Instructions:
* The examination is open book and notes.
* Please do not write on the backs of the pages.
* Note that problems have different point values.
* Please show your work.
* Be sure to budget your time.

Assume (unless stated otherwise in each problem):

- \( V_{dd} = 2.5 \text{ v.}, \ V_{ss} = 0 \text{ v.}, \)
- \( V_{tn} = .7 \text{ v.}, \ V_{tp} = -.7 \text{ v} \)
- \( V_{tn}(\text{body effect}) = .9 \text{ v.}, \ V_{tp}(\text{body effect}) = -.9 \text{ v.} \)
- Leakage current per transistor = .2 namp.
- \( \varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm and } \varepsilon_{\text{oxide}} = 3.9 \)
- \( R_s \text{ of silicide} = 4 \Omega \text{ per } \square \text{ (ohms per square). } \)
- \( R_s \text{ of metal} = .08 \Omega \text{ per } \square \text{ (ohms per square). } \)
- \( R_s \text{ of n diffusion} = 4.7 \Omega \text{ per } \square \text{ (ohms per square). } \)
- \( R_s \text{ of p diffusion} = 3.4 \Omega \text{ per } \square \text{ (ohms per square). } \)
- \( C_{jbsn} = 17.27 \times 10^{-4} \text{ pF/ } \mu \text{m}^2 \text{ and } C_{jbswn} = 4.17 \times 10^{-4} \text{ pF/ } \mu \text{m (micrometer). change} \)
- \( C_{jbsp} = 18.8 \times 10^{-4} \text{ pF/ } \mu \text{m}^2 \text{ and } C_{jbswp} = 3.17 \times 10^{-4} \text{ pF/ } \mu \text{m (micrometer). change} \)
- \( \lambda = .125 \mu \text{ (microns). } \)
- \( \beta_n \text{ (beta)} = 219.4 \text{ W/L } \mu \text{A (microamps)/V}^2 \text{ and } \beta_p \text{ (beta)} = 51 \text{ W/L } \mu \text{A/V}^2 \)
- \( T_{ox} = 57 \text{ angstroms for thinox, and 5000 angstroms for thick oxide. } \)
1. Compute the effective beta ($\beta$) of an NMOS transistor with channel resistance 1010 ohms when $V_{gs}=1.3\, \text{V}$, and the transistor is in the linear region.

2. An inverter driving an identical inverter has $C_{g(n+p)} = 29\, \text{fF}$, $C_{dn(\text{source or drain})} = 25\, \text{fF}$ and $C_{dp(\text{source or drain})} = 26\, \text{fF}$. How much capacitance contributes to the input rise and fall times of the second inverter in the chain (the output rise and fall times of the first inverter in the chain)?

3. Solve for the $\beta_{\text{peff}}$ (beta) of a 4-input NOR gate constructed of minimum size devices.

4. Using a chain of three inverters, assume each one can drive 3 times the capacitive load of the previous inverter. What size parameters in the third inverter have been changed to allow this to happen, and how have they been changed?

5. An inverter drives a long wire (5 mm) on a special kind of metal1 minimum width (3 lambda) to the input of another inverter. Both these inverters have identical size transistors. In order to speed up the circuit, Ernie Engineer inserts an identical inverter in the middle of the 5 mm wire. Ernie’s boss wants Ernie to insert an inverter that has transistors 3 times as wide as the other inverters in the middle of the wire.
   a) Compute the capacitance of each 2.5 mm section of the wire, assuming the oxide under the wire is two layers of oxide thick. Assume the special kind of metal1 has resistance .01 ohms per square.
   b) Show an RC ladder network for the original circuit that can be used to compute Elmore delay. Assume $C_{g(n\, \text{or} \, p)} = 100\, \text{ff}$, $R_{chn} = 500\, \text{ohms}$, $R_{chp} = 1000\, \text{ohms}$ and $C_{d(\text{drain or source})} = 40\, \text{ff}$ for the original inverters.
   c) Use equivalent circuits and the RC time constants to show Ernie’s boss whether Ernie’s design is better than the boss’s design or not.

6. A 3-input NOR gate is constructed of unit-size devices. Resize the PMOS devices so that rise and fall times are approximately equal.

7. An output from a complementary CMOS gate OUT1 is fed through a transmission gate before it terminates at the input to another complementary gate. What is the effect of the transmission gate on the signal OUT1 when transistors in the transmission gate are on?