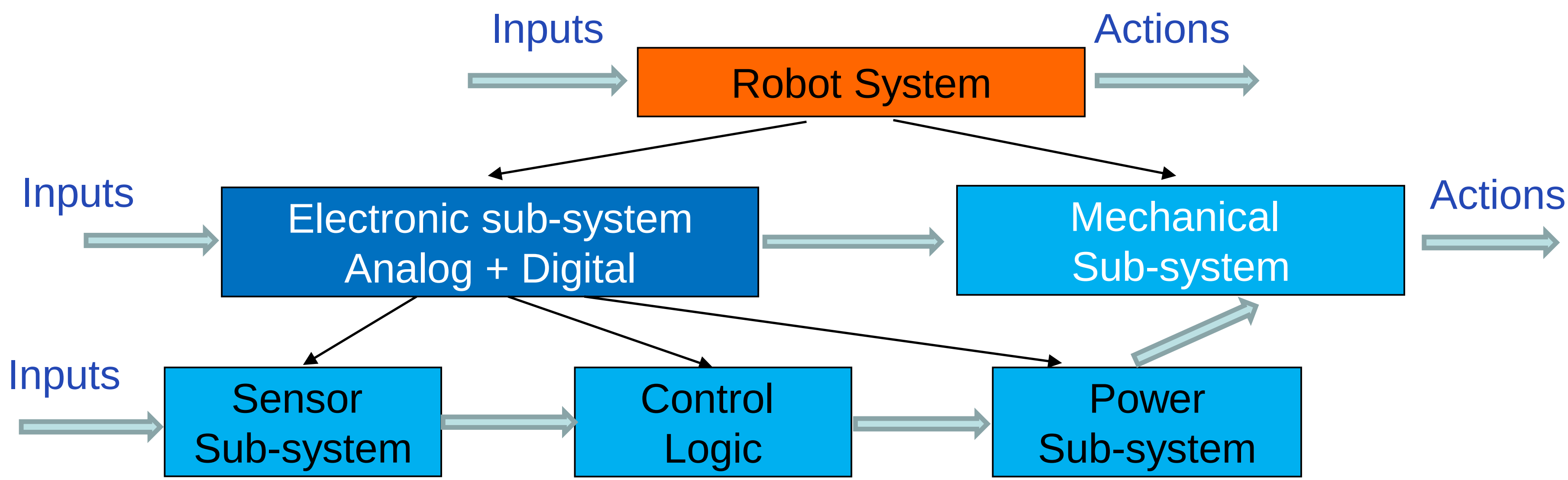
ELEC 1100: Introduction to Electro-Robot Design

Lecture 3: Transistors + H-bridge + Sensors

CHEN Wei, Dept. of ECE, HKUST

ELEC1100 ROADMAP

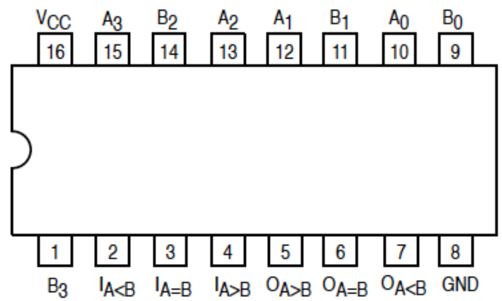


Sensor Basics:
Wk2: Sensor Basic

Basic electronics:
Wk1: Basic Electronics & DC Sources

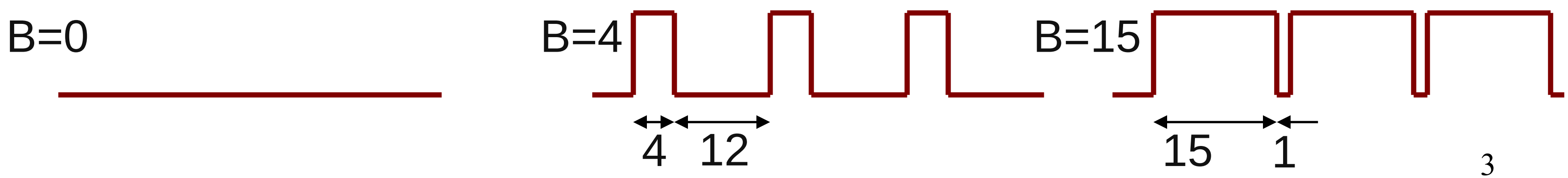
Motor Power Supply:
Wk1: Pulse Signal & PWM Control
Wk2: Transistor and H-Bridge

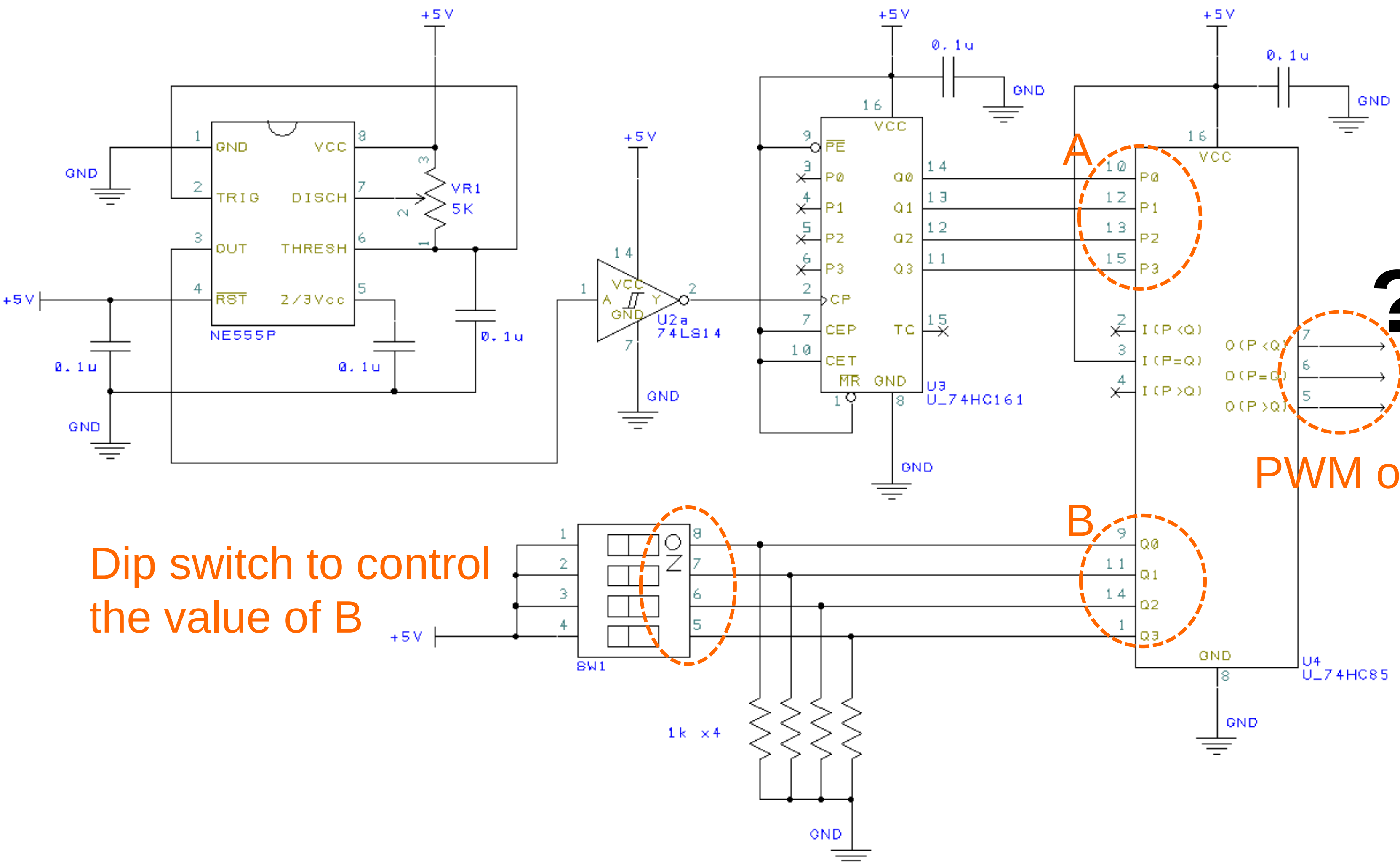
- A comparator compares 2 binary numbers A (=$A_3A_2A_1A_0$) and B (=$B_3B_2B_1B_0$)



- If A < B, the pin A<B will go high and so on
- Suppose the number A comes from the counter 74HC161 and starting from 0000
- By inputting a fixed number to B, we can control the duty cycle at output of A < B

$O_{A<B}$ output





A

B

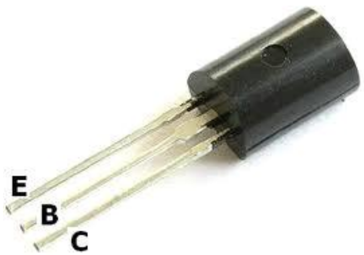
Dip switch to control the value of B

PWM output

?

INTERFACING PWM CIRCUIT TO THE MOTOR

- ❖ Brushed motors usually require very high current to drive it. Thus, the driving signal needs to be amplified by a transistor
- ❖ A transistor is a 3-terminal device that can be viewed as a electronic switch
- ❖ The conductivity between two of the terminals is controlled by the third terminal



Transistor

analogy

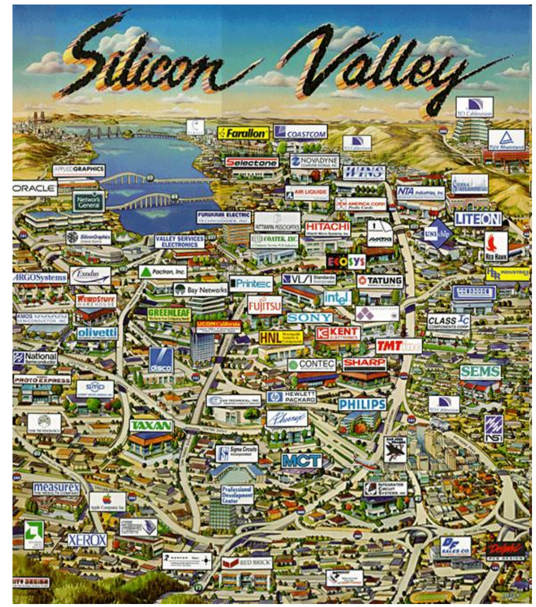
A SHORT HISTORY OF TRANSISTOR

- Invented in Bell Labs by William Shockley, John Bardeen and Walter H. Brattain

  - Shockley: “one of the century’s most important scientists”, Times Magazine
  - Bardeen: won Nobel Prize twice !
  - The three of them won the 1956 Nobel Prize in Physics for inventing the transistor

- Bardeen and Brattain made the breakthrough and Shockley put a nice ending
- However Shockley was not a good leader. Brattain refused to work for him anymore and Bardeen just quit

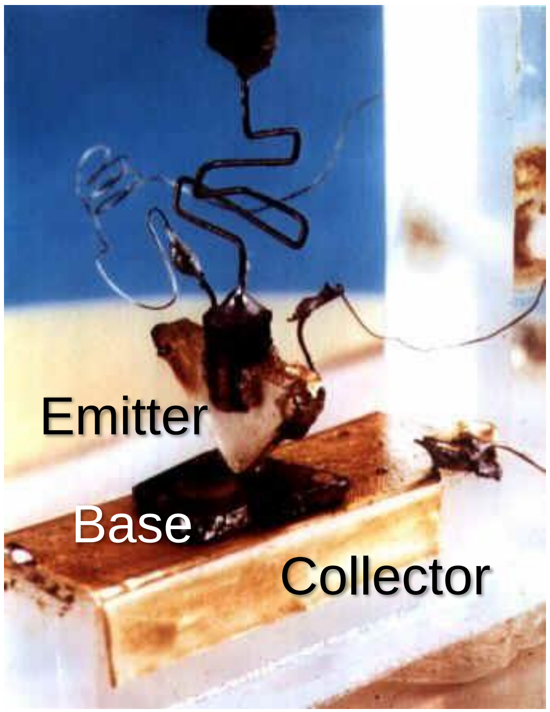
- Shockley moved to Stanford and founded Shockley Semiconductors in Palo Alto, the beginning of Silicon Valley

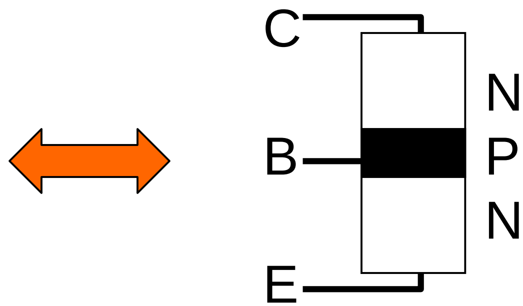


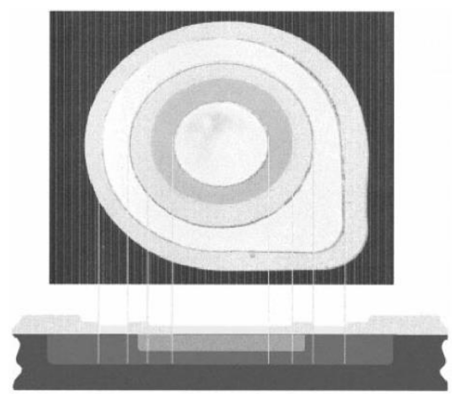
- Shockley hired the brightest scientists and engineers (e.g. Gordon Moore and Bob Noyce, founders of Intel) who founded many companies after they left Shockley

