Historical Development & Device Physics

CIT 595

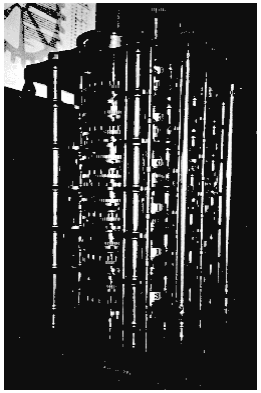
Spring 2007

Historical Development

- To fully appreciate the computers of today, it is helpful to understand how things got the way they are
- The evolution of computing machinery has taken place over several centuries
- In modern times computer evolution is usually classified into four generations (the digital ages)

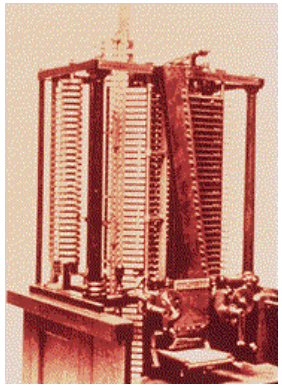
Before the digital age

- Age of the Mechanical Computers
- Charles Babbage invented a viable mechanical computer
- First one was called Difference Engine in early 1800 and was a special purpose calculator



difference engine

Babbage's second computer



analytical engine, 1834

- Analytical engine
  - general-purpose
  - used binary system
  - Arithmetic processing unit
  - punched cards as input
  - branch on result of previous instruction
  - Ada Lovelace (first programmer)
  - never quite completed

Review on Electric Circuit

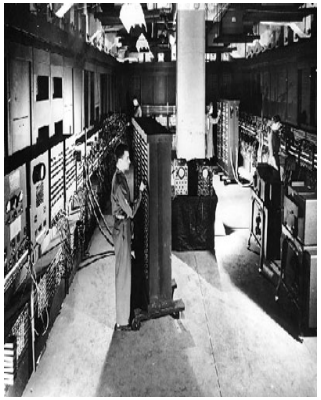
- An **electrical network/circuit** is an interconnection of electrical elements such as resistors, inductors, capacitors, transmission lines, voltage sources, current sources, and switches
- An electric circuit is formed when a conductive path (closed loop) is created to allow movement of charges
- This continuous movement of charges through the conductors of a circuit is called a ***current***, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

Review on Electric Circuit (contd..)

- The force motivating electrons to "flow" in a circuit is called ***voltage***. Voltage is a specific measure of potential energy that is always relative between two points.
  - how much ***potential*** energy exists to move charges from one particular point in that circuit to another particular point
- Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called ***resistance***
- The ***amount of current*** in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow

First Generation: Vacuum Tube Computers (1945 - 1953)

- ENIAC
  - Electronic Numerical Integrator and Computer
  - The ENIAC was the first *general-purpose electronic* computer
  - Created by John Mauchly and J. Presper Eckert at University of Pennsylvania, 1946
  - Made of vacuum tubes
    - 17468 vacuum tubes, occupied 1800 sq. feet, weighted 30 tons and consumed 174 kilowatts of power

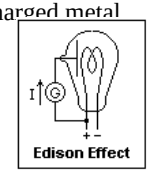


Vacuum Tube

- A device that controls the flow of electrons in evacuated space
- Discovery by Thomas Edison (1883) – birth of vacuum tube
  - Conducted series of electrical experiments in order prevent the light bulb filament from burning away and blackened
  - How the light bulb work?
    - Passing electricity through the filament caused it to heat up, and radiate light (release of photons)

Edison's Discoveries

- By placing filament mounted in a glass bulb which was vacuumized prevented the filament from oxidizing and burning up
- Edison also detected electrons flowing from the lighted filament to a metal plate (positive charged) mounted inside the bulb
- This became known as the ***Edison Effect*** **(**a.k.a thermionic emission i.e. emission of charged particles called thermions (+/- charges) from a charged metal



