| NAME: |
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Problem 1(40PTS):

Do the online tutorials:
http://www.engr.sjsu.edu/~dparent/ICGROUP/UNIX.pdf
and
http://www.engr.sjsu.edu/~dparent/ICGROUP/CDS_1.pdf

to either learn the basics of the tool or refresh your memory.

Problem 2(50PTS):

Design a CMOS inverter in **the tsmc .18 deep process** with the following specification:
tphl=tplh=30ps (with in 10%)
Cg=60fF
No layout required.

$A := 10300\Omega \quad C_{JSWN} := 2.47\cdot 10^{-12}\frac{F}{cm} \quad C_{JN} := 9.53\cdot 10^{-8}\frac{F}{cm^2} \quad C_{GDON} := 8.35\cdot 10^{-12}\frac{F}{cm}$

$L_N := .18\cdot 10^{-4}cm \quad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8}\cdot\left(\sqrt{.84+1.8}-\sqrt{.84}\right) \quad K_{EQ} = 0.721 \quad D_D := .36\cdot 10^{-4}cm$

$C_g := 60\cdot 10^{-15}F \quad N := 1 \quad N_{SN} := 1$

$\tau_{PHL} := .03\cdot 10^{-9}s \quad M := 1 \quad N_{SP} := 1 \quad S := 1 \quad R := 2.16$

$$W_N := \frac{C_g + C_{JSWN}\cdot 2\cdot D_D\cdot K_{EQ}\cdot(N+M)}{\frac{\tau_{PHL}}{N_{SN}\cdot L_N\cdot A} - (N + M\cdot R)\cdot\left(C_{JSWN}\cdot 2K_{EQ} + C_{JN}\cdot D_D K_{EQ} + 2\cdot C_{GDON}\right)}$$

$W_N = 6.698\times 10^{-4}\,cm$

$W_P := R\cdot W_N \quad W_P = 1.447\times 10^{-3}\,cm$

$\tau_{PHL\_M} := (39 - 5)\cdot 10^{-12}s$

$\tau_{PLH\_M} := (1037 - 1005)\cdot 10^{-12}s$

$W_N := \frac{\tau_{PHL\_M}}{\tau_{PHL}}\cdot W_N$ $W_N = 7.591\times 10^{-4}\,cm$ $Error := \frac{\tau_{PHL} - \tau_{PHL\_M}}{\tau_{PHL}}\cdot 100$

$Error = -13.333$

$W_P := \frac{\tau_{PLH\_M}}{\tau_{PLH}}\cdot W_P$ $W_P = 1.543\times 10^{-3}\,cm$ $Error := \frac{\tau_{PLH} - \tau_{PLH\_M}}{\tau_{PLH}}\cdot 100$

$\tau_{PHL\_M} := (36 - 5)\cdot 10^{-12}s$ $Error = -6.667$

+

$\tau_{PLH\_M} := (1036 - 1005)\cdot 10^{-12}s$

$W_N := \frac{\tau_{PHL\_M}}{\tau_{PHL}}\cdot W_N$ $W_N = 7.844\times 10^{-4}\,cm$ $Error := \frac{\tau_{PHL} - \tau_{PHL\_M}}{\tau_{PHL}}\cdot 100$

$Error = -3.333$

$W_P := \frac{\tau_{PLH\_M}}{\tau_{PLH}}\cdot W_P$ $W_P = 1.595\times 10^{-3}\,cm$ $Error := \frac{\tau_{PLH} - \tau_{PLH\_M}}{\tau_{PLH}}\cdot 100$

$Error = -3.333$

Problem 3(10PTS):

Develop a Model for a 2 input NAND gate (worst or slowest case) for **the tsmc .18 deep process.**

