MOSFET

As switches
Regions of Operation

• In analogue electronics, the MOSFETs are designed to operation in the pinch-off or saturation region.
  ▫ They are found in high speed and/or high power amplifiers, oscillators, current sources, etc.

• In digital electronics as well as power electronics, the primary use of a MOSFET are as a switch that connect and disconnect the circuitry at the drain of the MOSFET with the circuitry at the source. The modes of operation are the cut-off and triode/saturation regions.
  ▫ However, the MOSFET has to move through the pinch-off/saturation region to get between these two regions of operation.
Operation of a Switch

Typically, switches are used to connect and disconnect parts of one circuit with other parts of a circuit.

Here is a schematic for a circuit where the switch is used to connect a light bulb to the dc power supply. The switch used in this case is a single pole, single throw (SPST).

Questions:

What is the power dissipated by the Light?

Why would putting the switch between the Light and ground be dangerous when changing the light bulb?
Types of Switches

• Two common ways to connect or disconnect one part of a circuit with another:
  ▫ **Mechanical** – physical movement is required to make or break the connection.
    • Debounce circuits may be needed if the switch makes intermittent contact as its position is changed.
  ▫ **Electrical** – the conductivity of a component is changed from insulating to conducting and back again (vice versa).
    • Useful when switching is done remotely.
    • They are required in hazardous locations where sparks can ignite fires.
    • The lifetime and reliability of an electrical switch is typically better than a mechanical switch.
    • Usually their size is smaller than mechanical switch to allow the same amount of current to flow through the switch.
One way to analyse the operation of an NMOS inverter is to consider the MOSFET to be a switch.

Assume that $V_{in}$ is either 0V or 5V.
Cut-off Region

When Vin = 0V, which is equal to $V_{GS}$ and is less than $V_T$, the MOSFET acts like an open circuit.

No current flows through $R_D$.

The output voltage $V_o = V_{DD}$. 
Triode Transition

When Vin = 5V, which is equal to V_{GS} and is much greater than V_T, the MOSFET acts like a very small resistor is connected between its source and drain. This resistor is known as R_{DSon}.

Current will flow through R_D.

The output voltage V_o = V_{DD} - R_{DSon} I_D \sim V_{DD}.
Important Input Voltages

- **NMOS**
  - \( \text{Vin} = V_{\text{GS}} \)
    - Transition between cut-off and pinch-off regions
      - \( V_{\text{GS}} = V_{\text{TN}} \)
      - Last input voltage that results in \( Vo = 5V \)
    - Transition between pinch-off and triode regions
      - \( V_{\text{DS}} = V_{\text{GS}} - V_{\text{TN}} \)

- **PMOS**
  - \( V_{\text{GS}} = \text{Vin} - V_{\text{DD}} \)
    - Transition between cut-off and pinch-off regions
      - \( V_{\text{GS}} = - V_{\text{TP}} \)
      - Last input voltage that results in \( Vo = 0V \)
    - Transition between pinch-off and triode regions
      - \( V_{\text{DS}} = V_{\text{GS}} - V_{\text{TP}} \)
Enhancement Mode PMOS Switch

Does the switch allow current to flow when $V_{DD}$ is 0V or 5V?
Enhancement Mode and Depletion Mode Switches

**NMOS Enhancement Mode**
- Normally OFF
  - You have to apply a voltage to make $V_{GS}$ more positive than the threshold voltage for an NMOSFET to turn it on.

**NMOS Depletion Mode**
- Normally ON
  - You have to apply a voltage to make $V_{GS}$ more negative than the threshold voltage for an NMOSFET to turn it off.
NMOS Logic

Determine the truth table for this circuit.
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Power Losses

In a MOSFET switch, there are two ways in which power is dissipated:
1. Conductive loss
2. Switching loss
Conductive Loss

- When the switch is on and drain current flows, there is power dissipated in $R_{DSon}$.
- **We assume that no power is dissipated when the switch is off because no current flows (ideally).**
- **We assume that the MOSFET is on half of the time.**
- **We assume that the time that it takes to switch between on and off is very short compared to the length of time that the MOSFET is either on or off.**

$$P_{conductive} = \frac{V_{DS \, \text{min}}}{2} I_{D_{\text{max}}} = \frac{1}{2} R_{DSon} I_{D_{\text{max}}}^2$$
Switching Loss

• The assumption is that the current and voltage in a MOSFET do not change instantly, no matter how fast you switch $V_{\text{in}}$ between 0V and 5V.

$$P_{\text{switching}} \sim \frac{t_{\text{sw}on} V_{DS_{\text{max}}} I_{D_{\text{max}}} f_{sw}}{2} + \frac{t_{\text{sw}off} V_{DS_{\text{max}}} I_{D_{\text{max}}} f_{sw}}{2}$$

- We can also model this as the charging or discharging of the MOS capacitor.

$$P_{\text{switching}} \sim C_{\text{OSS}} V_{D_{\text{max}}}^2 f_{sw}$$

$f_{sw}$ is the frequency that the MOSFET is switching from off to on and back again, $t_{\text{sw}on}$ and $t_{\text{sw}off}$ are the length of time it takes to switch the MOSFET on and off, respectively, and $C_{\text{OSS}}$ is one measurement of the parasitic capacitance of MOSFET. The values for $t_{\text{sw}on}$, $t_{\text{sw}off}$, and $C_{\text{OSS}}$ are found in the datasheet for the MOSFET that you use as a switch.
mbed

- When you assign a value to a pin on the mbed, it causes a voltage to be applied to the MOSFET switch.

This is a MOSFET switch.