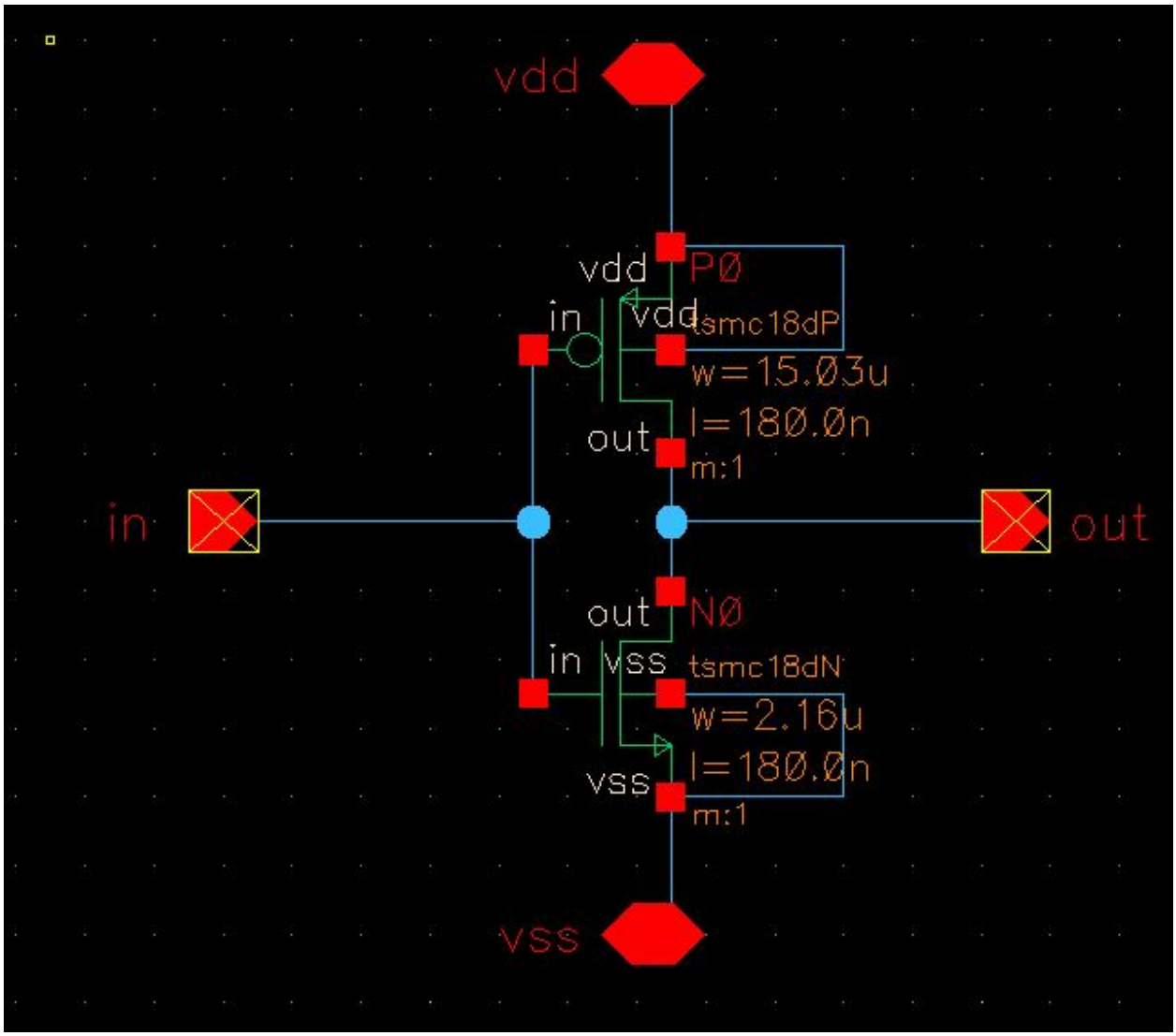
Q1 simulation verification



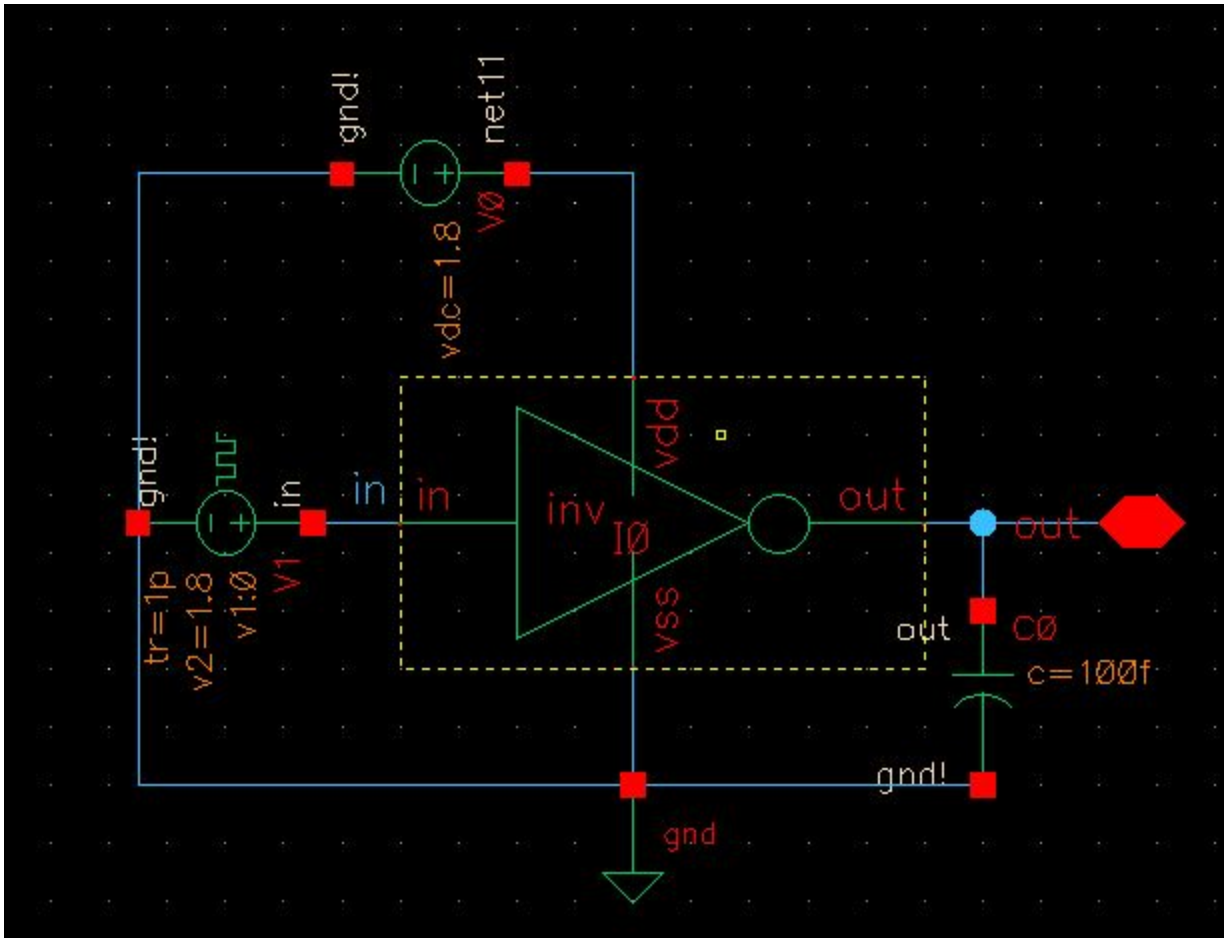
Q2

According to calculation, Wp/Lp=818.4, which is impossible to draw the layout.