THE FIRST TRANSISTOR

- Resemble the schematic shown earlier



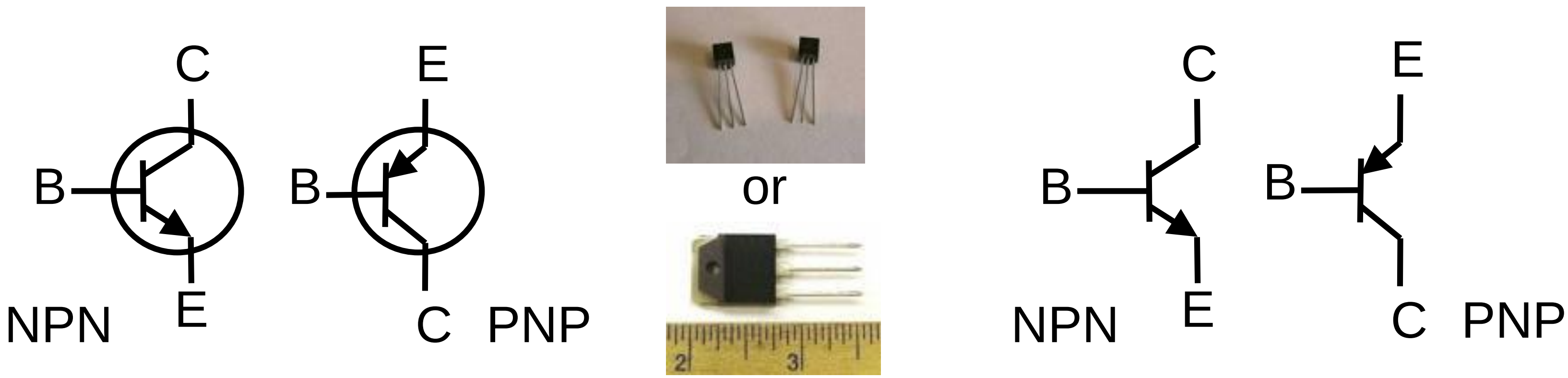




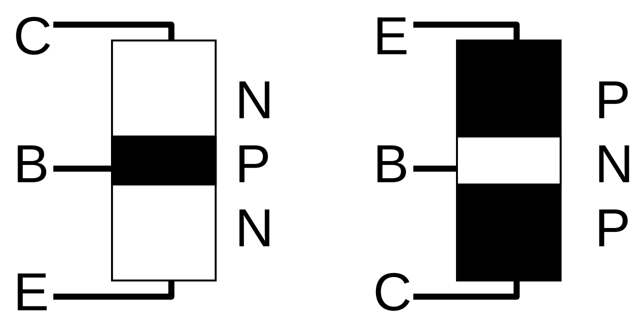
Modern planar transistors

BIPOLAR JUNCTION TRANSISTOR (BJT)

- There are two types of standard BJT



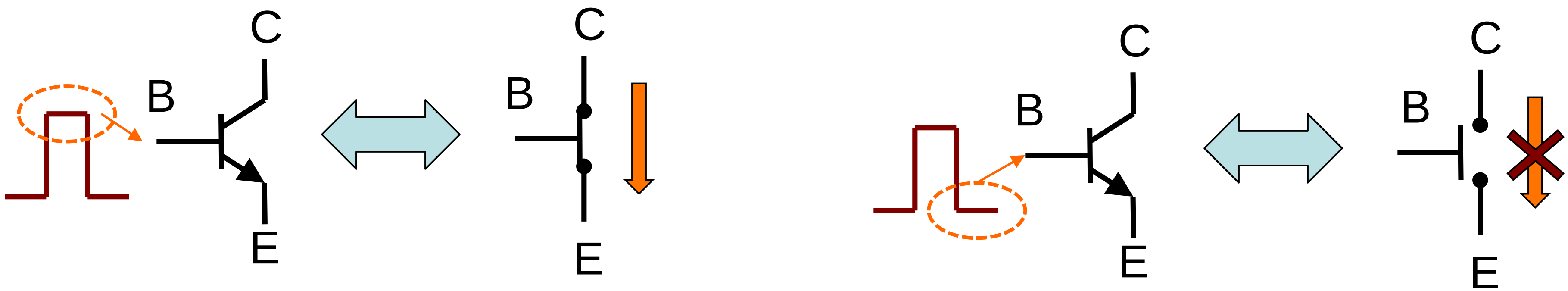
- The leads are labeled Collector (C), Base (B) and Emitter (E)
  - The N and P refers to the material type that is used to construct the transistor



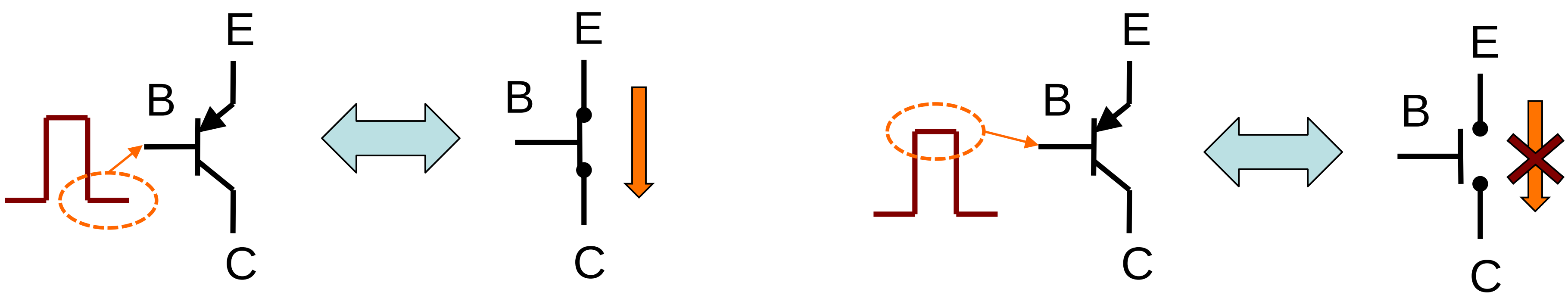
- Detail operation will be covered in other courses

TRANSISTORS AS SWITCHES

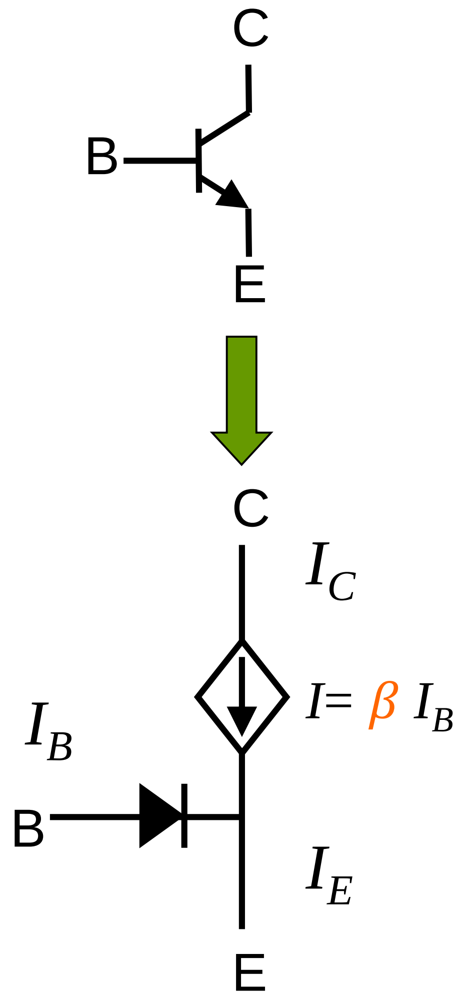
❖ Simple equivalent of NPN transistors



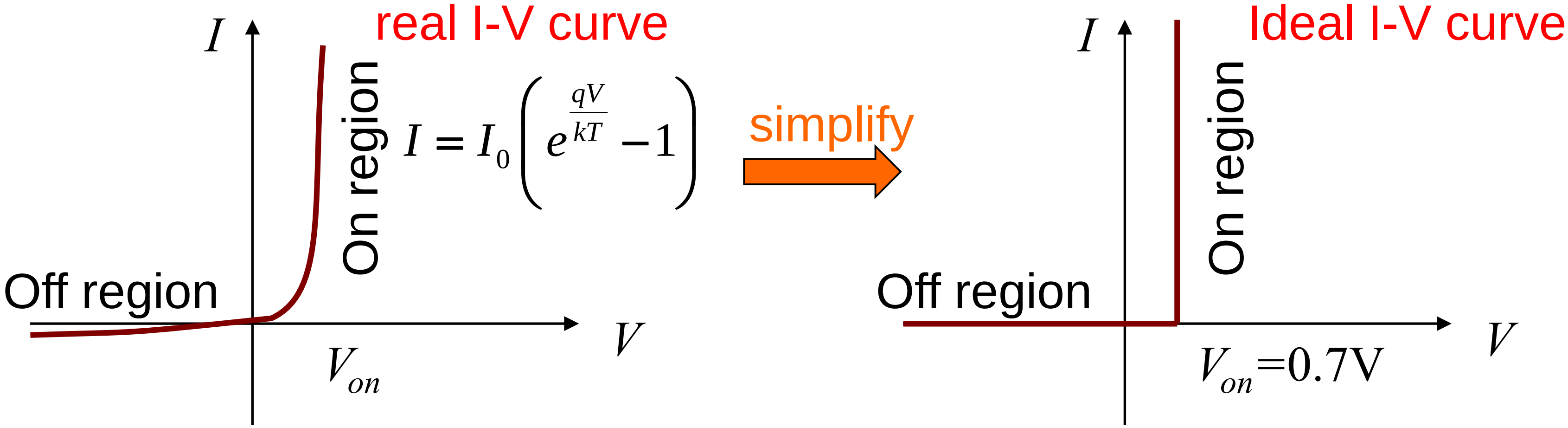
❖ Simple equivalent of PNP transistors

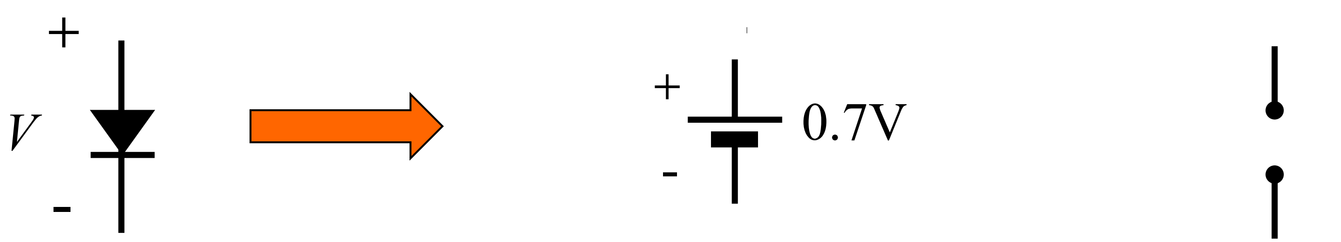


- The B-E terminal of a BJT is actually behaving like a diode
- A base current I_B flows only when the voltage V_{BE} across the base-emitter junction is about 0.7V
- Collector current is proportional to the base current, i.e., $I_C = \beta I_B$ where β is the current gain.
- β is in the range of 20-200, leading to an amplification of current



- To understand transistor operation, one needs to first understand diode circuits

