Switches and Transistors

CS 350, Lecture 9, Wed Feb 8, 2012

A. Why?

- On/off switches are natural to use with the voltages that represent binary data.
- Transistor circuits act as switches.

B. Outcomes

At the end of today, you should:

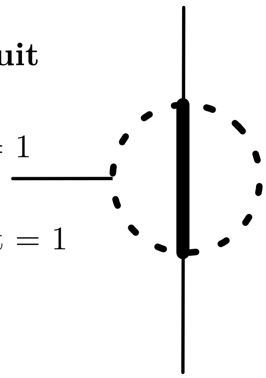
- Know what transistor switches do.
- Be able to read a simple voltage/current diagram.
- Be able to read a transistor-level diagram.

C. Transistors and Switches

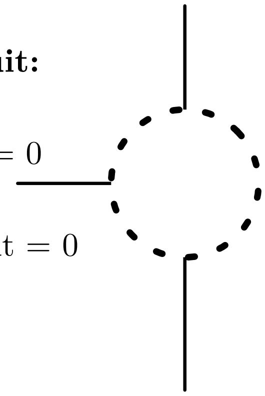
- Computers use switches
  - Switches turn current on/off
  - We combine switches to implement logic functions (AND, OR, etc).
  - Which we combine to build higher-level structures (memory, registers, etc).
- Electricity is the flow of electrons (or the flow of spaces for electrons).
  - Current is the amount of flow of electricity.
- Simple Switch Circuit
  - Switch open? No current, voltage exists.
    - Voltage is the potential force trying to move electricity to get a current.
    - Analogy: The water in a bucket exerts force against the bottom of the bucket. No water flow, so no current.
  - Switch closed? Current flows, voltage is zero.
    - Analogy: If the bottom of the bucket of water falls out, the water flows (so we have a current) and there's zero potential force holding the water back.
- **Complementary Metal-Oxide Semiconductor (CMOS) Transistors**
  - A transistor has a **base** (a.k.a. **gate**), a **collector**, and an **emitter**.
  - **A transistor acts like a switch**: A small amount of current between the base and emitter determines (possibly large) amount of current between collector and emitter.
    - **n-type**: Close switch when gate has voltage.
    - **p-type**: Close switch when gate has no voltage.

- **Voltage diagram**
  - In a voltage diagram, a switch is indicated by a dotted circle; current flows from the top line to the bottom line if the switch is closed (and doesn't flow if the switch is open). The line to the left (or right, not shown) indicates the signal for whether or not to close the switch.

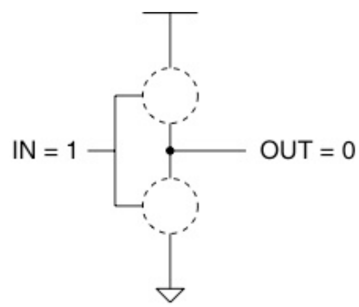
Closed circuit
n-type:
In = Out = 1
p-type:
In = 0, Out = 1



Open circuit:
n-type:
In = Out = 0
p-type:
In = 1, Out = 0



Exercise 3.2



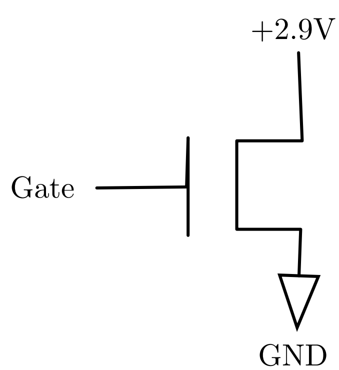
  - The voltage diagram to the right (from Exercise 3.2 in the textbook) shows a power source (the horizontal line at the top of the diagram) and power sink (the hollow arrowhead at the bottom of the diagram).
    - In your home, the sink is usually the earth because it has an extremely high ability to absorb electricity (hence "ground").
    - In a portable device, the source and sink the two ends of the battery.
  - As is the Exercise 3.2 diagram shows an **open circuit** because the output is connected neither to the power source or sink.
  - To represent **logical true**, we must connect the output to the source but not the sink; we'd close the top switch but not the bottom switch.
  - To represent **logical false**, we must connect the output to the sink but not the source; we'd close the bottom switch but not the top switch.
  - In a **short circuit**, the source is connected to the sink; we'd get one by closing both the top and bottom switches.
    - In general, if we try to do work with electric current, we introduce resistance to the flow (make a light bulb glow and generate heat; make a motor run and generate heat; power a display and generate heat; etc).
    - In a short circuit, if the source and sink are connected only by a wire, then the resistive load is the heat generated by lots of current running through the wire

(which might then melt or burn its insulation); if the short circuit is within a battery, the battery can overheat and catch fire.

