Examination 1, Thursday Oct. 12, 2000

NAME: _______________________________  SECTION: __________

Time: 80 minutes
Closed books, closed notes.

Good luck!
Problem 1 (25 points): Fig.1 shows a CMOS inverter. The characteristics of the p-channel and n-channel transistors for W/L = 1 are shown in Fig. 2. Figs.3(a-d) provide templates, which you should use to present your intermediate and final answers. For the inverter in Fig.1, derive graphically the following characteristics.

a) $V_{\text{OUT}}(V_{\text{IN}})$

b) $I_D(V_{\text{IN}})$

Assume that the NMOS transistor has $(W/L)_n = 1$ and the PMOS has $(W/L)_p = 2$. 

![Fig.1](image_url)
Characteristics of p-channel device with W/L = 1.

Characteristics of n-channel device with W/L = 1.

Fig.2
Fig. 3 (a-b)
Fig. 3 (c-d)
Problem 2 (25 points): Fig. 4 shows the layout of the n-well CMOS NAND gate studied in the recitations.
For this layout:

a) List all the layers, from the top to the bottom, at the drill points X and Y.

X:

Y:

b) Draw the cross-sections along the lines A-B and C-D. Place your solution in S1 and S2.

A

B

C

D

Fig. S1: Cross-section A-B

Fig. S2: Cross-section C-D
Problem 3. (25 points) Consider a complex CMOS logic gate that implements the boolean function $Y = ABC + DE + EFG$. (Do not try to optimize it.)

a) Draw the transistor-level schematic of this gate.

b) Size all NMOS and PMOS transistors in such a way that the worst-case rise and fall delays are equal to the fall delay of a minimum size CMOS inverter (i.e. W/L for the NMOS transistor is equal to 1).
Problem 4. (25 points) Consider the CMOS circuit shown in Fig.5. (The W/L ratios for each gate apply to both NMOS and PMOS transistors.) We want to determine the delay from a rising transition (0 → 1) on input X to the output Z. Let us denote by \( \tau = R_n C_n \) the product of the effective on-resistance and gate capacitance of the minimum sized NMOS transistor, i.e. \((W/L)_n = 1/1\). For the minimum sized PMOS transistor, we have \( R_p = 2R_n \). Also, the output Z drive load is \( C_L = 10C_n \).

\[\begin{array}{c}
\text{\textbf{X}} \\
\text{\textbf{Y}} \\
\end{array}\]

\[\begin{array}{c}
\text{\textbf{2/1}} \\
\text{\textbf{1/1}} \\
\text{\textbf{2/1}} \\
\text{\textbf{1/1}} \\
\text{\textbf{1/1}} \\
\end{array}\]

\[\begin{array}{c}
\text{\textbf{Z}} \\
\text{\textbf{C_L}} \\
\end{array}\]

a) Assuming that the rise and fall times are good approximations of the propagation delay, determine the delay from X to Z, in terms of \( \tau \), when \( Y = 0 \).

b) Now, assume that \( Y = 1 \). What is the new value for the propagation delay from X to Z? Can you comment on this?