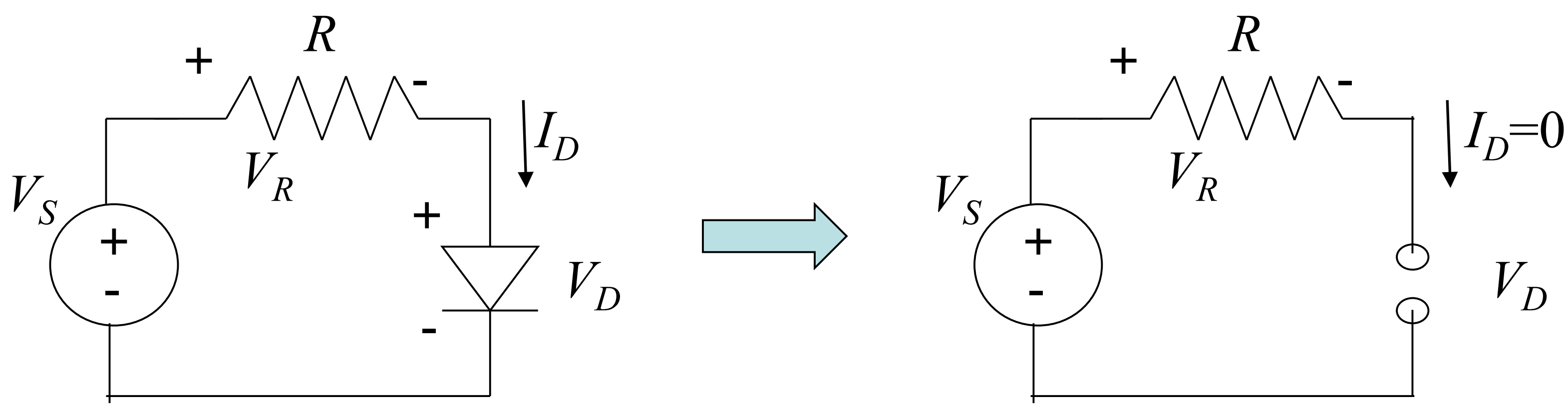




when $V > 0.7\text{V}$ when $V < 0.7\text{V}$

EXAMPLE OF DIODE CIRCUITS

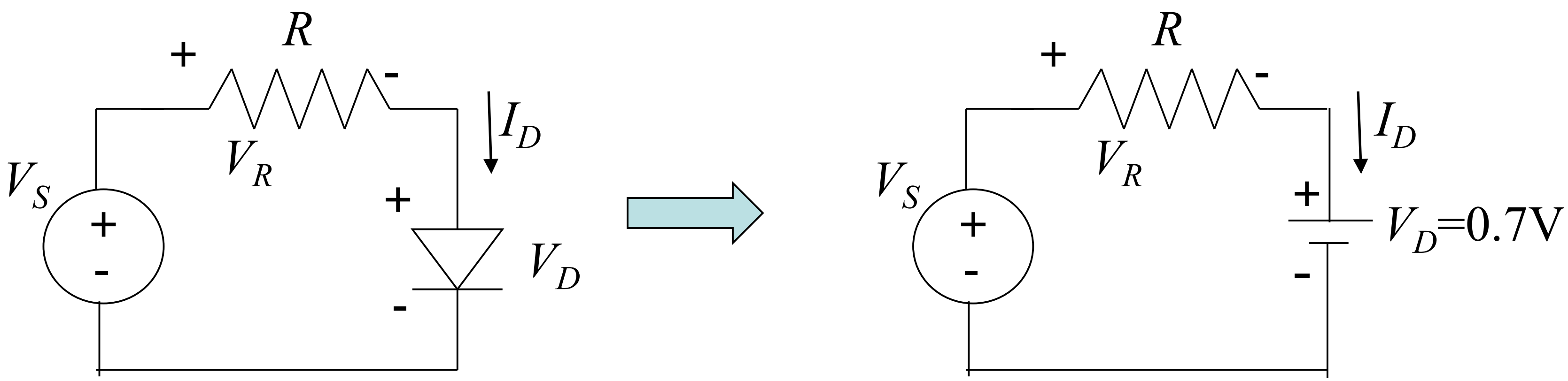
- Assume off region, replace it with the equivalent model



$$I_D = 0 \Rightarrow V_R = 0 \Rightarrow \boxed{V_D = V_S}$$

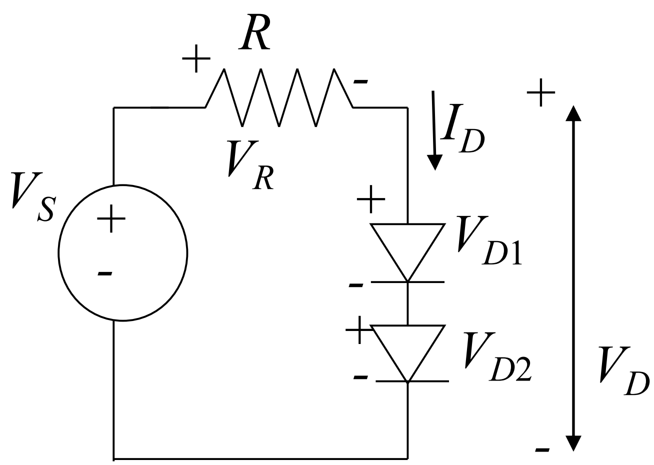
- If V_S<0.7V, the assumption is correct and answer found
- Otherwise, assumption is wrong and we try the other case

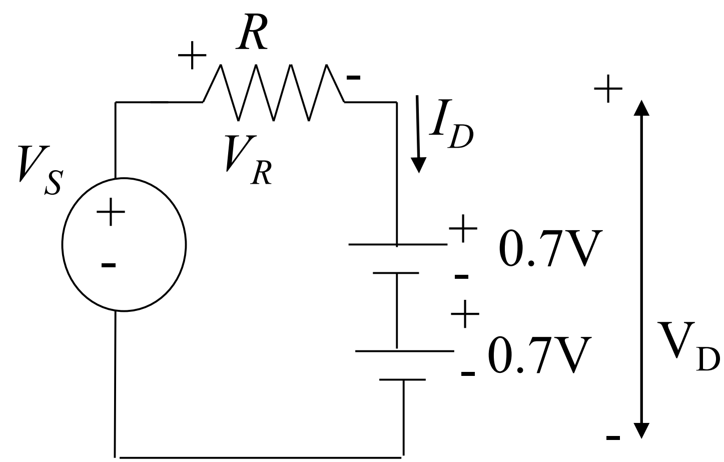
- When $V_S > 0.7\text{V}$



- We can obtain $V_S - 0.7 = V_R \Rightarrow I_D = \dfrac{V_S - 0.7}{R}$
- If the condition is incorrect (or $V_S < 0.7\text{V}$), $I_D < 0$
- It is important to have a resistance in series with a diode, or the current can be very large

❖ Circuit with two diodes can be solved in the same approach





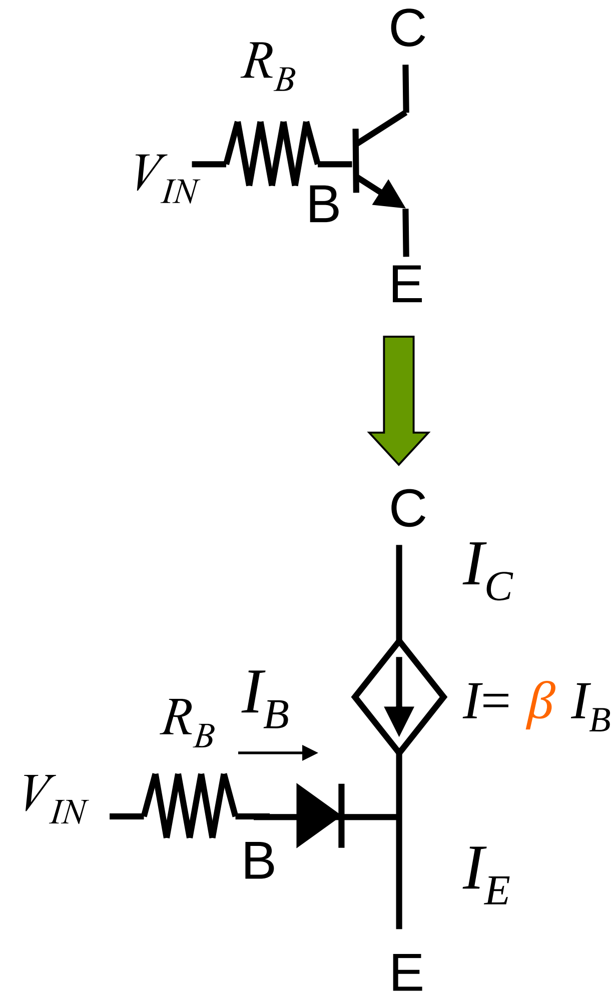
❖ It is simple and leave it to you as an exercise

- A resistor is always needed at the base to avoid a very high current

$$I_B = \frac{V_{IN} - 0.7}{R_B}$$

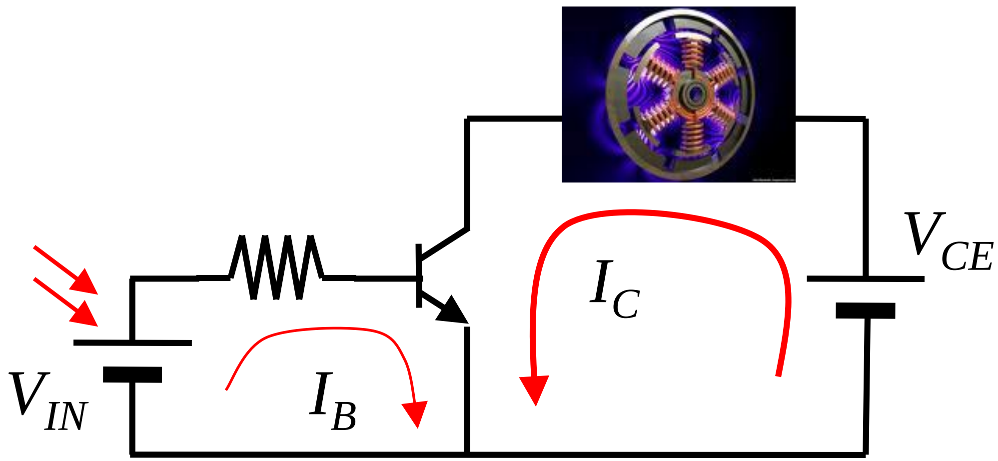
  - I_B=0, transistor is off
  - I_B small: active mode with transistor partially on
  - I_B large: transistor fully on

- As long as the input voltage V_{IN} is larger than 0.7V, you can consider the transistor is on (either partially or fully)



CIRCUIT EXAMPLE: LIGHT ACTIVATED SWITCH

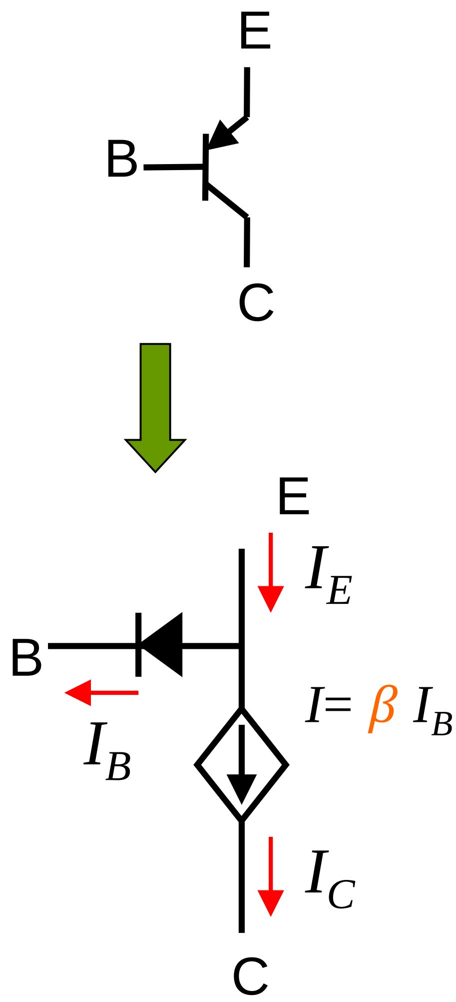
- Consider a circuit to turn on a fan under strong light
- You may simply connect the fan to a solar cell, but the solar cell is not powerful enough to drive the motor
- Consider using a solar cell to give the V_{BE} of a NPN transistor



- Can use a small power to control the delivery of a large power
- A transistor can be used as an “amplifier”

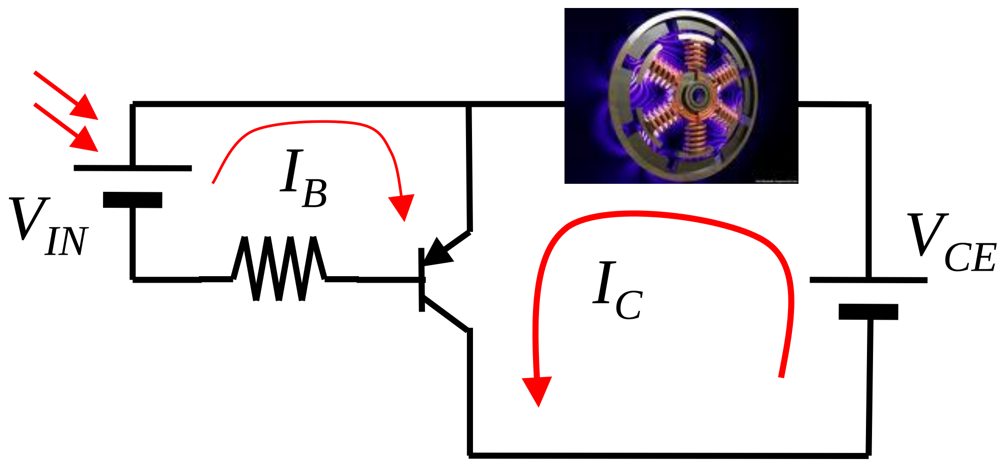
PNP TRANSISTOR

- PNP transistor is similar to NPN, but the diode is between the power supple and the input
- As long as $V_{BE} < -0.7V$, you may consider the transistor to be on
- Allow a switch to be turned on with low voltage



