Budapest University of Technology and Economics
Department of Electron Devices

BSc Course in Microelectronics

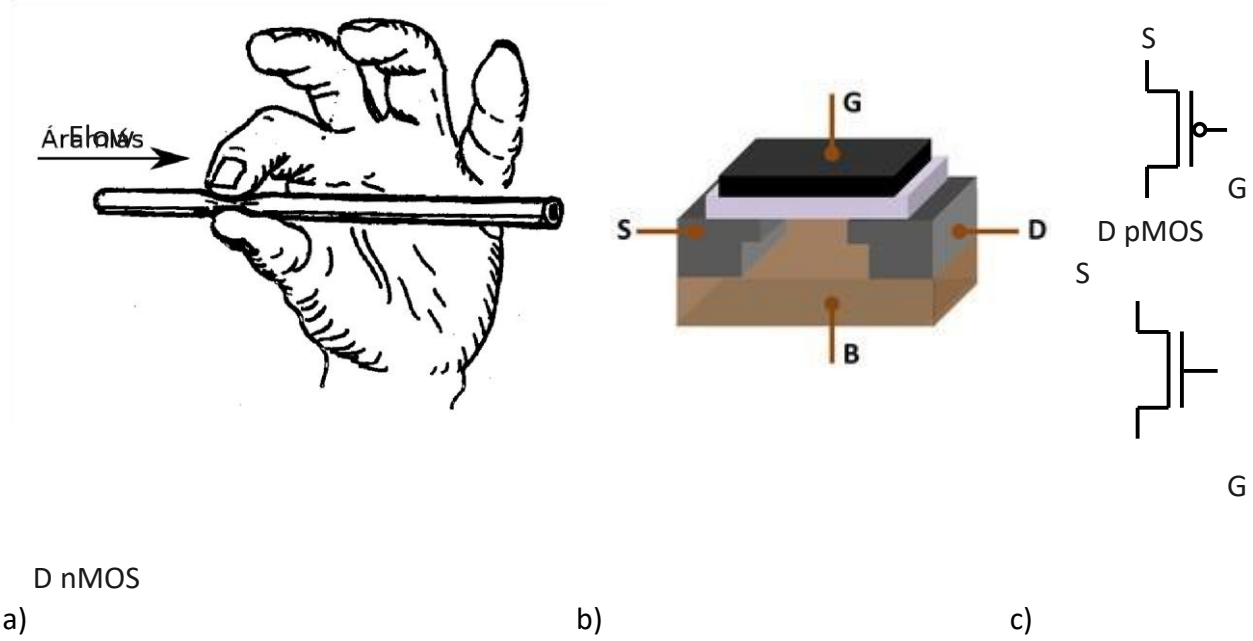
Laboratory Practice: CMOS circuit design and simulation

- Read through this summary carefully and answer the questions listed on the last page (similar questions are expected in the midterm test)

Introduction to field effect transistors

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a transistor used for amplifying or switching electronic signals. Unlike the bipolar junction transistor, the MOSFET is a unipolar device.

The MOSFET is a four-terminal device with source (S), gate (G), drain (D), bulk (B). In practical applications the bulk is shortened to the source, therefore the bulk is not shown on schematic symbols. The MOSFET is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common.



a) b) c)

Fig 1. a) understanding the field-effect b) cross section of a MOSFET transistor, c) schematic symbols of pMOS and nMOS transistors

In enhancement mode MOSFETs, a voltage drop across the oxide induces a conducting channel between the source and drain contacts via the field effect. The term "enhancement mode" refers to the increase of conductivity with increase in oxide electric field that adds carriers to the channel, also referred to as the inversion layer. The channel can contain electrons (called an nMOSFET or nMOS), or holes (called a pMOSFET or pMOS), opposite in type to the substrate, so nMOS is made with a p-type substrate, and pMOS with an n-type substrate.
The operation can be imagined by a straw tightened by two fingers. The flow-through rate can be affected by the force of tightening. In field effect transistors the channel can be closed or opened by applying external forces as well, though the external force is the voltage applied to the gate electrode. Therefore, the electric current flowing through the channel (source to drain) is affected by the gate voltage applied (drain current is controlled by gate voltage). Note, that in bipolar junction transistors the current flowing through the device (from emitter to collector) is affected by the base current (collector current is controlled by base current).

