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*Homework #10 Solutions*

*EECS 141*  
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**Problem 1 – 2-T Memory Cell**

(a) To write a '1' to X, we need:  $BL = V_{dd}$      $WS = V_{dd}$      $\overline{RS} = V_{dd}$   
M1 turns on.  $C_c$  is charged to  $V_{dd} - V_t$ . M2 turns on, but has no effect.

To write a '0' to X, we need:  $BL = 0$      $WS = V_{dd}$      $\overline{RS} = V_{dd}$   
M1 turns off.  $C_c$  is discharged to gnd. M2 remains off.

To read the cell, we need:  $BL = V_{dd}/2$      $WS = 0$      $\overline{RS} = 0$

If a '1' has been stored in  $C_c$ , M2 turns on. The bit line is pulled towards ground. There will be sense amplifiers that signal a dip in voltage along bit line. This dip will be sufficient to register a '1' in the cell. Conversely, if a '0' has been stored in  $C_c$ , M2 remains off. The bit line is unaffected.

(b) Max current is when  $V_x = V_{dd} - V_t$ ;  $\overline{V_{RS}} = 0$ ;  $V_{BL} = V_{dd}/2$ ;  
Since  $\overline{V_{RS}} < V_{BL}$ , BL is the drain, and RS is the source.

$$\text{Current thru M2} = kn' * (W/L)_{M2} * ((V_{dd} - 2V_t)V_{dd}/2 - V_{dd}^2/8)$$

Substituting  $kn' = 115 \mu A/V^2$ ,  $V_{dd} = 2.5$ ,  $V_t = 0.4$ ,

$\text{Max Current} = 247 \mu A$

(c) The only time the bit line is affected during a read operation is when a '1' has been stored.

$$\text{Current thru M2 when } V_{BL} = V_{dd}/2 - 200mV$$

$$= kn' * (W/L)_{M2} * ((V_{dd} - 2V_t)(V_{dd}/2 - 0.2) - (V_{dd}/2 - 0.2)^2/2)$$

$$= 227 \mu A$$

$$R_{eq} = 0.5((V_{dd}/2 - 0.2) / 227 + (V_{dd}/2)/247) = 4.84k\Omega$$

$$\tau = R_{eq}C_b = 9.68ns$$

A 200mV movement represents 0.2/1.25 of the total transient

$\text{Delay} = -\ln [1 - (0.2/1.25)]\tau = 0.174\tau = 1.68ns$

## Problem 2 – DRAM Memory Cell

- (a) Because we are using an NMOS transistor to pull up the voltage on the capacitor  $C_S$ , it only charges up to  $V_{DD} - V_T$ .  $V_T$ , of course, is increased by the body effect, which is dependent on the voltage stored in the cell. By iteration, you can solve for this voltage (something you have done a gazillion times in this class):

$$V_{DD} - V_T = V_S$$
$$V_{DD} - \left[ V_{T0} + g \left( \sqrt{2f + V_S} - \sqrt{2f} \right) \right] = V_S$$

$$V_S = 1.86V$$

- (b) During this operation, charge sharing occurs between  $C_S$  and  $C_{BL}$

$$C_S V_S + C_{BL} V_{BL} = (C_S + C_{BL}) V_{\text{final}}$$

$$V_{\text{final}} = (50 * 1.86 + 450 * 1.25) / (50 + 450) = 1.31 V$$



*Congratulations!*

*You've worked through all the homeworks, labs and projects in this semester successfully.*

*Hope you had fun in the class EE141 and good luck to your finals!*