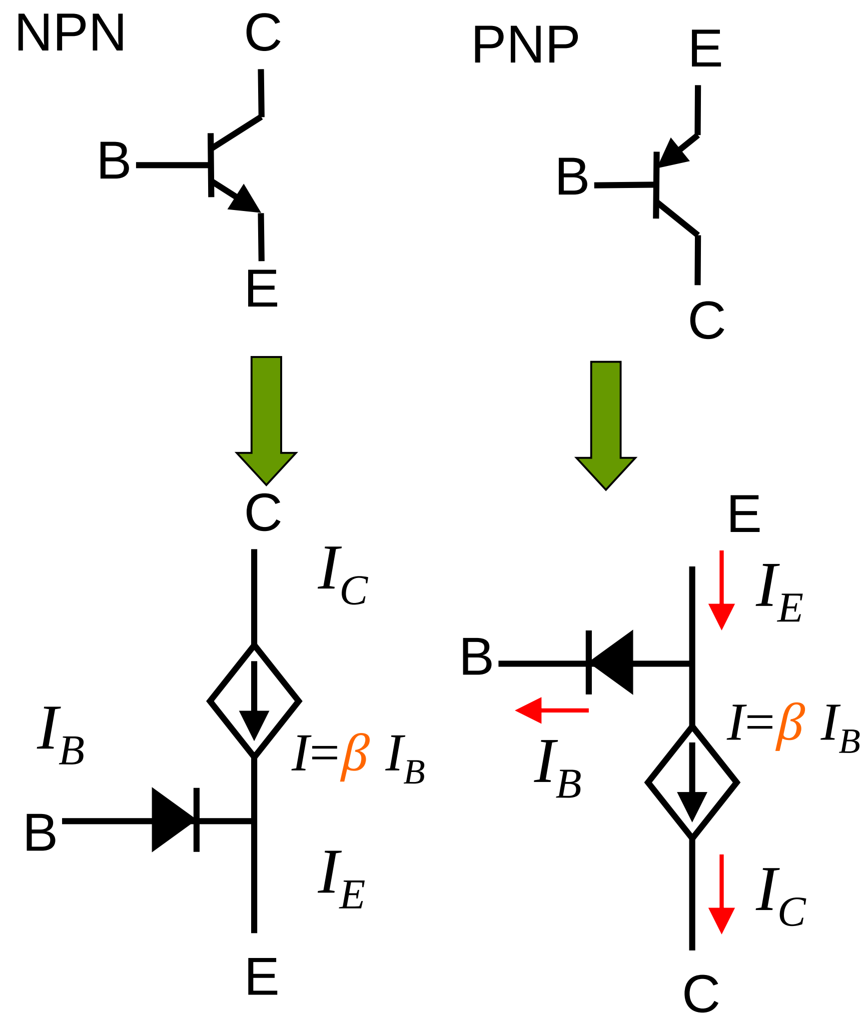
CIRCUIT EXAMPLE WITH PNP TRANSISTORS

❖ For the same circuit to turn on a fan under strong light using PNP transistor looks like the following:

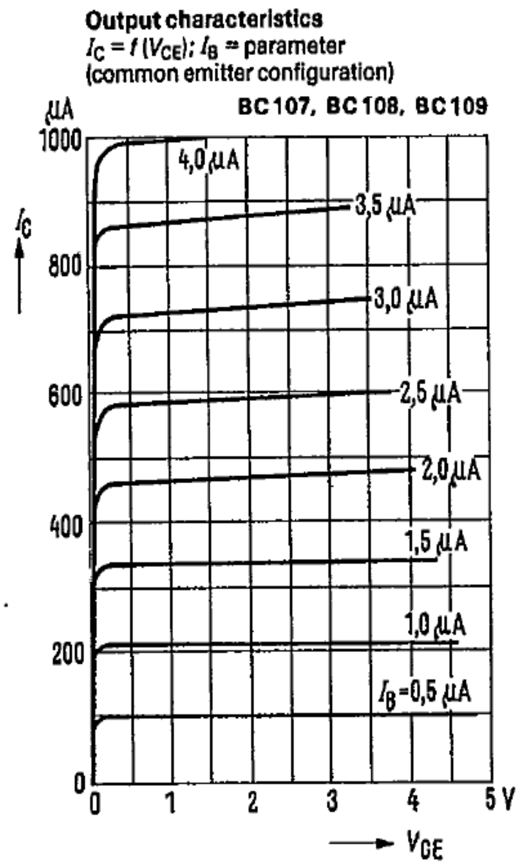


❖ The performance is exactly the same as the NPN case

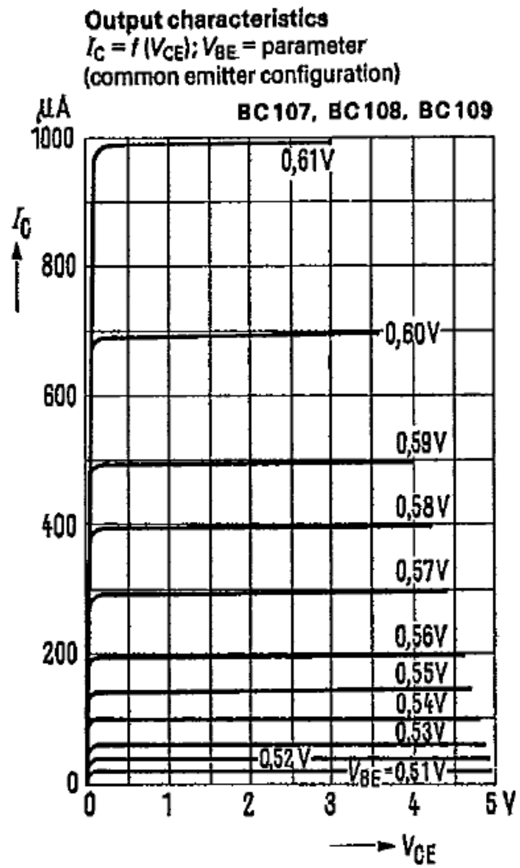
- NPN and PNP transistors and their equivalent circuits
- Calculating diode current by assuming it is either a battery or an open circuit
- Transistors can be used as a switch or an amplifier



SPECIFICATION OF BJT CHARACTERISTICS



Current Control

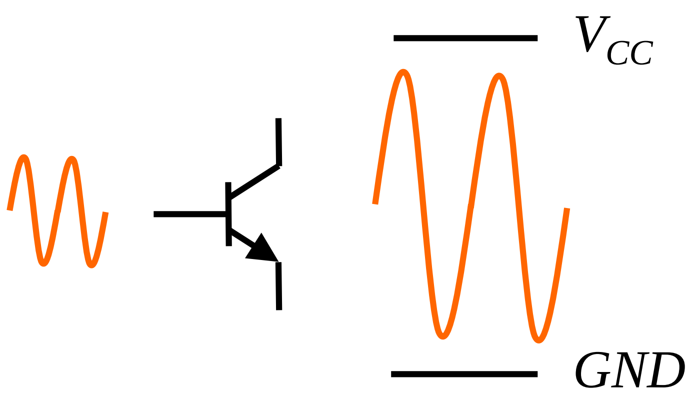


Voltage Control

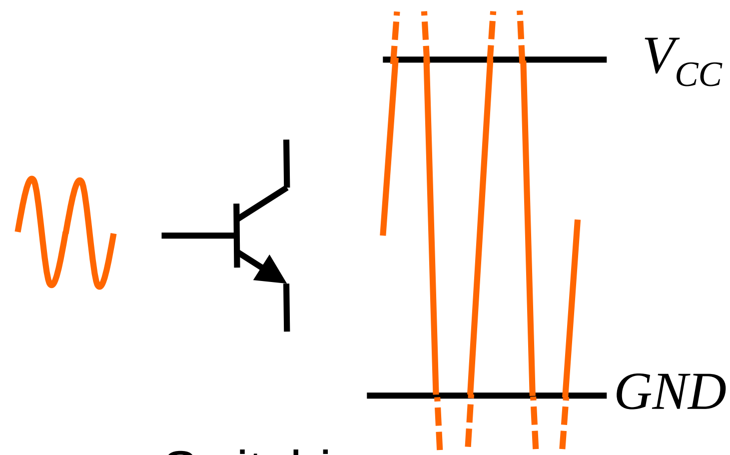
- I_C is more or less proportional to base current
- I_C is non-linearly dependent on V_{BE} and very sensitive to it
- As a result, current control is more easy to perform

SWITCH VERSUS AMPLIFIER

- Consider an AC signal input to an amplifier with different gain



Amplification

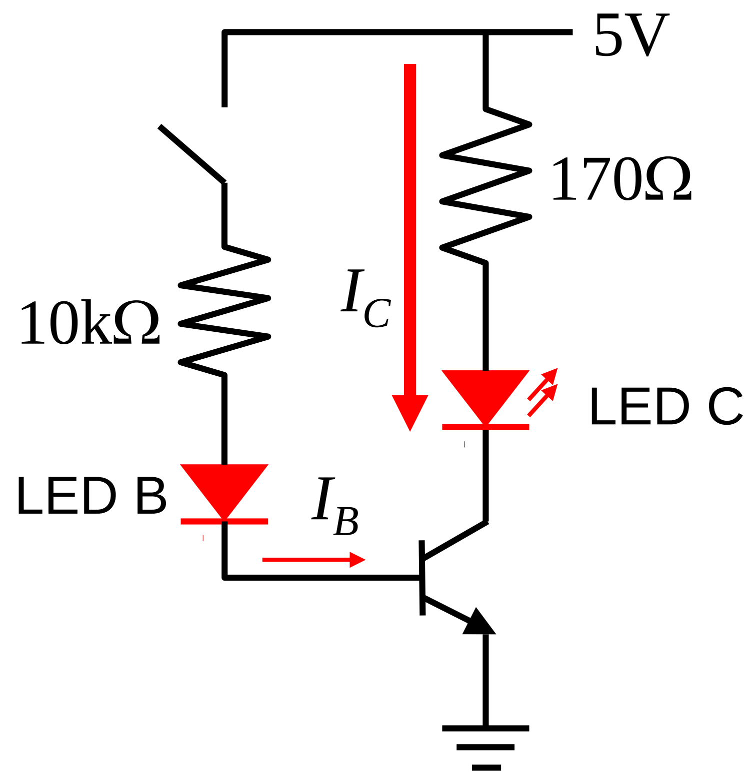


Switching

- For large input signal, an amplifier becomes a switch
- Many applications like audio and sensor signal processing require a transistor to operate in the amplification mode

EXAMPLE OF BJT CIRCUIT

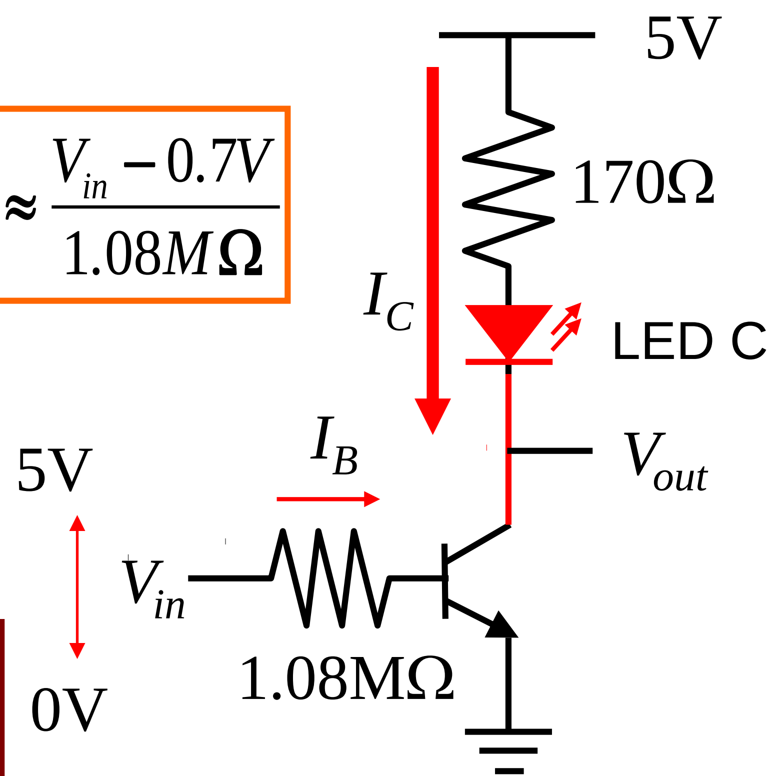
- When the switch is Open, there is no collector current
- When the switch is Closed, a small current flows into the base of the transistor, which is just enough to make the LED B glow dimly
- The transistor amplifies this small current to allow a large current to flow from its collector to its emitter that makes LED C to light brightly
- Question: what is the maximum possible collector current?



