## CMOS DEVICES

- A complementary CMOS inverter consists of a p-type and an n-type device connected in series.
- The DC transfer characteristics of the inverter are a function of the output voltage ($V_{out}$) with respect to the input voltage ($V_{in}$).

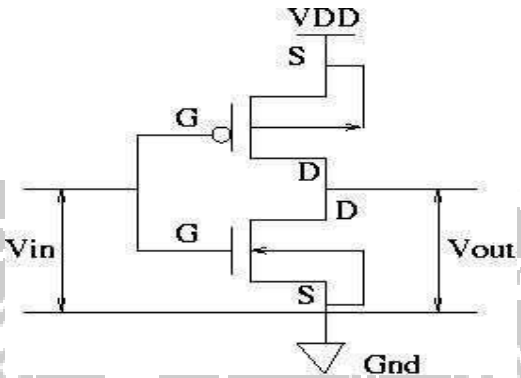


**Fig 1.4.1MOS Transistor**

[Source: Neil H.E. Weste, CMOS VLSI Design …]

- The MOS device first order Shockley equations describing the transistors in cut-off, linear and saturation modes can be used to generate the transfer characteristics of a CMOS inverter.
- Plotting these equations for both the n- and p-type devices produces the traces below.

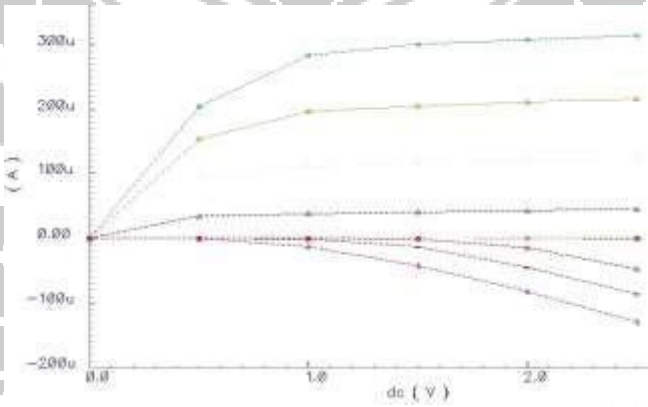


**Fig 1.4.2 MOS Transistor IV Characteristics**

[Source: Neil H.E. Weste, CMOS VLSI Design …]

- The DC transfer characteristic curve is determined by plotting the common points of $V_{gs}$ intersection after taking the absolute value of the p-device IV curves, reflecting superimposing them on the n- device IV curves.

- We basically solve for $V_{in(n\text{-}type)} = V_{in(p\text{-}type)}$ and $I_{ds(n\text{-}type)} = I_{ds(p\text{-}type)}$
- The desired switching point must be designed to be 50 % of magnitude of the supply voltage i.e. $V_{DD}/2$.
- Analysis of the superimposed n-type and p-type IV curves results in five regions in which the inverter operates.

- **Region A** occurs when 0 leq$V_{in}$ leq $V_{t(n\text{-}type)}$.
  - The n-device is in cut-off ($I_{dsn} = 0$).
  - p-device is in linear region,
  - $I_{dsn} = 0$ therefore $-I_{dsp} = 0$
  - $V_{dsp} = V_{out} - V_{DD}$, but $V_{dsp} = 0$ leading to an output of $V_{out} = V_{DD}$.
- **Region B** occurs when the condition $V_{tn}$ leq $V_{in}$ le $V_{DD}/2$ is met.
  - Here p-device is in its non-saturated region Vds neq 0.
  - n-device is in saturation

Saturation current Idsn is obtained by setting $V_{gs} = V_{in}$ resulting in the equation:

- In **region B** $I_{dsp}$ is governed by voltages $V_{gs}$ and $V_{ds}$ described by:
- Saturation currents for the two devices are:
- **Region D** is defined by the inequality
- p-device is in saturation while n-device is in its non-saturation region.

- Equating the drain currents allows us to solve for Vout. (See supplemental notes for algebraic manipulations).
- In **Region E** the input condition satisfies:
- The p-type device is in cut-off: $I_{dsp}=0$
- The n-type device is in linear mode
- $V_{gsp} = V_{in} - V_{DD}$ and this is a more positive value compared to $V_{tp}$.
- $V_{out} = 0$