Santa Clara University

Department of Electrical and Computer Engineering

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Name *(please print)*

- **Include this page with homework**
- **Write Name and Page Number on each page**

ELEN 153 **Problem Set #7** **Due: Thursday, 11-19-2020 12:00 pm**
Fall 2020

20

1. An inverter uses a power 3.3 V power supply and transistors with the following specification:
   nFET: Device Transconductance = 4.2 mA/V^2 ; Threshold voltage = 0.65 V
   pFET: Device Transconductance = 1.5 mA/V^2. Threshold voltage = - 0.5 V.
   The parasitic FET capacitance at the output node is estimated to be C_{FET} = 85.7 fF.
   a) Find transistor resistances. b) Calculate the rise and fall times at the output when C_L = 0.
   c) Calculate the rise and fall times when an external load C_L = 146 fF is connected to the output d) Plot rise and fall times as functions of C_L.

20

2. Consider the nFET chain shown in Fig. P7.1(see page below). This represents a portion of a NAND3 gate. The output capacitance has a value of 139 fF while the internal values are C_1 = 32 fF and C_2 = 45 fF. The transistors are identical with Device Transconductance = 4.27 mA/V^2 in a process where power supply is 4.0 V and Threshold voltage is 0.8 V.
   a) Find the discharge time constant using the Elmore formula for a ladder RC network.
   b) Find the time constant if we ignore C_1 and C_2. What is the percentage error introduced if we do not include the internal capacitors ?

20

3. A 0.33 μm thick and 2.68 μm wide interconnect line shown in Fig. 14.3 (see page below) has 0.47 μm thick insulating oxide between the line and the substrate.
   a) Calculate the self capacitance per unit length of the line that includes the effects of the fringing electric field from the edges and sides of the line.
   b) The interconnect line has a sheet resistance of 0.072 Ω/□. Find the values of <u>total</u> line resistance and <u>total</u> self capacitance if the line is 57 μm long.
   c) Construct a 7-rung ladder equivalent circuit for the line, and determine the time constant of the line. Compare this with the time constant obtained using a single-rung equivalent circuit.

15

4. Consider two interconnect lines separated by a spacing of 0.67 μm. Each individual line is 1.2 μm wide and 0.34 μm thick. The thickness of the insulating oxide between the line and the substrate is 0.52 μm.
   a) Calculate the self-capacitance per unit length for a line that includes the effects of the fringing electric field from the edges and sides of the line.
   b) Calculate the coupling capacitance per unit length between the two lines.
   c) Suppose that the lines are both 23 μm long, find the total capacitance seen looking into one of the lines.

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Problem 3.

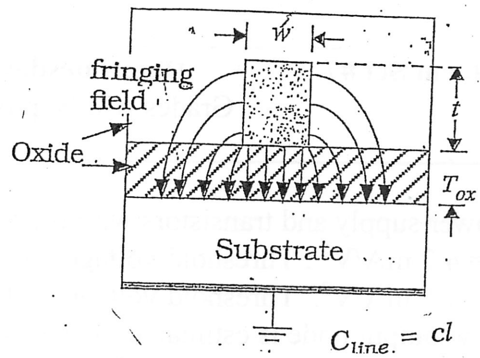


Fig. 14.3

Problem 2

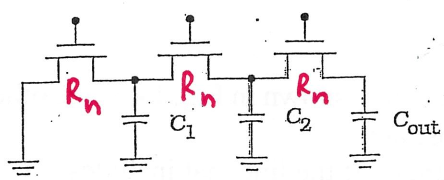
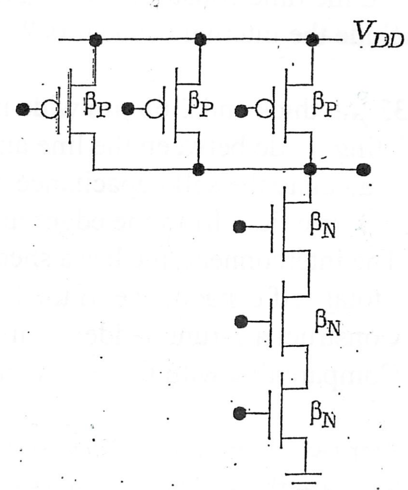