Edison Effect

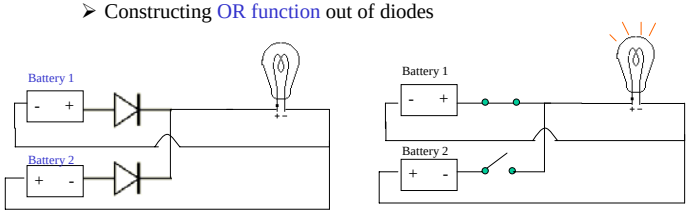
Application of Vacuum Tube

- The current flow was when the plate was connected to the positive end of the filament, but not when the plate was connected to the negative side
- John Fleming studied Edison's effect (around 1905)
  - to detect radio waves and to convert them to electricity
  - Patented this device as ***diode***

- **Diode** is a component that restricts the direction of movement of charge carriers. Essentially, it allows an electric current to flow in one direction, but blocks it in the opposite direction.
  - electrons flow within the tube from the negatively charged (*cathode)* to the positively charged (*anode). Electric current flows in the opposite direction*

Uses of Diodes

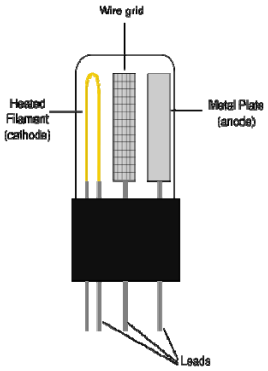
- Used as rectifiers, and switches
- Use as a switch
  - Constructing OR function out of diodes



Battery 1 orientation makes the diode conduct (acts as switch closed). Battery 2 orientation does not make the diode conduct (switch is opened). However Battery 1 orientation forms a path in the circuit such that current flows through the circuit and bulb is lit. There are 4 different combinations of battery orientation. Testing these orientation, you will soon realize that this is an OR function i.e. either diodes conducts then the bulb lights up.

Triode

- Same function as Diode
- Additional element added to the diode called control grid
- The control grid can reduce or prevent electron flow from the cathode to the anode of the a diode
- The control grid is charged negatively to repel electrons from flowing from filament to plate
  - The larger the charge on the grid, the smaller the electron flow to plate



Drawback of the Vacuum Tube

- Occupied a lot of space
  - ENIAC occupied 1800 sq feet

- They use enormous amounts of electrical power to heat the cathode
  - The heat dissipation can cause melt down of the device
  - Overcome the problem large cooling systems are employed e.g. ENIAC consumed 174 kilowatts of power

Second Generation:Transistorized Computers (1954 - 1965)

- Invented at Bell Labs in 1948
  - Inventors: John Bardeen, Walter Brattain, and William Shockley (Nobel prize, 1956)
- A **transistor** is a semiconductor device that is used as amplifier or switch
  - Equivalent to Triode of the First generation

Semiconductor

- Semiconductor material are in between conductors (like metals) and insulators (like glass)
  - In pure form, it is non-conducting
  - E.g. silicon crystal - has 4 electrons in its outer orbital, which form perfect covalent bonds with four neighboring atoms, leaving no electrons to conduct electric current
  - You can change the behavior of silicon and turn it into a conductor by **doping** it. In doping, you mix a small amount of an **impurity** into the silicon crystal

Semiconductor Doping

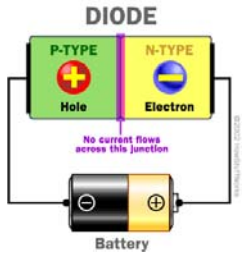
- **N-type**
  - In N-type doping, phosphorus or arsenic is added to the silicon in small quantities
  - Phosphorus and arsenic each have 5 outer electrons
  - The 5th electron has nothing to bond to, so it's free to move around
  - The created free electrons allow an electric current to flow through the silicon
  - Electrons have a negative charge, hence the name N-type

Semiconductor Doping (contd..)

- P-type
  - In P-type doping, boron or gallium is the dopant
  - Boron and gallium each have only three outer electrons
  - When mixed with silicon, they form "holes" in the where a silicon electron has nothing to bond to
  - The absence of an electron creates the effect of a positive charge, hence the name P-type
  - Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space

Semiconductor Diode

- No current flows across the junction because the holes and the electrons are each moving in the wrong direction
- But If we reverse the direction then….



Reference: HowStuffWorks.com

Semiconductor Diode (contd..)