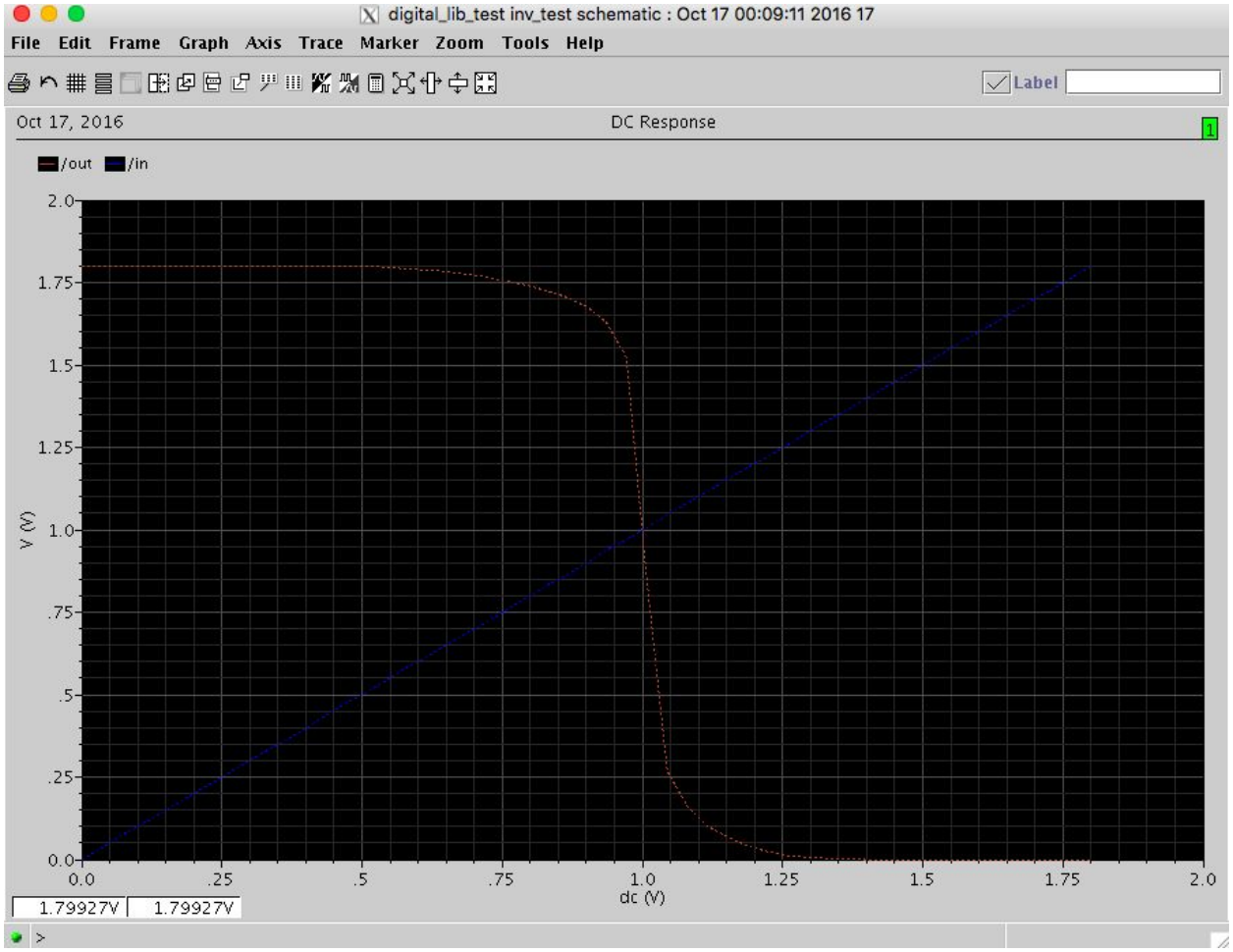
We tune the numbers and get the following result to obtain Vlt=1.



Schematic of inverter designed.