MAXIMUM AND ACTUAL COLLECTOR CURRENT

❖ Consider the following circuit, assuming β = 100

$$I_B \approx \frac{V_{in} - 0.7V}{1.08M\Omega}$$



$$I_{C\,max} \approx \frac{5 - 0.7V}{170\Omega} = 25mA$$

with V_{in}=5V

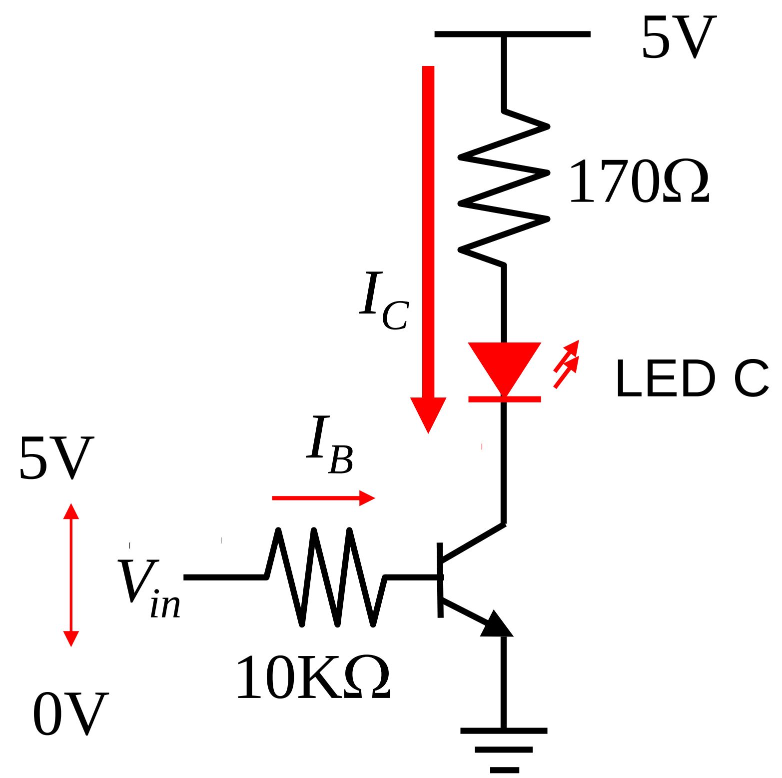
$$I_B \approx \frac{5V - 0.7V}{1.08M\Omega} = 4\mu A$$

$I_C = \beta\, I_B = 0.4mA$

Department of Electronic and Computer Engineering, The Hong Kong University of Science & Technology

AT HIGH BASE CURRENT

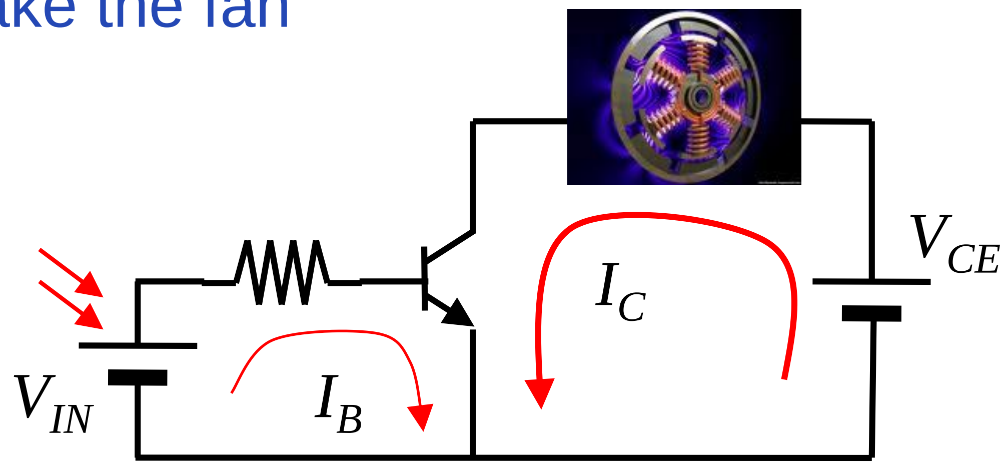
- In the given figure, $I_B \approx 0.43\text{mA}$
- With $\beta = 100$ and using the given relationship, $I_C = I_B \times \beta = 43\text{mA}$
- This I_C is higher than the 25mA allowed thus a gain of $\beta = 100$ is not possible
- When the transistor is fully turned on with high I_B, we call the transistor is saturated
- The transistor behaviors as a switch



MORE EXAMPLE

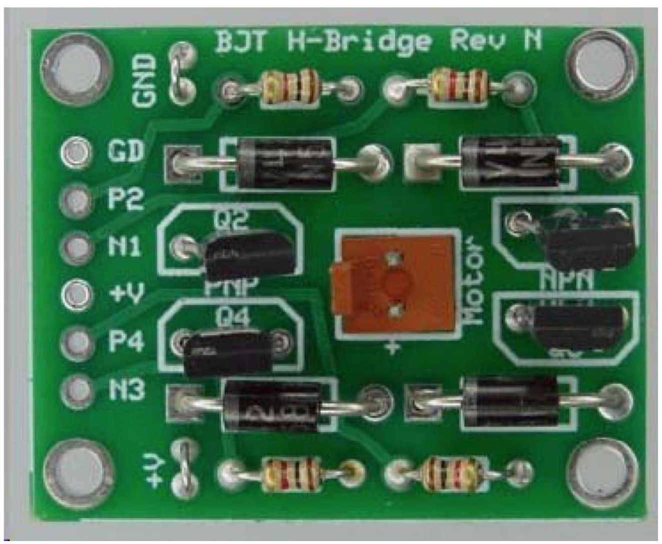
- How to make the light controlled fan behaves like a switch that whenever there is light, the fan is fully on?

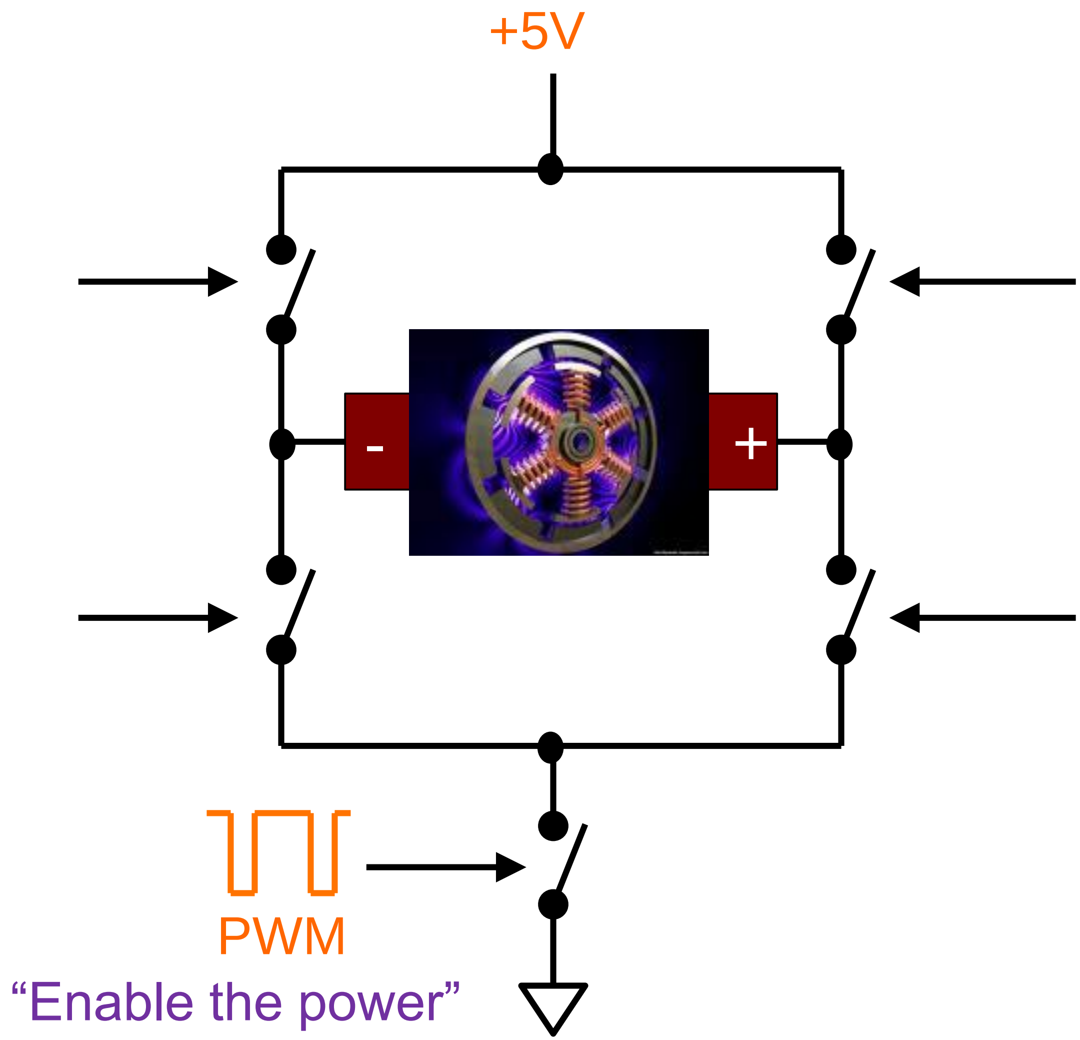
- How to make the speed of the fan proportional to the light input (i.e. stronger light would make the fan turn faster)?



H-BRIDGE CIRCUIT (SWITCHES)

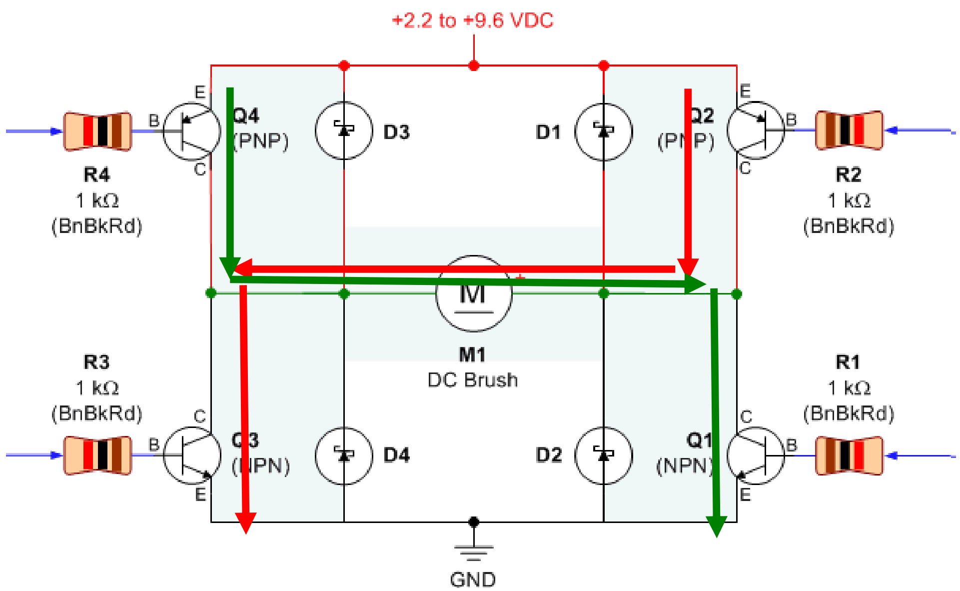
- It is the circuit to control both the motor direction and speed
- Use a direction (DIR) pin to control the switches





H-BRIDGE OPERATION SUMMARY

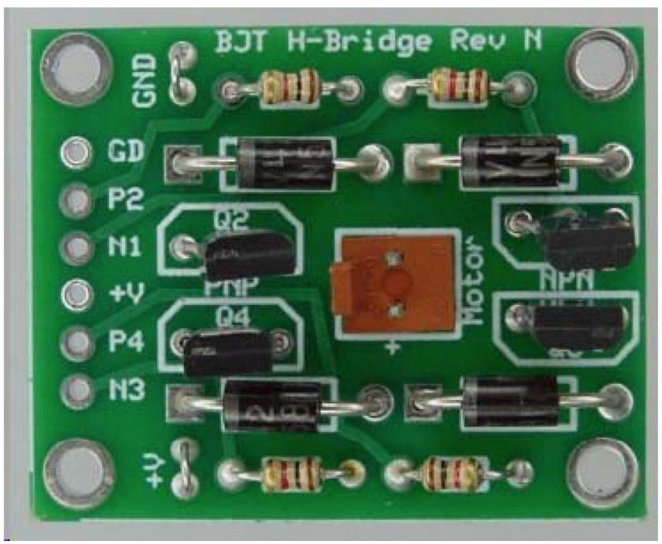
Command	R1	R2	R3	R4
Coast/Roll/Off	GND or disconnected	+VDC or disconnected	GND or disconnected	+VDC or disconnected
Forward:	GND or disconnected	GND	+VDC	+VDC or disconnected
Reverse:	+VDC	+VDC or disconnected	GND or disconnected	GND