Figure P7.1



NAND3

a) Elmore Formula:

$$\left.\begin{aligned} \tau_n &= C_{OUT}(R_n+R_n+R_n) \\ &\quad + C_2(R_n+R_n) \\ &\quad + C_1 \cdot R_n \\ \tau_n &= C_{OUT}\,3R_n + C_2\,2R_n + C_1 R_1 \end{aligned}\right\}$$

1) a) $R_n = \dfrac{1}{\beta_n (V_{DD} - V_{Tn})} = \dfrac{1}{4.2(\frac{1}{1000})(3.3 - 0.65)} = 89.85\,\Omega$

$R_p = \dfrac{1}{\beta_p (V_{DD} - |V_{Tp}|)} = \dfrac{1}{(1.5)(\frac{1}{1000})(3.3 - 0.5)} = 238.10\,\Omega$

b) $C_{out} = C_{FET} + C_L = 85.7 \text{ fF}$

$t_f = R_n C_{out} \ln(9) = (89.85)(85.7)\ln(9) = 16918$

$= 16.92 \text{ ps}$

$t_r = R_p C_{out} \ln(9) = (238.10)(85.7)\ln(9) = 44834$

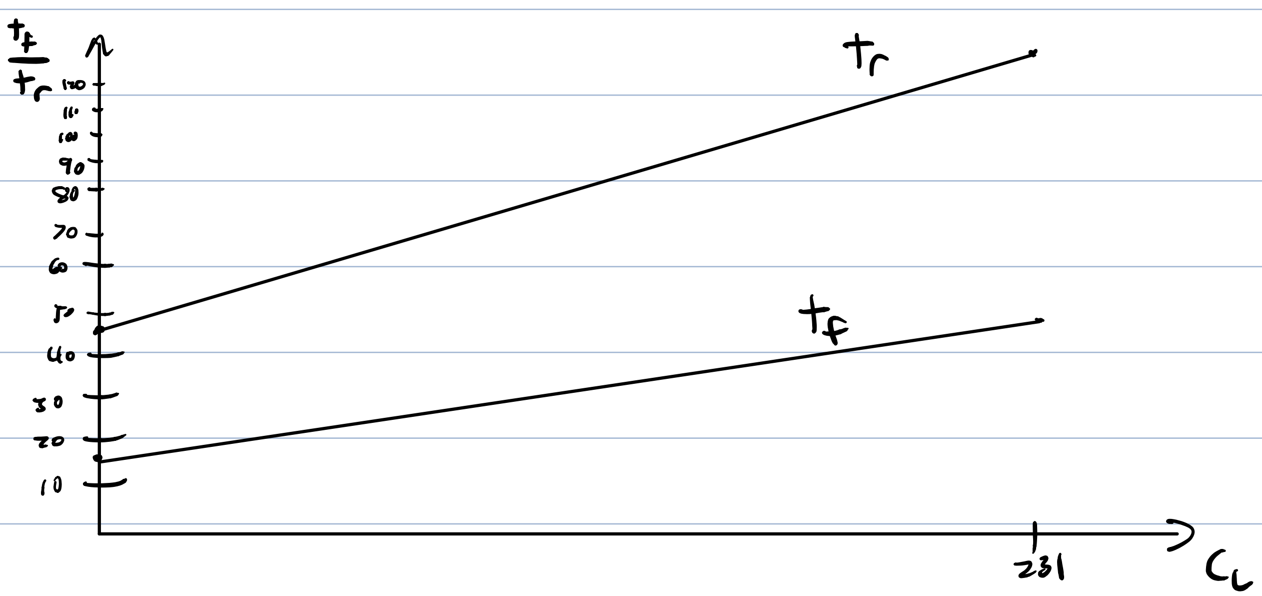
$= 44.83 \text{ ps}$

c) $C_{out} = 85.7 + 146 = 231.7$

$t_f = (89.85)(231.7)\ln(9) = 45.74 \text{ ps}$

$t_r = (238.1)(231.7)\ln(9) = 121.22 \text{ ps}$

d)