Simulation circuit.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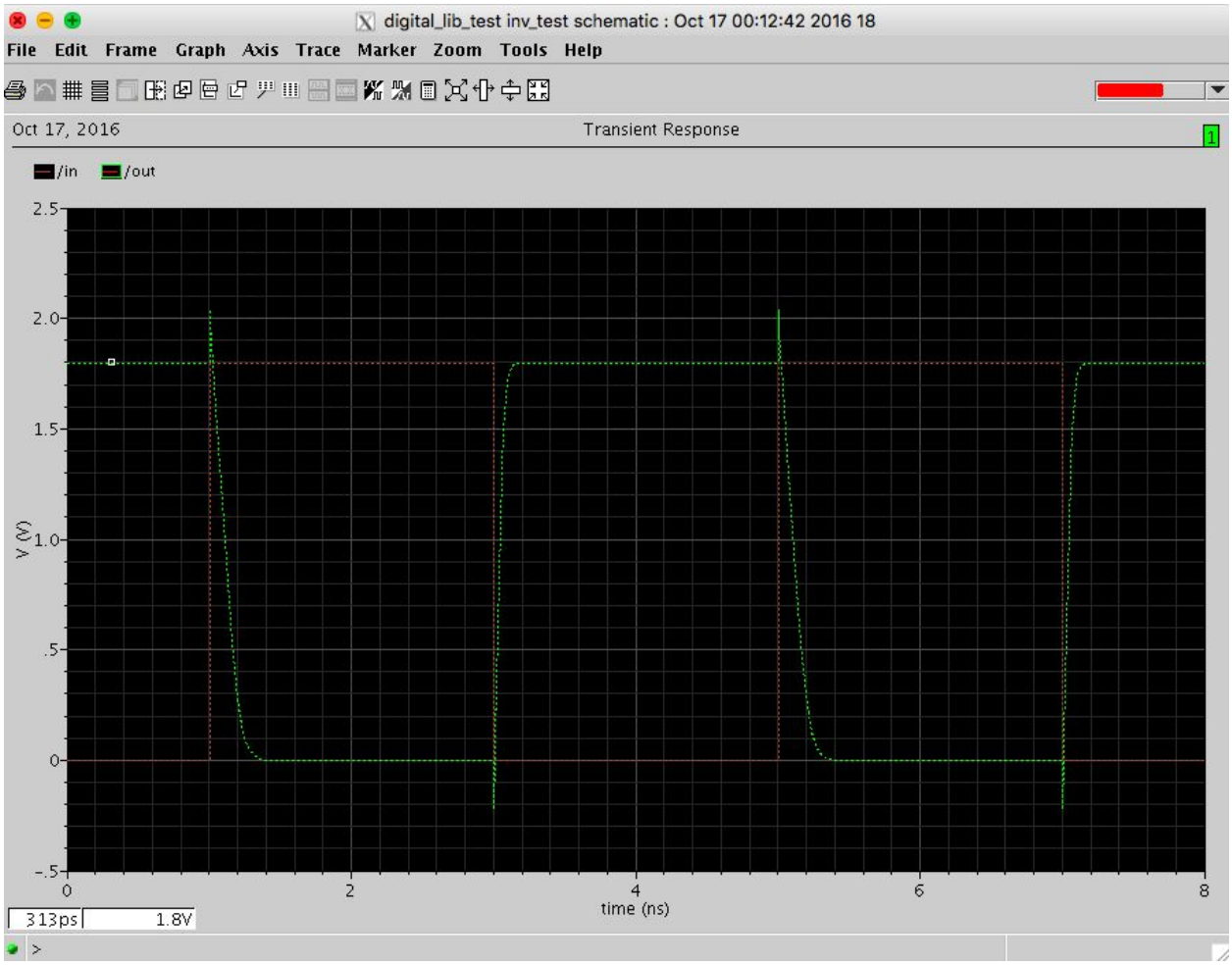
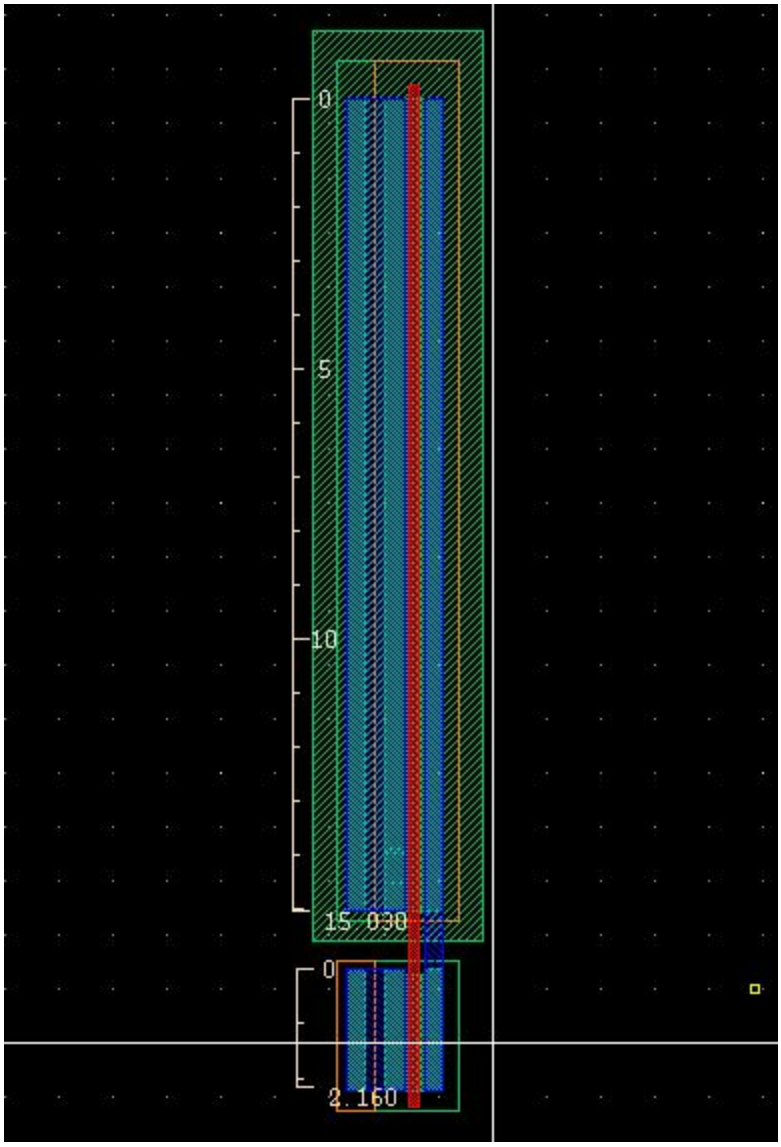