**Find A and R**.

A=7070 ohms and R=1.45, for a trise=tfall of input=10ps

| | | TPM | TPS | ERROR | W old | W new |
|---|---|---|---|---|---|---|
| 53 | 5 | 48 | 70 | -31.4286 | 3.68 | 2.523429 |
| 1069 | 1005 | 64 | 70 | -8.57143 | 3.98 | 3.638857 |
| 65.68 | 5 | 60.68 | 70 | -13.3143 | 2.523429 | 2.187452 |
| 1065.5 | 1005 | 60.5 | 70 | -13.5714 | 3.638857 | 3.145012 |
| 69 | 5 | 64 | 70 | -8.57143 | 2.187452 | 1.999956 |
| 1069.5 | 1005 | 64.5 | 70 | -7.85714 | 3.145012 | 2.897904 |
| 71.74 | 5 | 66.74 | 70 | -4.65714 | 1.999956 | 1.906815 |
| 1071.7 | 1005 | 66.7 | 70 | -4.71429 | 2.897904 | 2.761289 |
| 73.15 | 5 | 68.15 | 70 | -2.64286 | 1.906815 | 1.856421 |
| 1073.4 | 1005 | 68.4 | 70 | -2.28571 | 2.761289 | 2.698173 |
| 74.11 | 5 | 69.11 | 70 | -1.27143 | 1.856421 | 1.832818 |
| 1074 | 1005 | 69 | 70 | -1.42857 | 2.698173 | 2.659628 |
| 74.49 | 5 | 69.49 | 70 | -0.72857 | 1.832818 | 1.819465 |
| 1074.6 | 1005 | 69.6 | 70 | -0.57143 | 2.659628 | 2.64443 |

$A := 7070\Omega \quad C_{JSWN} := 2.47\cdot10^{-12}\frac{F}{cm} \quad C_{JN} := 9.53\cdot10^{-8}\frac{F}{cm^2} \quad C_{GDON} := 8.35\cdot10^{-12}\frac{F}{cm}$

$L_N := .18\cdot10^{-4}cm \quad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8}\cdot\left(\sqrt{.84+1.8}-\sqrt{.84}\right) \quad K_{EQ} = 0.721 \quad D_D := .36\cdot10^{-4}cm$

$C_g := 25\cdot10^{-15}F \quad N := 3 \quad N_{SN} := 2$

$\tau_{PHL} := .07\cdot10^{-9}s \quad M := 2 \quad N_{SP} := 1 \quad S := 1 \quad R := 1.45$

$$W_N := \frac{C_g + C_{JSWN}\cdot2\cdot D_D\cdot K_{EQ}\cdot(N+M)}{\frac{\tau_{PHL}}{N_{SN}\cdot L_N\cdot A} - (N+M\cdot R)\cdot\left(C_{JSWN}\cdot2K_{EQ} + C_{JN}\cdot D_D K_{EQ} + 2\cdot C_{GDON}\right)}$$

$W_N = 1.82\times10^{-4}cm$

$W_P := R\cdot W_N \quad W_P = 2.639\times10^{-4}cm$

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Verify the model for various loads and a 3 input NAND gate.

$A := 7070\Omega \quad C_{JSWN} := 2.47\cdot 10^{-12}\frac{F}{cm} \quad C_{JN} := 9.53\cdot 10^{-8}\frac{F}{cm^2} \quad C_{GDON} := 8.35\cdot 10^{-12}\frac{F}{cm}$

$L_N := .18\cdot 10^{-4}cm \quad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8}\cdot\left(\sqrt{.84+1.8}-\sqrt{.84}\right) \quad K_{EQ} = 0.721 \quad D_D := .36\cdot 10^{-4}cm$

$C_g := 25\cdot 10^{-15}F \quad N := 3 \quad N_{SN} := 2$

$\tau_{PHL} := .1\cdot 10^{-9}s \quad M := 2 \quad N_{SP} := 1 \quad S := 1 \quad R := 1.45$

$$W_N := \frac{C_g + C_{JSWN}\cdot 2\cdot D_D\cdot K_{EQ}\cdot(N+M)}{\frac{\tau_{PHL}}{N_{SN}\cdot L_N\cdot A} - (N + M\cdot R)\cdot\left(C_{JSWN}\cdot 2K_{EQ} + C_{JN}\cdot D_D K_{EQ} + 2\cdot C_{GDON}\right)}$$

$W_N = 9.91\times 10^{-5}cm$

$W_P := R\cdot W_N \quad W_P = 1.437\times 10^{-4}cm \qquad \tau_{PLH} := \tau_{PHL}$