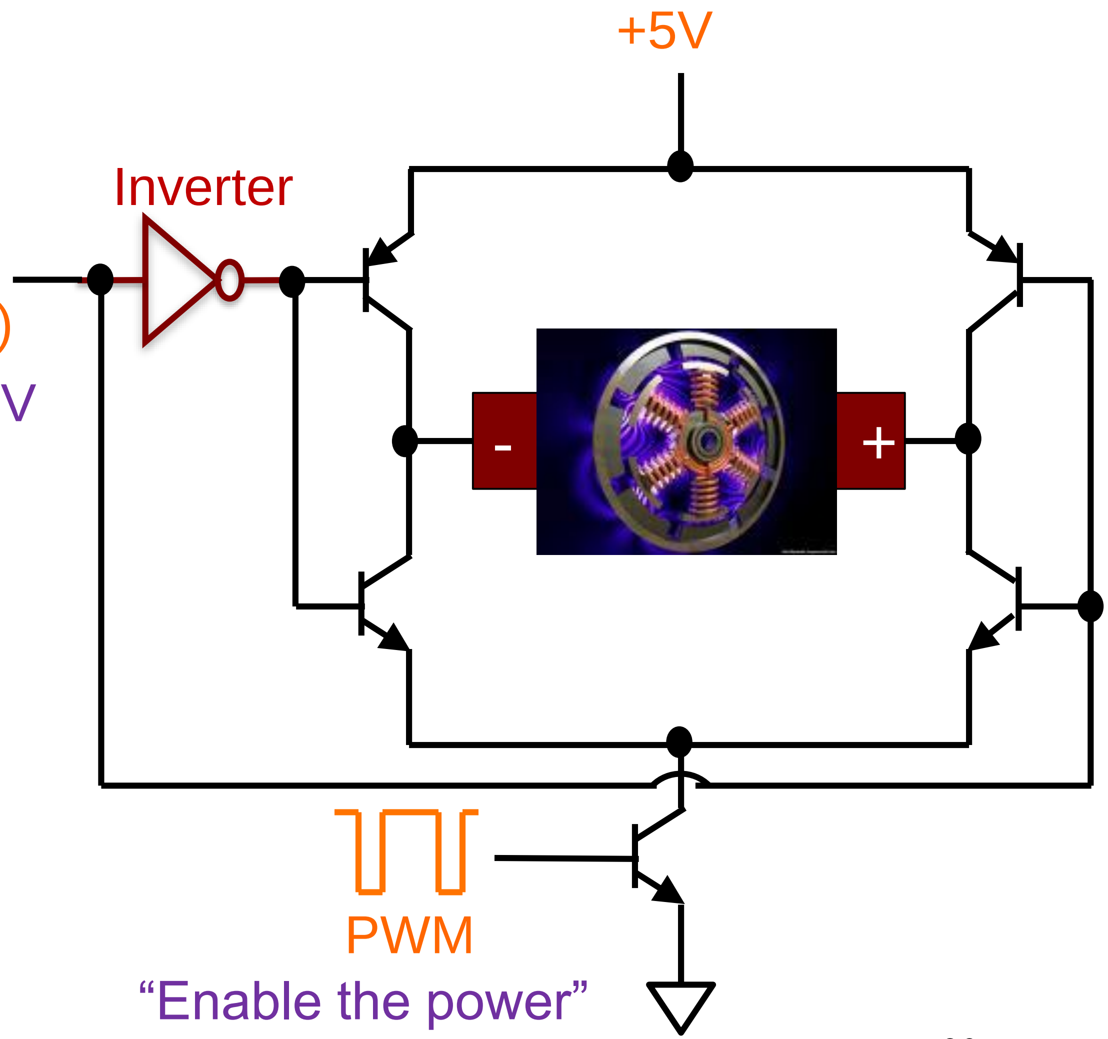


- It is the circuit to control both the motor direction and speed

DIR
(Direction)

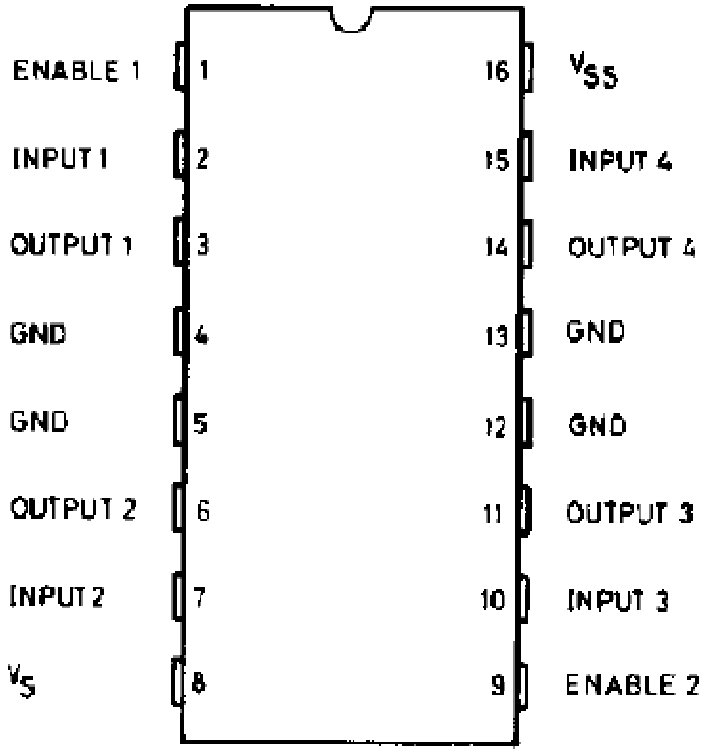
Connect to either 5V or 0V

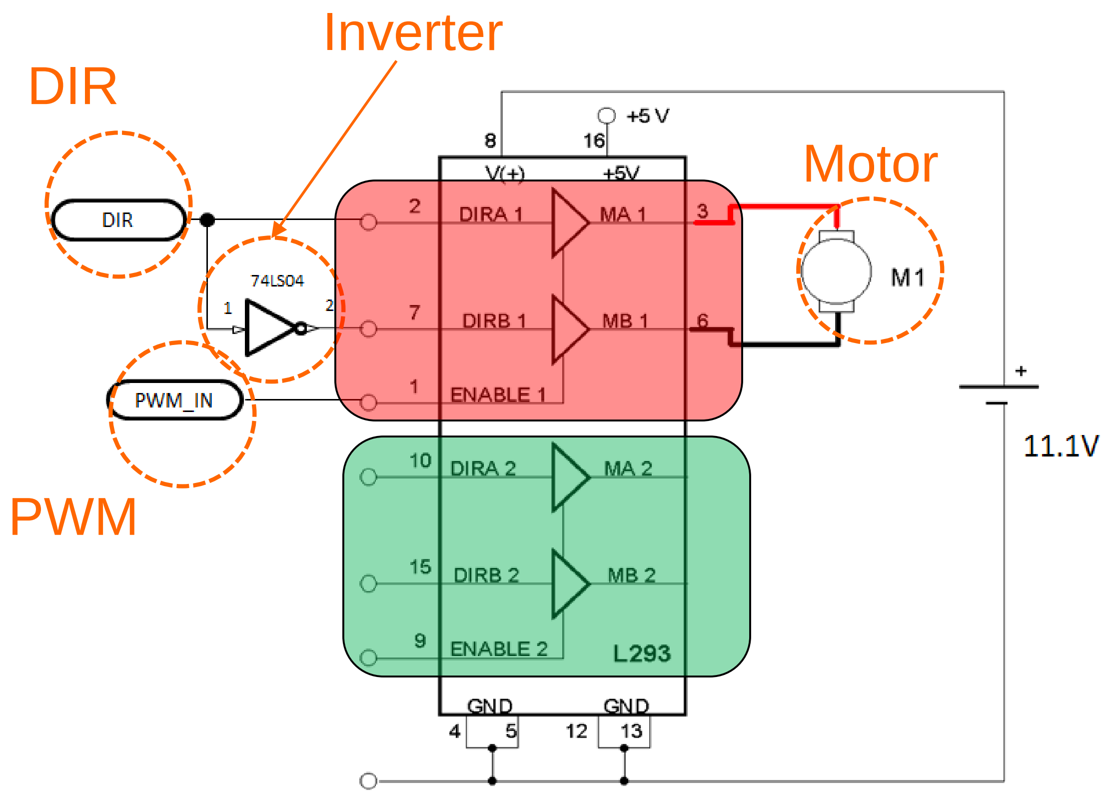




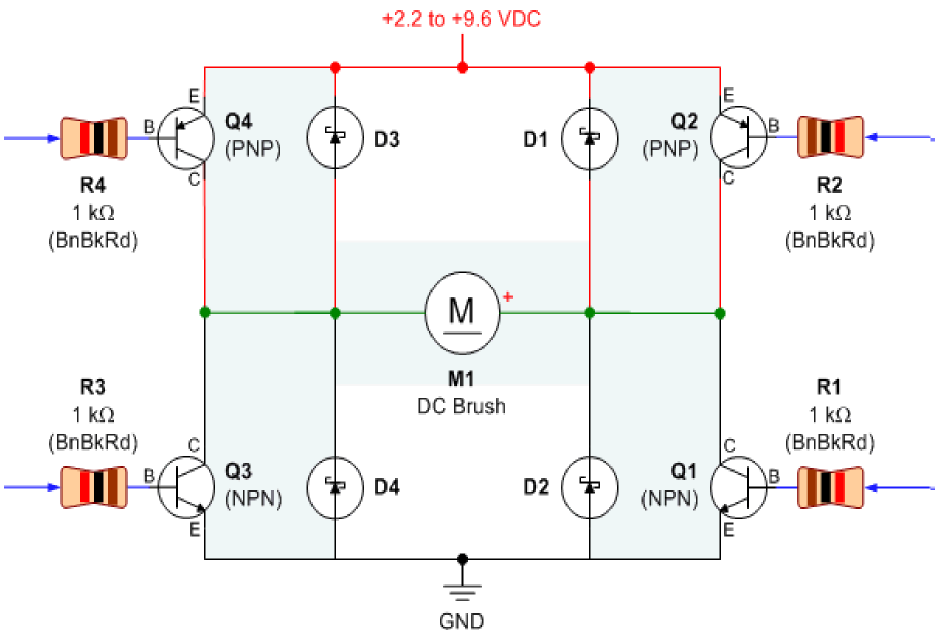
H-BRIDGE IC – L293B

❖ To simplify your task without using transistors, you may use the H-bridge IC in your lab and project



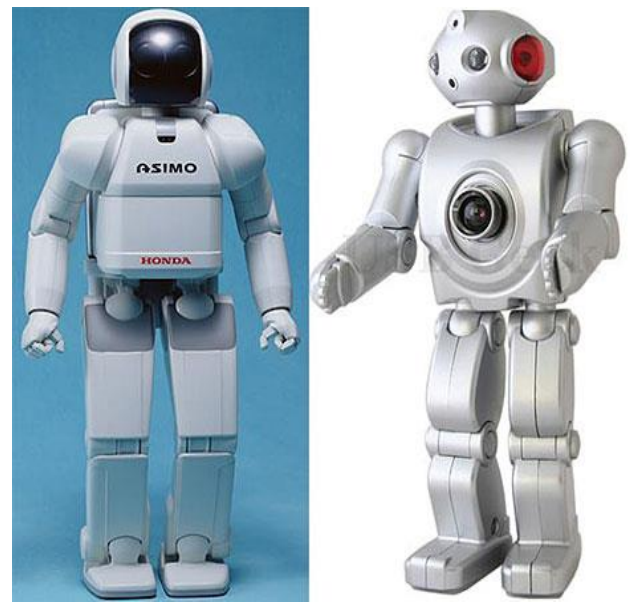


- A transistor can work in the switch mode or amplification mode
- A switch mode happens when the input current is very high that saturates the transistor
- Transistors can be used to construct a H-Bridge to drive a motor

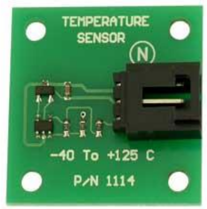


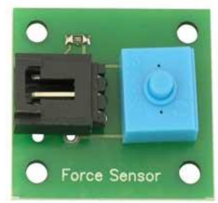
WHAT IS A SENSOR?

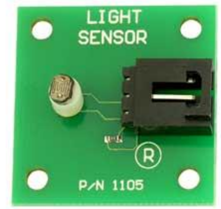
- A device that measures or detects a real-world condition, such as motion, heat or light and converts the condition into an analog or digital representation
- It is the equivalent of eyes, ears and skin of a Robot to found out the environment it is situated
- Make up of camera, microphone, gyroscope etc.