File Edit Frame Graph Axis Trace Marker Zoom Tools Help
Label
Oct 17, 2016
DC Response
1
/out
/in
2.0
1.75
1.5
1.25
1.0
.75
.5
.25
0.0
V (V)
0.0
.25
.5
.75
1.0
1.25
1.5
1.75
2.0
dc (V)
1.79927V
1.79927V

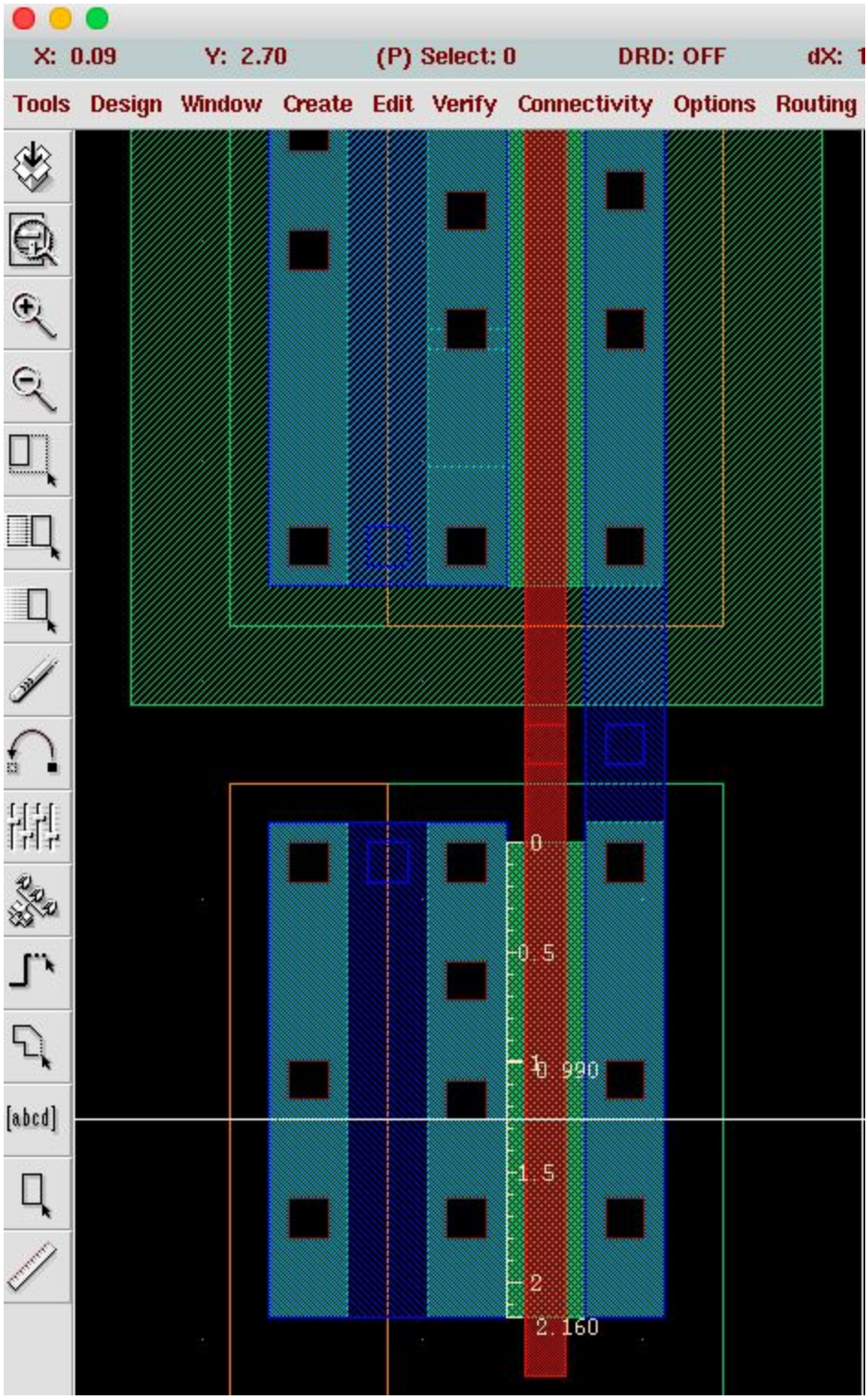
DC analysis



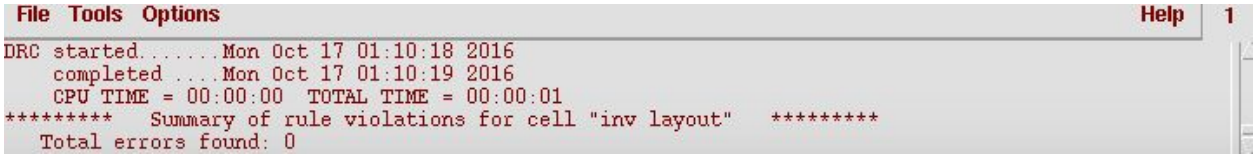
Transient analysis