$\tau_{PHL\_M} := (100-5)\cdot 10^{-12}s \qquad Error := \frac{\tau_{PHL}-\tau_{PHL\_M}}{\tau_{PHL}}\cdot 100 \quad Error = 5$

$\tau_{PLH\_M} := (1010-1005)\cdot 10^{-12}s \qquad Error := \frac{\tau_{PLH}-\tau_{PLH\_M}}{\tau_{PLH}}\cdot 100 \qquad Error = 5$

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$A := 7070\Omega$ $\quad C_{JSWN} := 2.47 \cdot 10^{-12} \frac{F}{cm}$ $\quad C_{JN} := 9.53 \cdot 10^{-8} \frac{F}{cm^2}$ $\quad C_{GDON} := 8.35 \cdot 10^{-12} \frac{F}{cm}$

$L_N := .18 \cdot 10^{-4} cm$ $\quad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8} \cdot \left(\sqrt{.84 + 1.8} - \sqrt{.84}\right)$ $\quad K_{EQ} = 0.721$ $\quad D_D := .36 \cdot 10^{-4} cm$

$C_g := 50 \cdot 10^{-15} F$ $\quad N := 3$ $\quad N_{SN} := 2$

$\tau_{PHL} := .055 \cdot 10^{-9} s$ $\quad M := 2$ $\quad N_{SP} := 1$ $\quad S := 1$ $\quad R := 1.45$

$$W_N := \frac{C_g + C_{JSWN} \cdot 2 \cdot D_D \cdot K_{EQ} \cdot (N + M)}{\frac{\tau_{PHL}}{N_{SN} \cdot L_N \cdot A} - (N + M \cdot R) \cdot \left(C_{JSWN} \cdot 2K_{EQ} + C_{JN} \cdot D_D K_{EQ} + 2 \cdot C_{GDON}\right)}$$

$W_N = 6.18 \times 10^{-4} cm$

$W_P := R \cdot W_N$ $\quad W_P = 8.961 \times 10^{-4} cm$

$\tau_{PLH} := \tau_{PHL}$

$\tau_{PHL\_M} := (61 - 5) \cdot 10^{-12} s$ $\quad Error := \frac{\tau_{PHL} - \tau_{PHL\_M}}{\tau_{PHL}} \cdot 100$ $\quad Error = -1.818$

$\tau_{PLH\_M} := (1060 - 1005) \cdot 10^{-12} s$ $\quad Error := \frac{\tau_{PLH} - \tau_{PLH\_M}}{\tau_{PLH}} \cdot 100$ $\quad Error = 1.175 \times 10^{-14}$

$A := 7070\Omega \qquad C_{JSWN} := 2.47 \cdot 10^{-12} \frac{F}{cm} \qquad C_{JN} := 9.53 \cdot 10^{-8} \frac{F}{cm^2} \qquad C_{GDON} := 8.35 \cdot 10^{-12} \frac{F}{cm}$

$L_N := .18 \cdot 10^{-4} cm \qquad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8} \cdot \left(\sqrt{.84 + 1.8} - \sqrt{.84}\right) \qquad K_{EQ} = 0.721 \qquad D_D := .36 \cdot 10^{-4} cm$

$C_g := 25 \cdot 10^{-15} F \qquad N := 5 \qquad N_{SN} := 3$

$\tau_{PHL} := .15 \cdot 10^{-9} s \qquad M := 3 \qquad N_{SP} := 1 \qquad S := 1 \qquad R := 1.45$

$$W_N := \frac{C_g + C_{JSWN} \cdot 2 \cdot D_D \cdot K_{EQ} \cdot (N + M)}{\frac{\tau_{PHL}}{N_{SN} \cdot L_N \cdot A} - (N + M \cdot R) \cdot \left(C_{JSWN} \cdot 2K_{EQ} + C_{JN} \cdot D_D K_{EQ} + 2 \cdot C_{GDON}\right)}$$

$W_N = 1.444 \times 10^{-4} cm$

$W_P := R \cdot W_N \quad W_P = 2.093 \times 10^{-4} cm \qquad \tau_{PLH} := \tau_{PHL}$

$\tau_{PHL\_M} := (83 - 5) \cdot 10^{-12} s \qquad Error := \frac{\tau_{PHL} - \tau_{PHL\_M}}{\tau_{PHL}} \cdot 100 \qquad Error = 48$

