COE 360 Principles of VLSI Design
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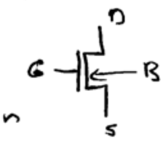
Lecture#9

Types of MOS Transistor

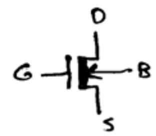
1. Enhancement MOS transistor
2. Depletion MOS transistor
3. Summary of operation of MOS transistors

- There are two types of nMOS transistors:

  - Enhancement-type: This is the regular known type where $V_t > 0$ and the transistor conducts when $V_{gs} \geq V_{tn}$

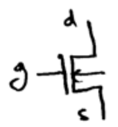


  - Depletion-type: Using selective ion implantation into the channel, the threshold voltage of an n-channel can be made negative. This means that the resulting nmos transistor will have a conducting channel, enabling current flow between its source and drain, as long as V_{gs} is larger than the negative threshold voltage V_{td} (i.e. $V_{td} < 0$). Such a device is called a depletion-type (or normally on) n-channel MOS.



- Summary of operation of MOS transistors

	cutoff	nonsaturated	saturated
1. Enhancement nMOS	$V_{gs} < V_{tn}$	$V_{gd} \geq V_{tn}$	$V_{gd} < V_{tn}$
		$V_{gs} - V_{ds} \geq V_{tn}$	$V_{gs} - V_{ds} < V_{tn}$
		$V_{gs} - V_{tn} \geq V_{ds}$	$V_{gs} - V_{tn} < V_{ds}$
		$V_{gs} \geq V_{tn}$	$V_{gs} \geq V_{tn}$



$V_{tn} > 0$

2. **nmos** (depletion)

	cutoff	nonsaturated	saturated
nmos (depletion)	$V_{gs} < V_{td}$	$V_{gs} \geq V_{td}$	$V_{gs} \geq V_{td}$
		$V_{gd} \geq V_{td}$	$V_{gd} < V_{td}$
		$V_{gs} - V_{ds} \geq V_{td}$	$V_{gs} - V_{ds} < V_{td}$
		$V_{gs} - V_{td} \geq V_{ds}$	$V_{gs} - V_{td} < V_{ds}$

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* Note that $V_{td} < 0$

3. **pmos**

	cutoff	nonsaturated	saturated
pmos	$V_{gs} > V_{tp}$	$V_{gs} \leq V_{tp}$	$V_{gs} \leq V_{tp}$
		$V_{gd} \leq V_{tp}$	$V_{gd} > V_{tp}$
		$V_{gs} - V_{ds} \leq V_{tp}$	$V_{gs} - V_{ds} > V_{tp}$
		$V_{gs} - V_{tp} \leq V_{ds}$	$V_{gs} - V_{tp} > V_{ds}$

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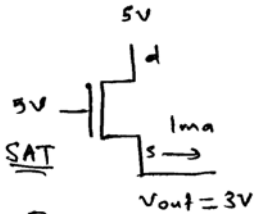
* Note that $V_{tp} < 0$

* Note that the current equations for the nonsaturated and saturated regions are the same for the three types of transistors.

Example

Given an enhancement-type nmos transistor with $\mu C_{ox} = 150\ \mu A/V^2$, $V_{to} = 0.7\ V$, $\gamma = 0.5\ volt^{1/2}$, $2\phi_b = 0.6$ volt. It is required to use this transistor as a pull-up which should be able to deliver a current of 1mA while the output voltage is maintained at 3 volts. If the transistor uses the minimum channel length of 1.5μ and a minimum grid size of 0.25μ, calculate the minimum width of such a transistor.



Solution

$V_{gs} = 5 - 3 = 2\ V$

$V_{gd} = 0 < 0.7 \Rightarrow$ transistor is <u>SAT</u>

$$V_T = V_{To} + \gamma \left[\sqrt{2\phi_b + |V_{sb}|} - \sqrt{2\phi_b} \right]$$

$$= 0.7 + 0.5 \left[\sqrt{0.6 + 3} - \sqrt{0.6} \right]$$

$$= 1.26\ V$$

$$I_{ds} = \frac{\beta}{2} \left[V_{gs} - V_T \right]^2 = \frac{\mu C_{ox}}{2} \frac{W}{L} \left[V_{gs} - V_T \right]^2$$

$$\Rightarrow \frac{W}{L} = \frac{2 I_{ds}}{\mu C_{ox} (V_{gs} - V_T)^2} = \frac{2 \times 1}{0.150\ (2 - 1.26)^2}$$

$$= 24.44$$

Thus, $\boxed{L = 1.5\mu}$, $W = 24.44 * 1.5 = 36.66$

$\Rightarrow \boxed{W = 36.75}$