MOSFETs in digital circuits

MOSFETs are commonly used in digital circuits. For investigating the digital operation, the following rules may applied:

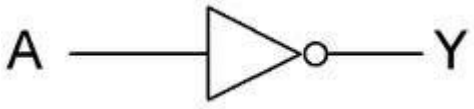
- In switching mode (in digital circuits) only two state of the transistor is utilized: the channel conduct, when we say 'the transistor is opened', or the channel does not conduct, when we say 'the transistor is closed'.
- Binary values are corresponding voltage values. E.g. binary 1 means 5 V, binary 0 means 0 V.
- From this aspect the operation of the nMOS and pMOS are the opposite.
- The nMOS transistor is normally closed, and opens when a positive voltage (e.g. 5 V) is applied to the gate electrode. When the gate voltage is 0 V, the nMOS transistor is closed.
- However, the pMOS transistor closes when a positive voltage (e.g. 5 V) is applied to the gate electrode, but the channel is opened otherwise (e.g. the gate voltage is 0 V).
- Schematically, when the transistor is opened, it can be substituted by a short. When the transistor is closed, it can be substituted by an open.

Digital circuits are commonly built of using both pMOS and nMOS transistors. This type of digital circuits is called cMOS (means complementary MOS). A cMOS circuitry is consists a pMOS circuit block connected to the power supply (Vdd) and an nMOS circuit block connected to the ground (Vss). Two important characteristics of CMOS devices are high noise immunity and low static power consumption. Since one transistor of the pair is always off, the series combination draws significant power only momentarily during switching between on and off states. Consequently, CMOS devices do not produce as much waste heat as other forms of logic, for example transistor-transistor logic (TTL) or NMOS logic, which normally have some standing current even when not changing state. CMOS also allows a high density of logic functions on a chip. It was primarily for this reason that CMOS became the most used technology to be implemented in VLSI chips.

CMOS inverter

The simplest digital circuit is the inverter. An inverter has an input and an output. The output is always the opposite value of the input. The figure above describes the way of operation. When the input is '1' (gate voltages are e.g. 5 V) the pMOS closes and the nMOS opens, therefore the output is shorted to the ground. The output voltage equals to the ground potential, the digital value is '0'. If the input is '0' (gate voltages are 0 V) the pMOS opens and the nMOS closes. The output is shorted to the power supply, therefore the output voltage refers to '1' (e.g. 5 V).

IN	OUT
A	NOT A
1	0
0	1



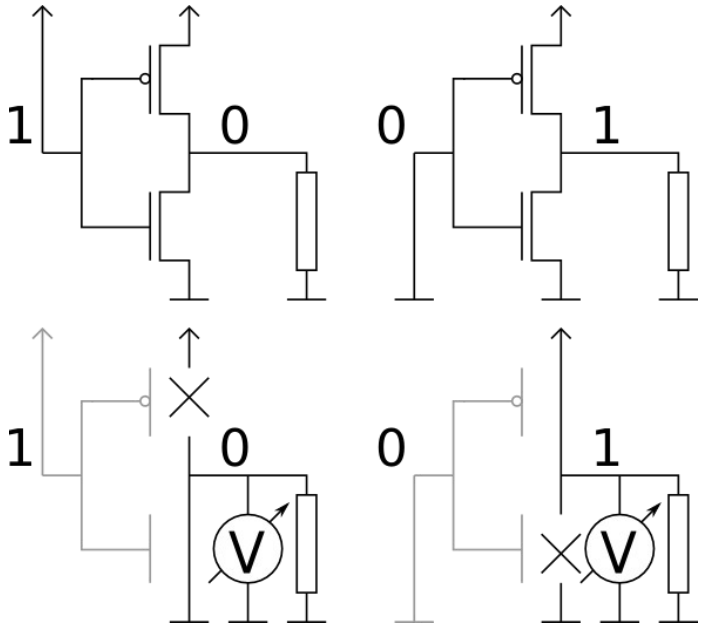


Fig 2. The inverter operation

Questions

1. What MOSFET stands for? What is the difference between nMOS and pMOS? How the terminals are called?
2. Describe the main differences between a bipolar junction transistor and a field effect transistor.
3. What is cMOS? What are the main advantages of cMOS circuits?
4. *Collect information from the internet:* What is the minimal feature size (MFS) for a modern CPU today?
5. Describe the operation of a cMOS inverter, if the input is 1 (/ 0).