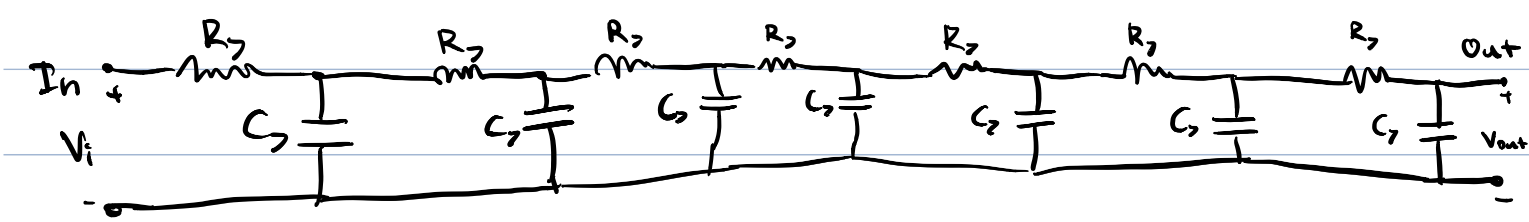
2) a)
$$R_n = \frac{1}{\beta_n (V_{DD} - V_{Tn})} = \frac{1}{(4.27 \cdot 10^{-3}\ A/V^2)(4 - 0.8)}$$
$$= 73.19\ \Omega$$
$$\tau_n = R_n (3C_{out} + 2C_2 + C_1)$$
$$= (73.19)(3(139) + 2(45) + 32)$$
$$= 39.45\ ps$$

b) $\tau_n = 3R_n C_{out} = 3(73.19)(139) = 30.52\ ps$
$$\%\ error = \left| \frac{30.52 - 39.45}{39.45} \right| \cdot 100 = 22.64\%$$

3) a)
$$C = \varepsilon_{ox}\left(1.15\left(\frac{W}{T_{ox}}\right) + 2.8\left(\frac{t}{T_{ox}}\right)^{0.222}\right)$$
$$= (3.9(8.854 \cdot 10^{-14}))\left(1.15\left(\frac{2.68}{0.47}\right) + 2.8\left(\frac{0.33}{0.47}\right)^{0.222}\right)$$
$$= 3.16 \cdot 10^{-12}\ F/cm$$

b)
$$R_{line} = R_s\left(\frac{l}{w}\right) = (0.072)\left(\frac{57\ mm}{2.69\ mm}\right) = 1.53\ \Omega$$
$$C_{line} = cl = (3.16 \cdot 10^{-12})(57\ mm)\left(\frac{1}{10000}\right) =$$
$$18\ fF$$

c)
$$R_7 = \frac{1}{7} R_{line} = \frac{1}{7}(1.53) = 0.219\ \Omega$$
$$C_7 = \frac{1}{7} C_{line} = \frac{1}{7}(18) = 2.57\ fF$$



$$\tau_7 = \frac{m(m+1)}{2m^2} R_{line} C_{line} = \frac{8}{2(7)}(1.53)(18) = 15.74 \text{ fs}$$

$$\tau_1 = \frac{1+1}{2(1)}(1.53)(18) = 27.54 \text{ fs}$$

$$\tau_7 < \tau_1$$

4) a) $$C = (3.9)(8.854 \cdot 10^{-14})\left(1.15\left(\frac{1.2}{.52}\right) + 2.8\left(\frac{.34}{.52}\right)^{0.222}\right)$$

$$= 1.796 \cdot 10^{-12} \text{ F/cm}$$

b) $$C_c = \varepsilon_{ox}\left(0.03\left(\frac{W}{T_{ox}}\right) + 0.83\left(\frac{t}{T_{ox}}\right) - 0.07\left(\frac{t}{T_{ox}}\right)^{0.222}\right)\left(\frac{S}{T_{ox}}\right)^{-1.34}$$

$$= (3.9)(8.854 \cdot 10^{-14})\left(0.03\left(\frac{1.2}{0.52}\right) + 0.83\left(\frac{0.34}{0.52}\right) - 0.07\left(\frac{0.34}{0.52}\right)^{0.222}\right)\left(\frac{0.67}{1.2}\right)$$

$$= 2.439 \cdot 10^{-13} \text{ F/cm}$$

c) $$C_{line} = (C + C_c)\,l = (1.796 \cdot 10^{-12} + 2.439 \cdot 10^{-13})(23)\left(\frac{1}{1000}\right)$$

$$= 4.692 \text{ fF}$$