$\tau_{PLH\_M} := (1083 - 1005) \cdot 10^{-12} s \qquad Error := \frac{\tau_{PLH} - \tau_{PLH\_M}}{\tau_{PLH}} \cdot 100 \qquad Error = 48$

| | | TPM | TPS | ERROR | W old | W new |
|---|---|---|---|---|---|---|
| 62 | 5 | 57 | 100 | -43 | 5.276 | 3.00732 |
| 1101 | 1005 | 96 | 100 | -4 | 7.65 | 7.344 |
| 120 | 5 | 115 | 100 | 15 | 3.00732 | 3.458418 |
| 1054 | 1005 | 49 | 100 | -51 | 7.344 | 3.59856 |
| 84 | 5 | 79 | 100 | -21 | 3.458418 | 2.73215 |
| 1089 | 1005 | 84 | 100 | -16 | 3.59856 | 3.02279 |
| 92 | 5 | 87 | 100 | -13 | 2.73215 | 2.376971 |
| 1092 | 1005 | 87 | 100 | -13 | 3.02279 | 2.629828 |
| 96 | 5 | 91 | 100 | -9 | 2.376971 | 2.163043 |
| 1097 | 1005 | 92 | 100 | -8 | 2.629828 | 2.419441 |
| 100 | 5 | 95 | 100 | -5 | 2.163043 | 2.054891 |
| 1100 | 1005 | 95 | 100 | -5 | 2.419441 | 2.298469 |
| 102 | 5 | 97 | 100 | -3 | 2.054891 | 1.993244 |
| 1102 | 1005 | 97 | 100 | -3 | 2.298469 | 2.229515 |
| 104 | 5 | 99 | 100 | -1 | 1.993244 | 1.973312 |
| 1103 | 1005 | 98 | 100 | -2 | 2.229515 | 2.184925 |

$A := 5750\Omega \quad C_{JSWN} := 2.47 \cdot 10^{-12} \frac{F}{cm} \quad C_{JN} := 9.53 \cdot 10^{-8} \frac{F}{cm^2} \quad C_{GDON} := 8.35 \cdot 10^{-12} \frac{F}{cm}$

$L_N := .18 \cdot 10^{-4} cm \quad K_{EQ} := \frac{-2\sqrt{.84}}{-1.8} \cdot \left(\sqrt{.84 + 1.8} - \sqrt{.84}\right) \quad K_{EQ} = 0.721 \quad D_D := .36 \cdot 10^{-4} cm$

$C_g := 25 \cdot 10^{-15} F \quad N := 5 \quad N_{SN} := 3$

$\tau_{PHL} := .1 \cdot 10^{-9} s \quad M := 3 \quad N_{SP} := 1 \quad S := 1 \quad R := 1.12$

$$W_N := \frac{C_g + C_{JSWN} \cdot 2 \cdot D_D \cdot K_{EQ} \cdot (N + M)}{\frac{\tau_{PHL}}{N_{SN} \cdot L_N \cdot A} - (N + M \cdot R) \cdot \left(C_{JSWN} \cdot 2K_{EQ} + C_{JN} \cdot D_D K_{EQ} + 2 \cdot C_{GDON}\right)}$$

$W_N = 1.972 \times 10^{-4} cm$

$W_P := R \cdot W_N \quad W_P = 2.209 \times 10^{-4} cm \qquad \tau_{PLH} := \tau_{PHL}$

A and R are different for the inverter, nand2, and nand3 because the effective channel length is increasing with these gates, and thus the electric field is reduced, which reduced the electric field so we switch form (vg-vt) to $(vg\text{-}vt)^2$ relationship.

Explain why A and R are different for the inverter and the nand.

Problem 3(10PTS):

Label each section of the ID graph as being in sub threshold, saturation, and velocity saturation.

Write down the generic equations for each area of operation.

Describe why each area of the graph follows the generic equation.

Redraw the graph if L was increased by 3 times

sub threshold follows a "BJT" like dependence based on diffusion.
Normal saturation follows $(Vg\text{-}Vt)^2$, and velocity saturation follows (Vg-VT) because the un x E field linear relationship no longer holds because the carries are bouncing off the lattice.