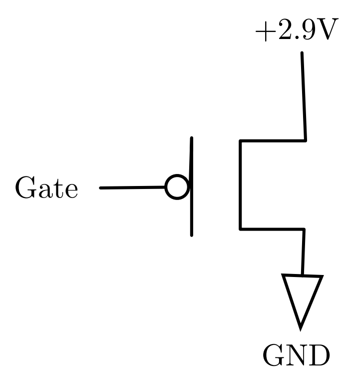
- To determine whether a voltage diagram represents logical true, logical false, an open circuit, or a short circuit
  - First, see if (a) the source is connected to the output and if (b) the output is connected to the sink.
  - For logical true, we need (a) and not (b).
  - For logical false, we need (b) and not (a).
  - If neither (a) nor (b) hold, we have an open circuit.
  - If both (a) and (b) hold, we have a short circuit.
- Note that which switches are open or closed depends on the input signals, so we have to check all possible input combinations.

- **Transistor-level diagram**
  - A transistor-level diagram has the same structure as a voltage diagram, but instead of switches indicated by circles, we have transistor switches.
  - Again, current enters at the top and exits at the bottom (if the switch is closed).
  - The two types of transistors have slightly different graphical elements.
    - (Note the little circuit on the p-type transistor indicating that switch is closed when the gate is not on; the little circle indicating "not" will appear later in logic gate diagrams.)

n-type transistor: Closes when gate has voltage

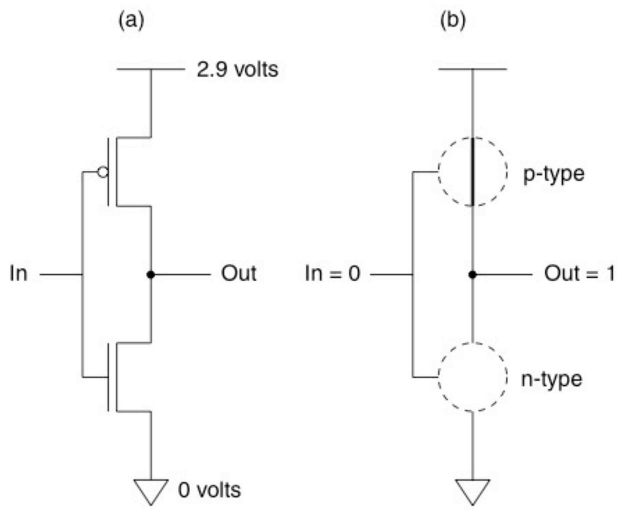


p-type transistor: Closes when gate has no voltage

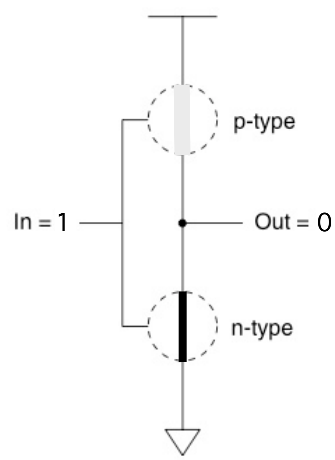


- **Voltage Inverter**
  - Device takes input voltage and produces an output voltage
    - The voltages of the input and output are opposite.
    - Gate also needs to be connected to power and ground.
  - Inverter uses 2 switches.
    - Figure 3.4 (a) shows p-type transistor on top, n-type below.
    - Figure 3.4 (b) shows voltage diagram when input is 0
    - Extension of figure 3.4 (below right) shows voltage diagram when input is 1.
  - As a logical device, a voltage inverter negates the input to get the output.

Figure 3.4



(Extension of Figure 3.4)



(c)

In	Out
0 volts	2.9 volts
2.9 volts	0 volts

(d)

In	Out
0	1
1	0