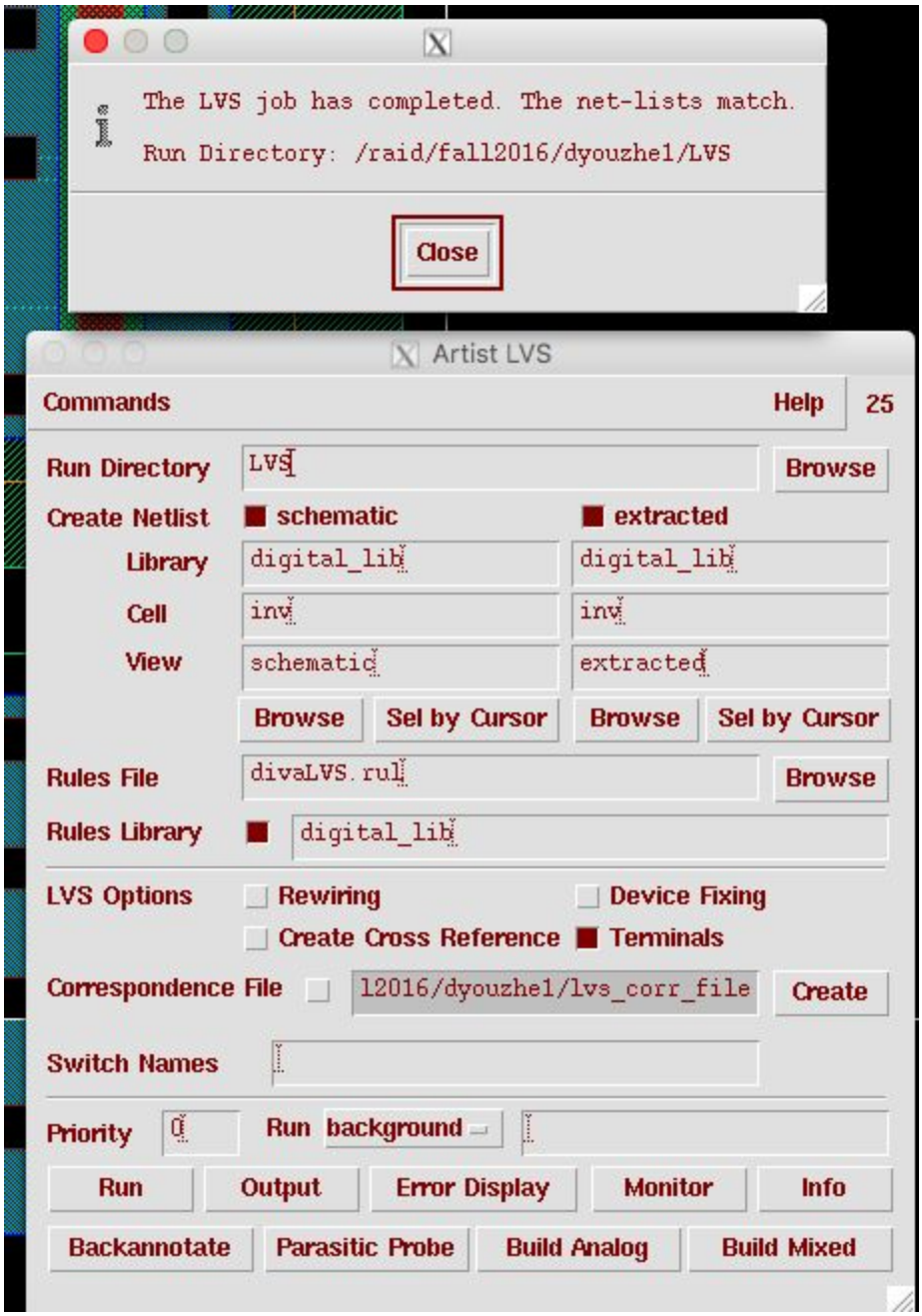
Layout full view



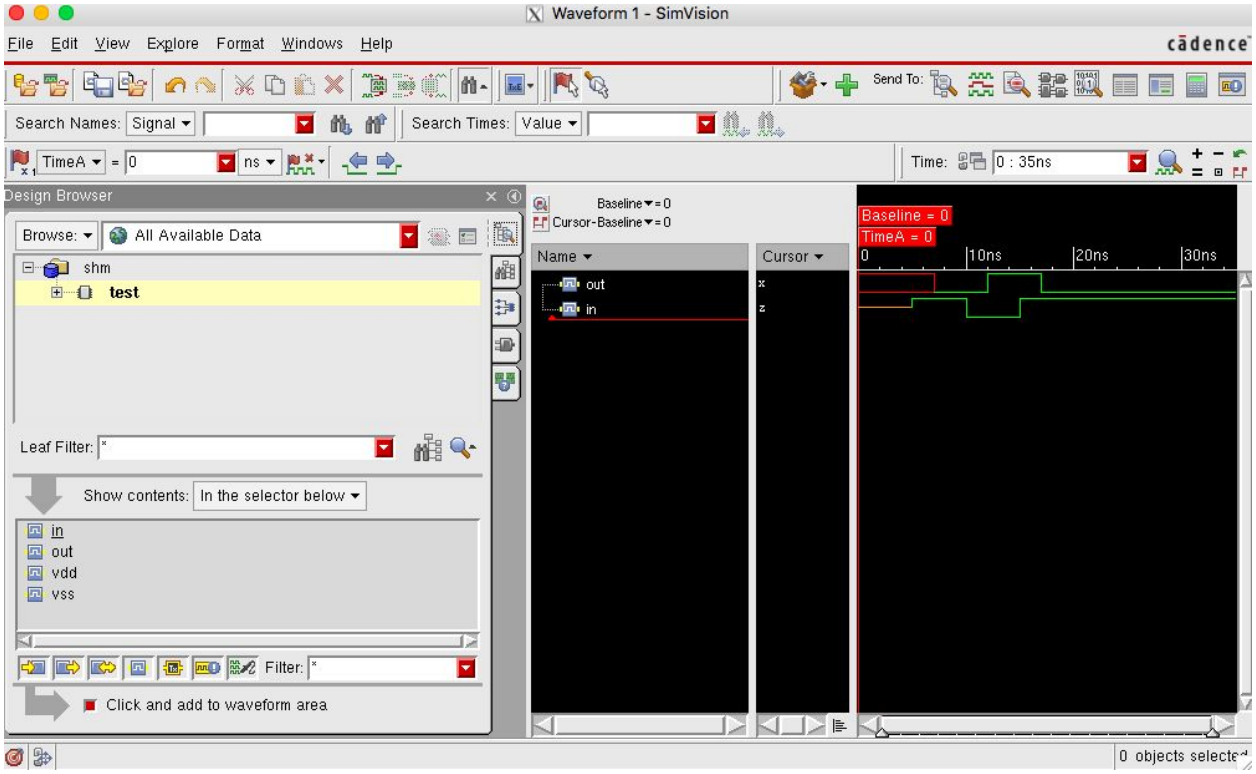
Layout details



DRC check



LVS check



Verilog simulation