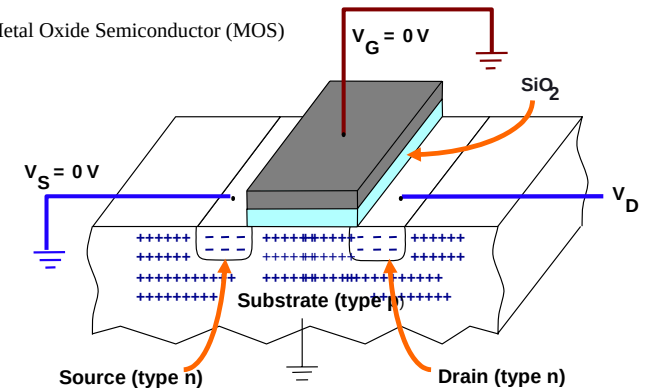
- If you **flip the battery around**, the diode conducts electricity
  - The free electrons in the N-type silicon are repelled by the negative terminal of the battery. The holes in the P-type silicon are repelled by the positive terminal
  - At the **junction** between the N-type and P-type silicon, holes and free electrons meet. The electrons fill the holes. Those holes and free electrons cease to exist, and new holes and electrons spring up to take their place. The effect is that **current flows** through the junction
    - Basically enough pressure (potential built up) so that the charges move/current flows

Semiconductor Transistor

- A **transistor** is created by using **three layers** instead of two layers like in the diode
  - You can create either an NPN or a PNP sandwich.
- A transistor looks like two diodes back-to-back. You'd imagine that no current could flow through a transistor because back-to-back diodes would block current both ways
- However, when you apply a small current to the **center layer** of the sandwich, a much larger current can flow through the sandwich as a whole. This gives a transistor its **switching** behavior.
  - A small current can turn a larger current on and off

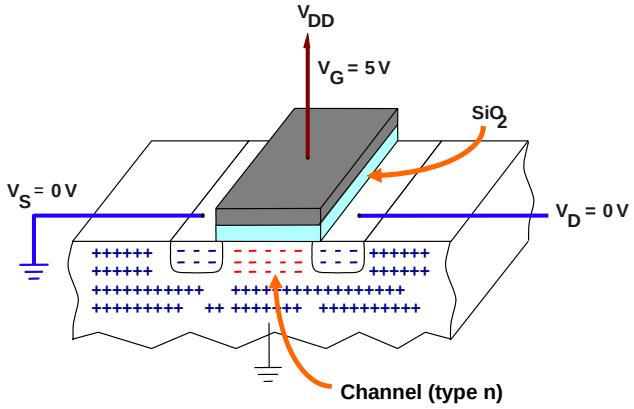
NMOS Transistor is Off (non-conducting)

Metal Oxide Semiconductor (MOS)



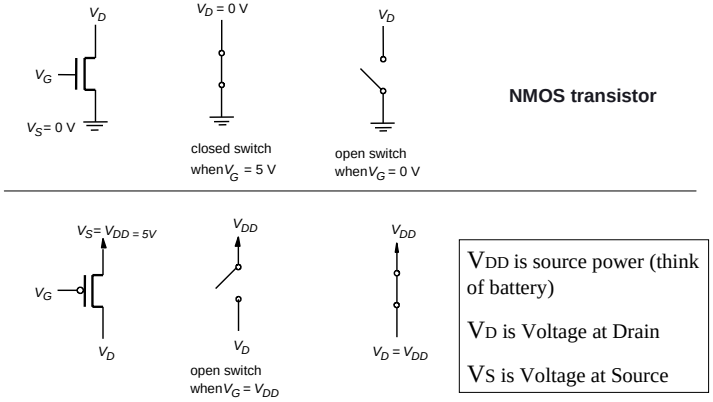
When V_G = 0 V, the transistor is off

N type MOS Transistor ON (conducting)



When V_G= 5 V, the transistor is ON

MOS Transistor Symbol

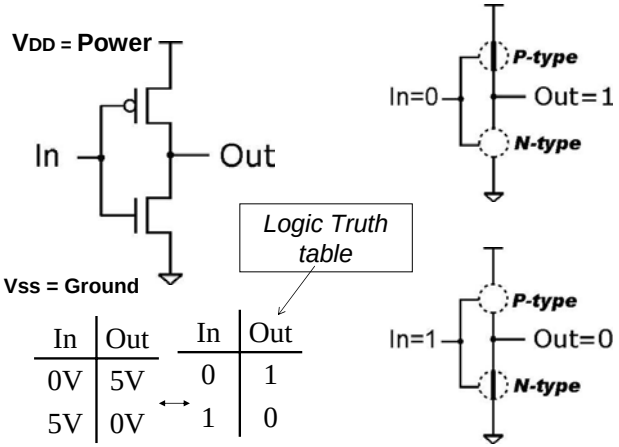


V_{DD} is source power (think of battery)

