# Santa Clara University

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

**ELEN 153** **Problem Set #8** **Due: Tuesday, 12-01-2020 12:00 pm**
**Fall 2020**

1. The storage capacitor in a DRAM has a value of 135.6 pF. The circuitry restricts the capacitor voltage to a maximum value of 5.0 V. When the access nFET is OFF, a 46 pA constant leakage current flows off the storage capacitor.
   a) What is the maximum number of electrons that can be stored in the storage capacitor ?
   b) Assuming that the leakage current when the nFET is OFF to be constant, how many electrons leave the storage capacitor in 1 second due to the leakage current ?
   c) Calculate time required to reduce stored electrons down to $2.74 \times 10^8$ at this constant leakage current.

2. A DRAM cell has a storage capacitance of 59.6 fF. It is used in a system where power supply is 3.3 V and the threshold voltage of the access nFET is 0.72 V.
   a) Find the maximum amount of charge (in coulomb) that can be stored in the storage capacitor.
   b) Suppose that the storage capacitor is charged to its maximum voltage level. The Word line controlling the access nFET is dropped to WL = 0 at time t = 0. The nFET leakage current is estimated to be 48.7 nA and assumed to be constant. To detect a logic 1 state, the voltage on the bit line must be at least 1.27 V. Calculate the hold time and the minimum refresh frequency of the cell.

3. Consider a DRAM cell that has a 32 fF storage capacitance and a 119 fF bit line capacitance. The power supply is 4.2 V and the access nFET has a threshold voltage of 0.68 V. The nFET leakage current from the storage capacitor is estimated to be 28 fA and assumed to be constant,
   The capacitor has the maximum voltage across it when the WL is brought down to 0 at time t = 0.
   Subsequently, a read operation is initiated at time t = 0.095s by elevating the WL to 1.
   Calculate the voltage read on the bit line at this time.

1) $C = 135.6\ pF$ LIV 1

$V = 5.0\ V$

$I = 46\ pA$

a) $C = \frac{q}{V}$

$\Rightarrow q = (135.6 \cdot 10^{-12}) \cdot 5.0 = 6.78 \cdot 10^{-10}\ C$

$e^- = \frac{6.78 \cdot 10^{-10}}{1.602 \cdot 10^{-19}} = 4.23 \cdot 10^{9}\ e$

b) $I = \frac{q}{t}$

$\Rightarrow 46 \cdot 10^{-12} = q$

$\#\ e^- = \frac{46 \cdot 10^{-12}}{1.602 \cdot 10^{-19}} = 2.87 \cdot 10^{8}\ e$

c) $I = 46 \cdot 10^{-12}$

$q = (2.74 \cdot 10^{8}) \cdot (1.602 \cdot 10^{-19}) = 4.39 \cdot 10^{-11}$

$t = \frac{q}{I} = \frac{4.39 \cdot 10^{-11}}{46 \cdot 10^{-12}} = 0.95\ s$

2) $C_s = 59.6\ fF = 59.6 \cdot 10^{-15}\ F$

$V_{DD} = 3.3$

$V_{Tn} = 0.72$

a) $V_s = 3.3 - 0.72 = 2.58\ V$

$Q = CV = (59.6 \cdot 10^{-15})(2.58) = 1.54 \cdot 10^{-13}\ C$

b) $I_o = 48.7\ nA = 44.5 \cdot 10^{-9}\ A$

$V_{bi} = 1.27\ V$

$R_{eq} = \frac{V_{bi}}{I_o} = \frac{1.27}{44.5 \cdot 10^{-9}} = 2.85 \cdot 10^{7}\ \Omega$

$V_{bi} = \frac{C_s V_s + C_b V_{DD}}{C_s + C_b}$

$1.27 = \frac{(59.6 \cdot 10^{-15} \cdot 2.58) + 3.3 C_b}{(59.6 \cdot 10^{-15}) + C_b}$

$-3.3 C_b + 1.27((59.6 \cdot 10^{-15}) + C_b) = (59.6 \cdot 10^{-15} \cdot 2.58)$

$= -2.03C_b = (1.54 \cdot 10^{-13}) - (7.5692 \cdot 10^{-14})$ LIV 2

$C_b = 3.85 \cdot 10^{-14}$

$t = (3.85 \cdot 10^{-14})(2.85 \cdot 10^{7}) = 1.096 \cdot 10^{-6}\,s$

$= 1.096\ \mu s$

3) $C_b = 119 \cdot 10^{-15}\,F$

$I_o = 28 \cdot 10^{-15}\,A$

$V_{DD} = 4.2V$

$C_s = 32 \cdot 10^{-15}\,F$

$V_{th} = 0.68\ V$

$t = 0.095$

$V_s = 4.2 - 0.68 = 3.52\,V$

$R_{eq} = \frac{t}{C_b} = \frac{0.095}{119 \cdot 10^{-15}} = 7.98 \cdot 10^{11}$

$V_{final} = (28 \cdot 10^{-15})(7.98 \cdot 10^{11}) = 0.022\ V$

$-((C_b \cdot [V_{BL}])) + C_s \cdot V_s = [C_s + C_b]\, V_{final}$

$-(119 \cdot 10^{-15} \cdot V_{BL}) + (32 \cdot 10^{-15} \cdot 3.52) = ((32 \cdot 10^{-15}) + (119 \cdot 10^{-15}))\, 0.022$

$V_{BL} = 0.919\ V$