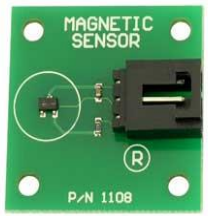


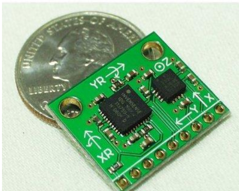
TYPES OF SENSOR







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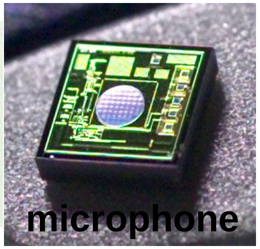
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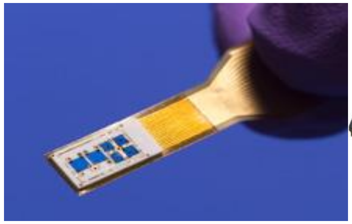
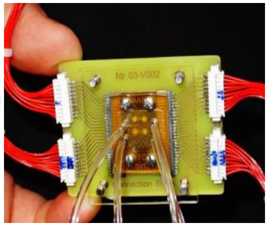
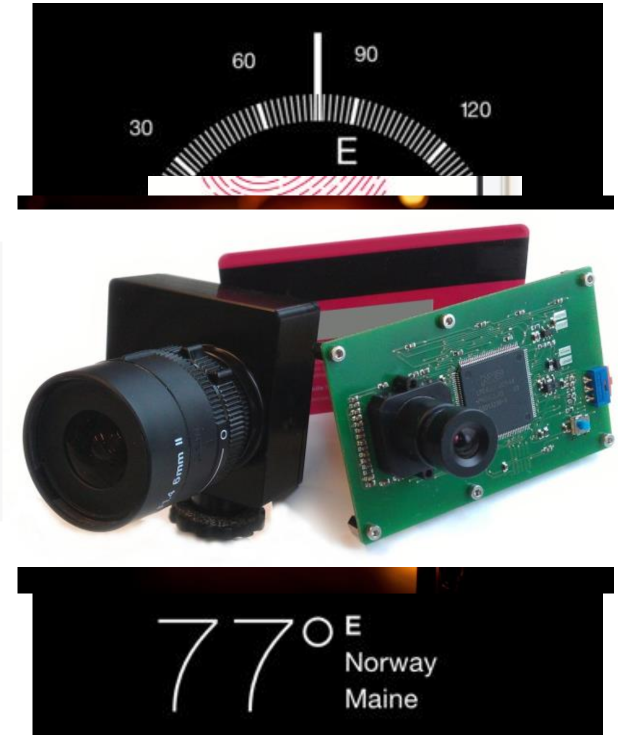

chemical sensor

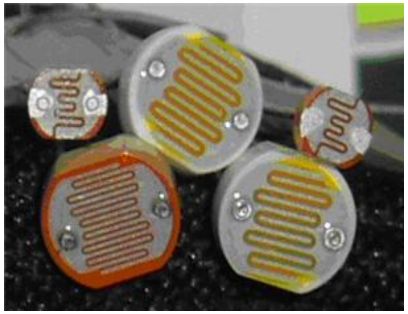
image sensor

biosensor

gyroscope

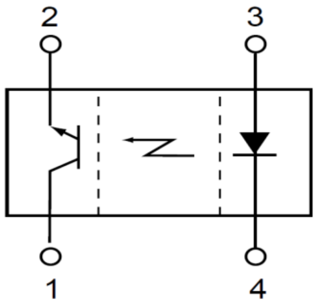
OPTICAL SENSORS

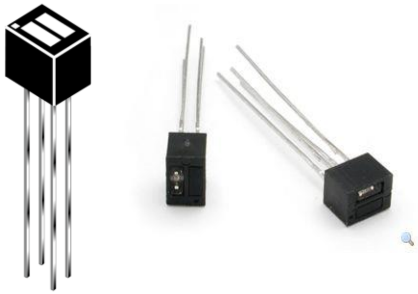
- Example of common optical sensors are light sensitive resistor (CdS) and photodiode
- Optical sensors can be combined with light sources to produce line sensors to detect position (the one you used in your lab)



CdS

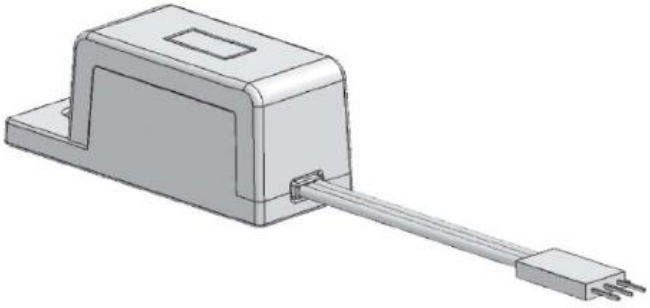
Photodiode





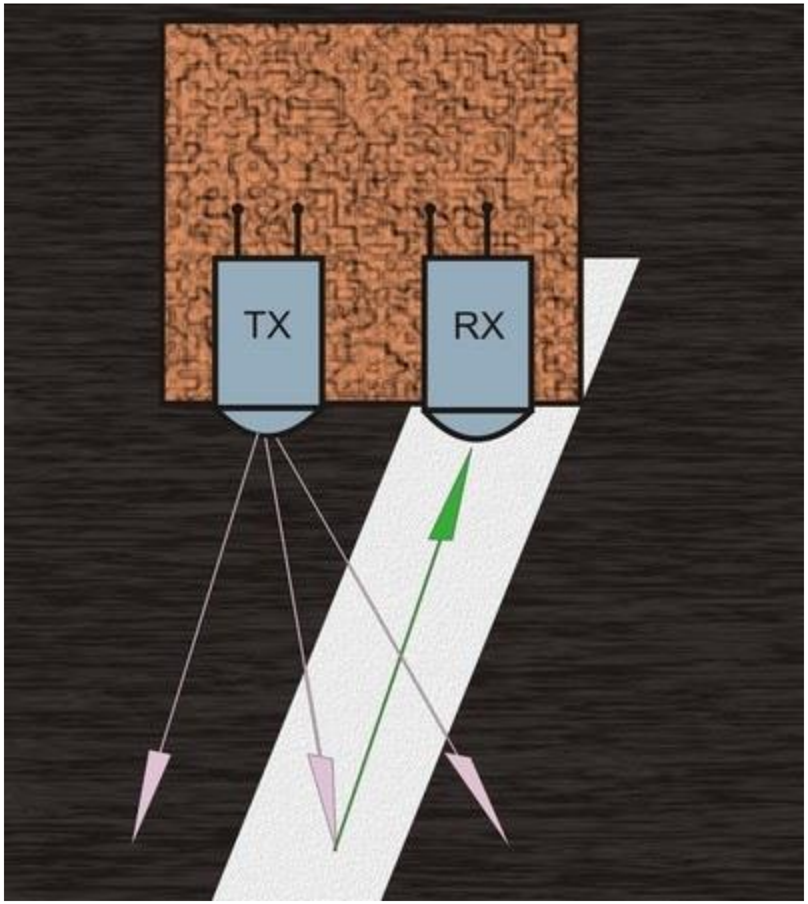
Line Sensor

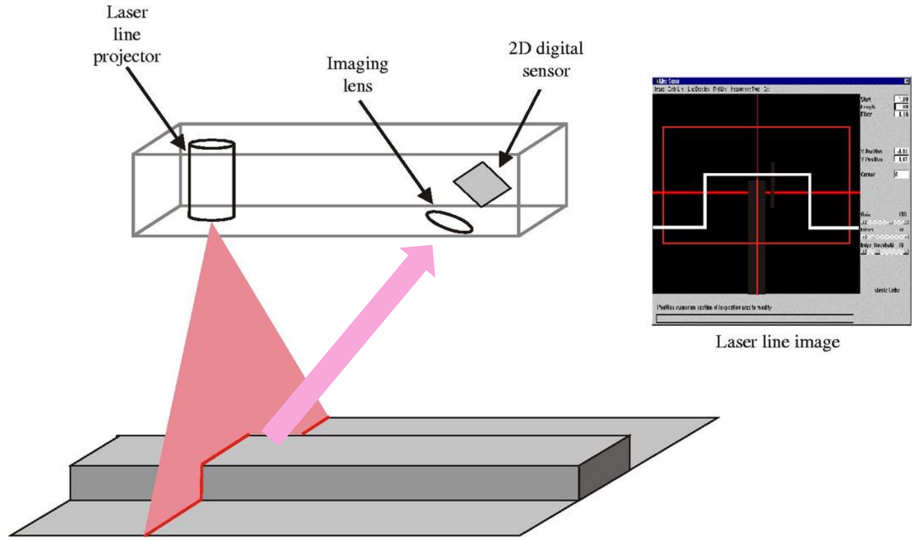
LINE SENSORS

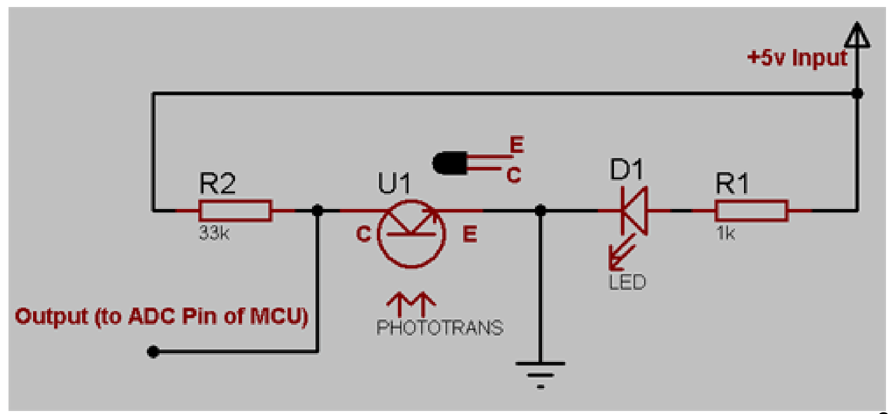


- The Navidroid include an infrared light sensor and an infrared LED
- The LED illuminates the surface and the light sensor picks up the infrared radiation
- Light-colored surface will reflect more light than dark surface
- Therefore a dark line in a pale surface or a pale line in a dark surface can be detected

LINE SENSORS

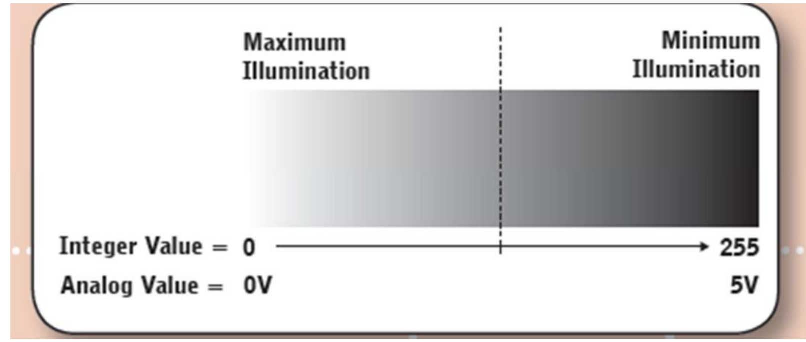




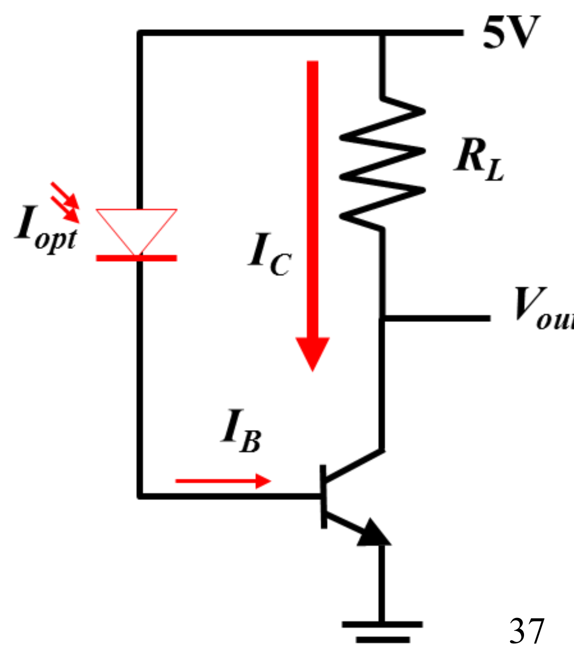


SENSOR OUTPUT

- The sensor output will be around 0 V when the surface is pale or highly reflective

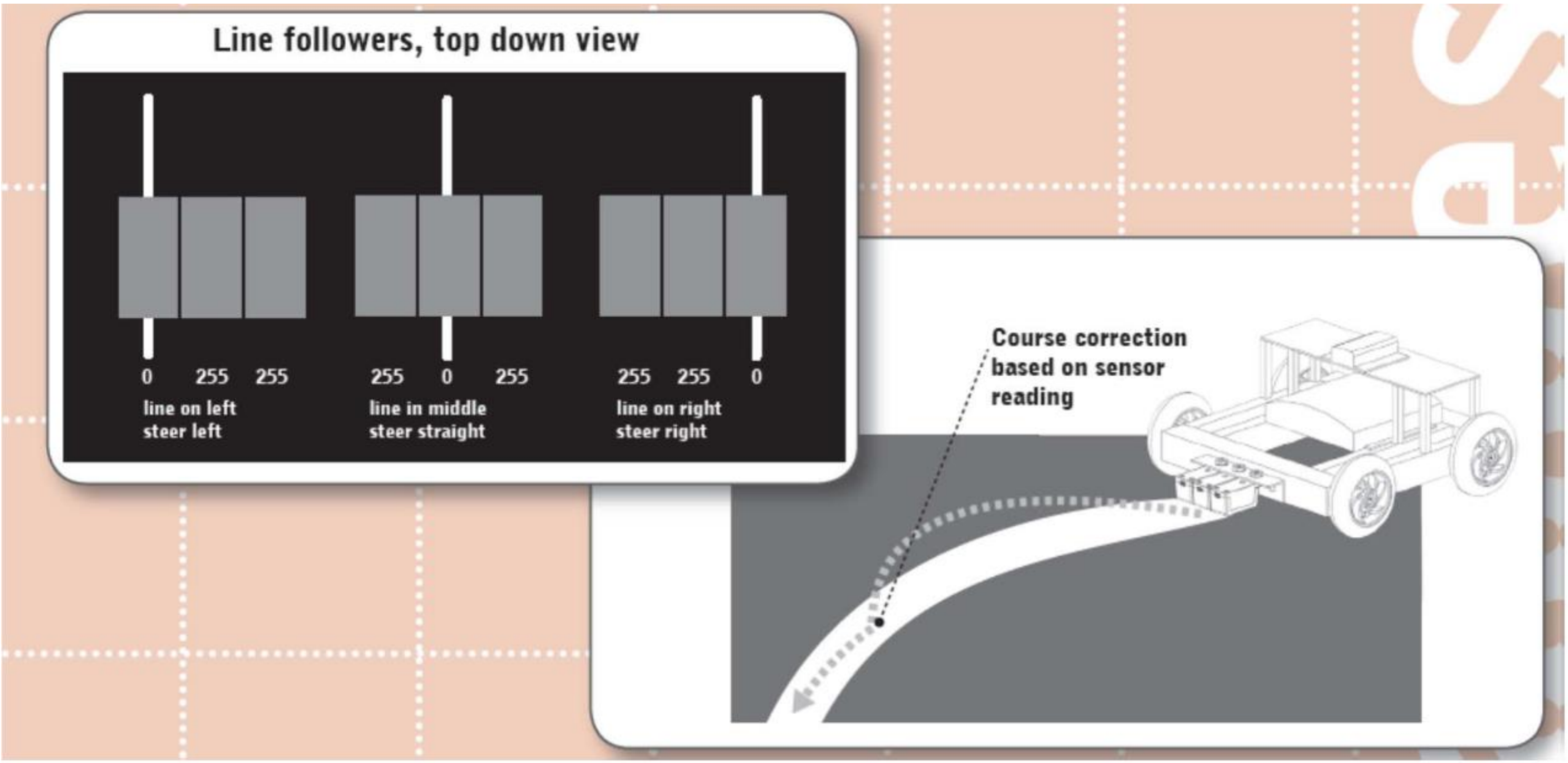


- When the reflected light is lower than a certain reference value, the output will be close to 5V
- By adjusting the reference value, you will be able to distinguish a pale or a dark surface