V_D is Voltage at Drain

V_S is Voltage at Source

Example: Inverter (NOT Gate) Using both N & P MOS



In	Out
0V	5V
5V	0V

In	Out
0	1
1	0

Previous Example: CMOS Inverter

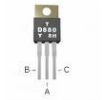
- Complementary MOS (CMOS)
- Uses both n-type and p-type MOS transistors
  - ➢p-type
    - ❑Attached to POWER (high voltage)
    - ❑Pulls output voltage UP when input is zero
  - ➢n-type
    - ❑Attached to GROUND (low voltage)
    - ❑Pulls output voltage DOWN when input is one

Basic Functions

- In the last example we saw how inverter function is implemented using transistors
- Similarly other basic functions such as AND, OR, NAND, NOR etc can be built
- In Chapter 3 we will study that from basic functions we can make more complex functions such as XOR, MUX, Adders, Memory

Advantage of Transistor over Vacuum Tube

- Smaller size
- Highly automated manufacturing
- Lower cost (in volume production)
- No warm-up period (most vacuum tubes need 10 to 60 seconds to function correctly)
- Lower power dissipation
- Higher reliability and greater physical ruggedness



Third Generation: Integrated Circuit Computer (1965 - 1980)

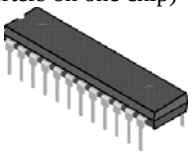
- Integrated Circuits or chips contain dozens transistors on single silicon chip
- Made computers faster, smaller, cheaper
- Computer manufacturers of this era were characterized as IBM and the BUNCH (Burroughs, Unisys, NCR, Control Data, and Honeywell)

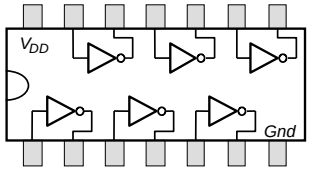
Fourth Generation: VLSI Computers (1980 – Current)

- Very Large Scale Integrated circuits (VLSI) have more than 10,000 components per chip
- Enabled the creation of microprocessors
  - The first was the 4-bit Intel 4004
  - Later versions, such as the 8080, 8086, and 8088 spawned the idea of "personal computing."
  - Intel 80 series had around 29,000 transistors

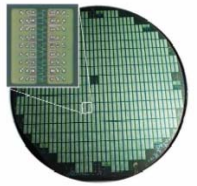
Integrated Circuits (IC) Examples

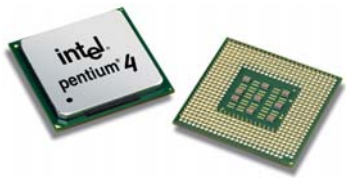
7404 Chip
(6 Inverters on one chip)





Millions of Transistors on silicon Wafer (VLSI)





Moore's Law (Rule of Thumb)

- Gordon Moore, Intel founder said

  "The density of transistors in an integrated circuit will double every year."

- Contemporary version: "The density of silicon chips doubles every 18 months."
  - also, prices decline
  - first described in 1965
  - experts predict this trend might continue until ~2020
  - limited when size reaches molecular level

Moore's Law example

DEC PDP-11, mid 1970's

DEC LSI-11, Early 1980's

These 2 computers were functionally equivalent

Transistor Density Increase

- **Intel Pentium II processor(1997)**
  - ➢7 million transistors
- **Intel Pentium III processor(1999)**
  - ➢28 million transistors
- **Intel Pentium 4 processor(2000)**
  - ➢42 million transistors

Corollary to Moore's Law

- Rock's Law (Intel financier)
  - ➢"The cost of capital equipment to build semiconductors will double every four years."
  - ➢In 1968, a new chip plant cost about $12,000.
  - ➢In late 1990s the cost had come to $12 million

Need alternative means to build chips**…may be quantum computing???**

Next Class

- Boolean Algebra and Digital Logic