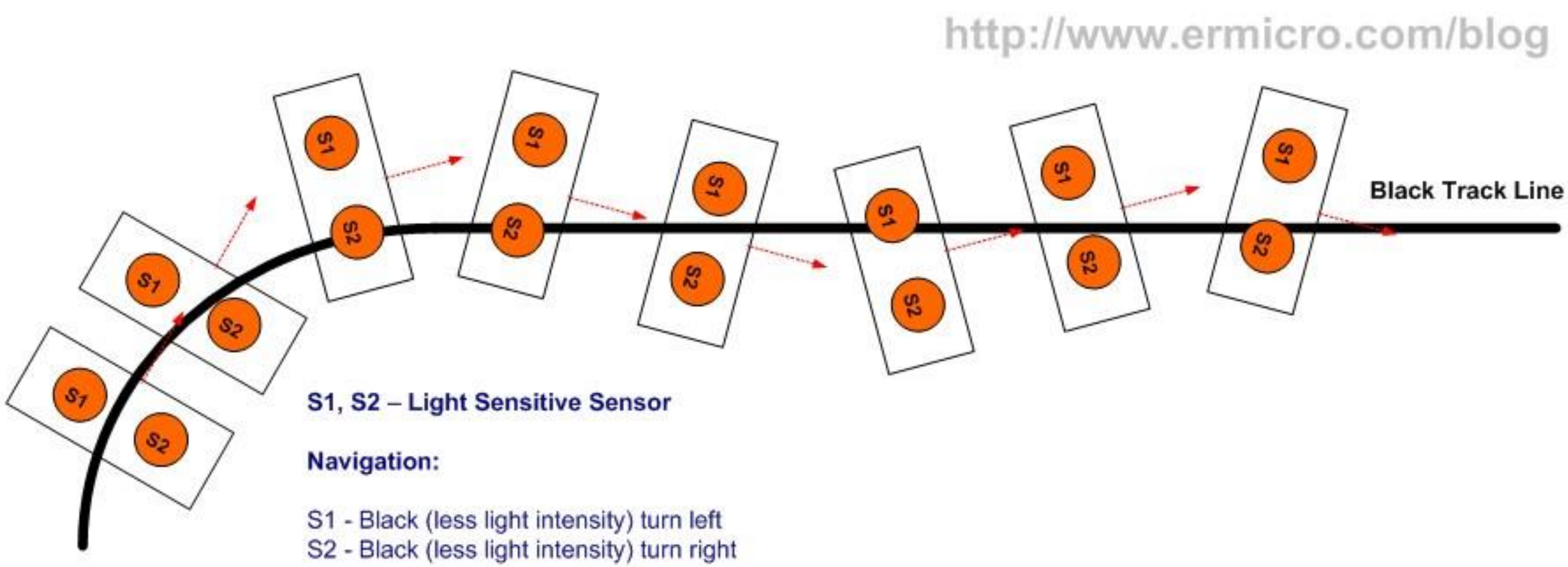


LINE SENSORS IN YOUR ROBOT

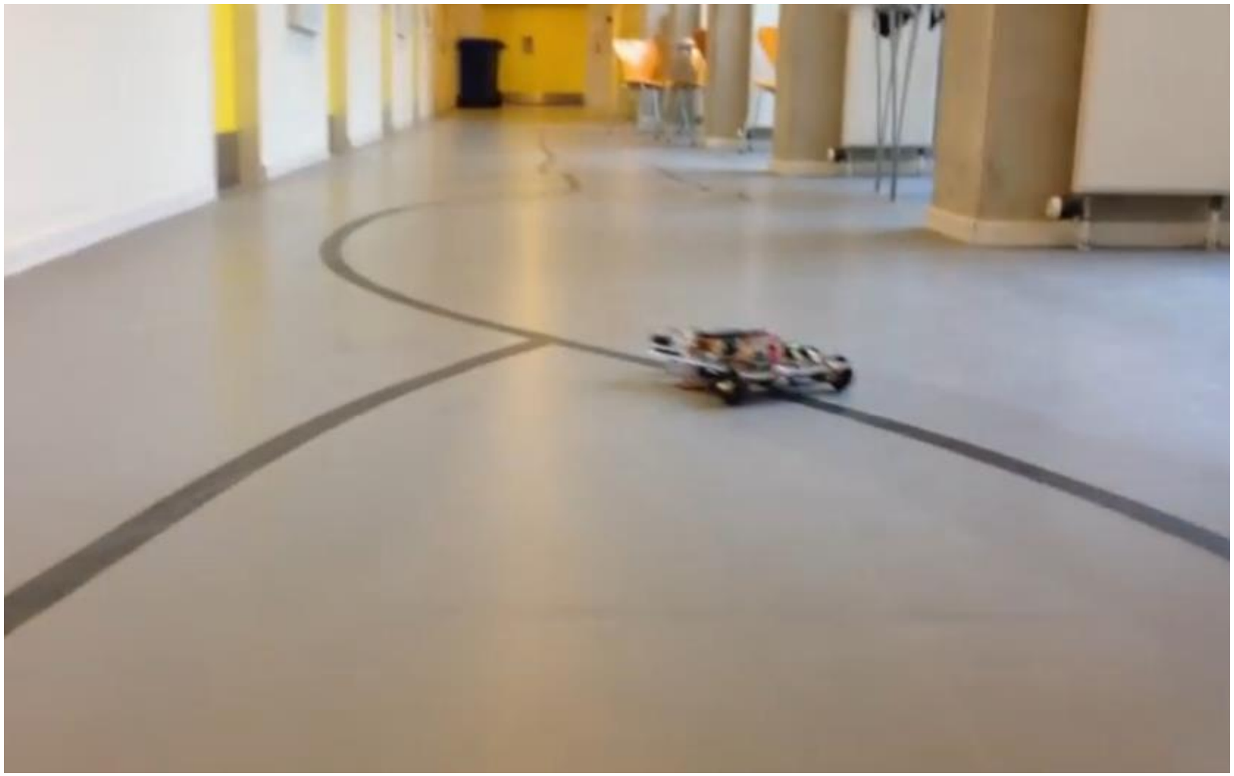
- Option 1: Three line sensors are used together



- Option 2: Two line sensors are used together



Example of Line tracking navigation on the Line Follower Robot (LFR)



https://www.youtube.com/watch?v=Cf-V-giXiRw

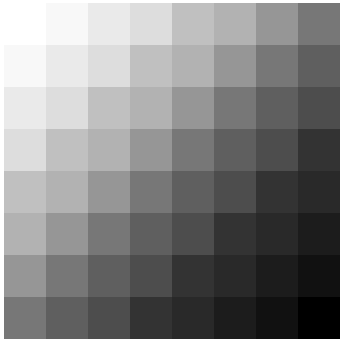
ANALOG AND DIGITAL REPRESENTATION OF CURRENT

- After sensor detects the signal, it has to be represented and stored some where

Analog representation

Stored as voltage or current value

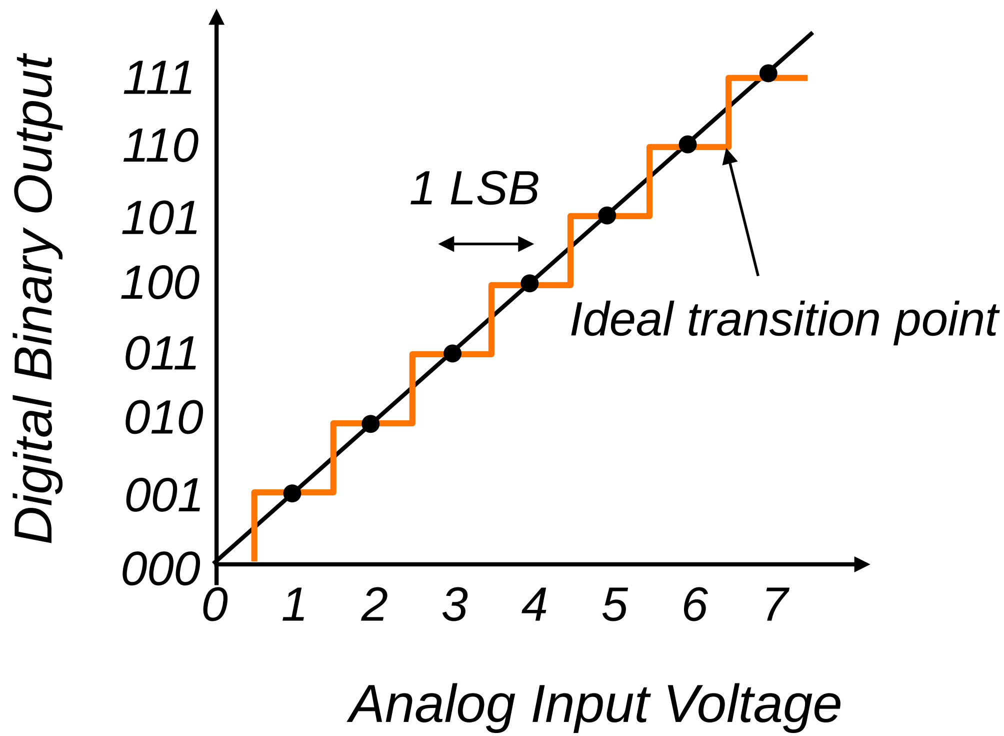
Digital representation



Stored as pulses or numbers

- Some data loss in digital representation, but more easy to store and duplicate

❖ Converting a voltage level to binary number and store as 1/0

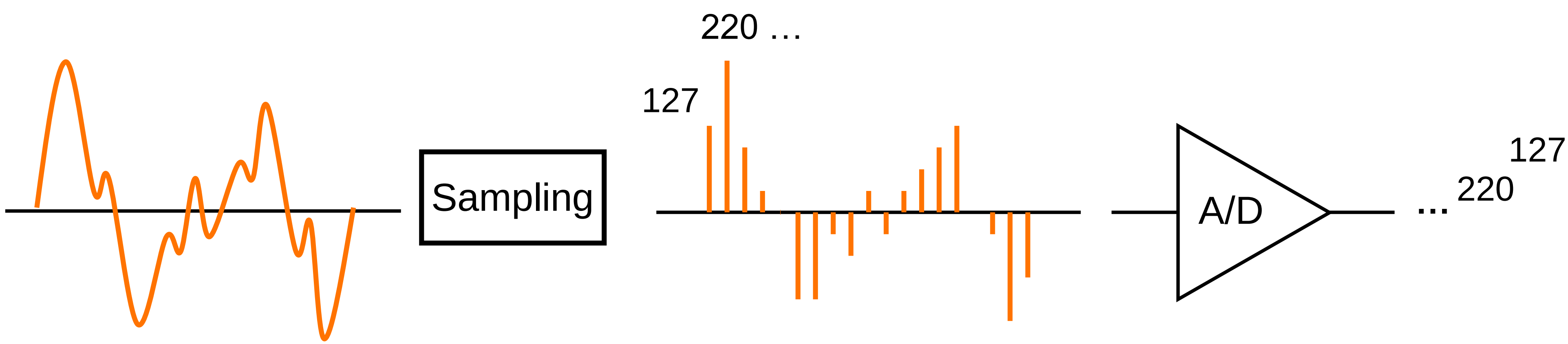


LSB = Least Significant Bit

$$1\ LSB = \frac{\text{maximum voltage range}}{\text{number of binary levels}}$$

- The smaller the LSB, the more accurate the conversion and the smaller the quantization error

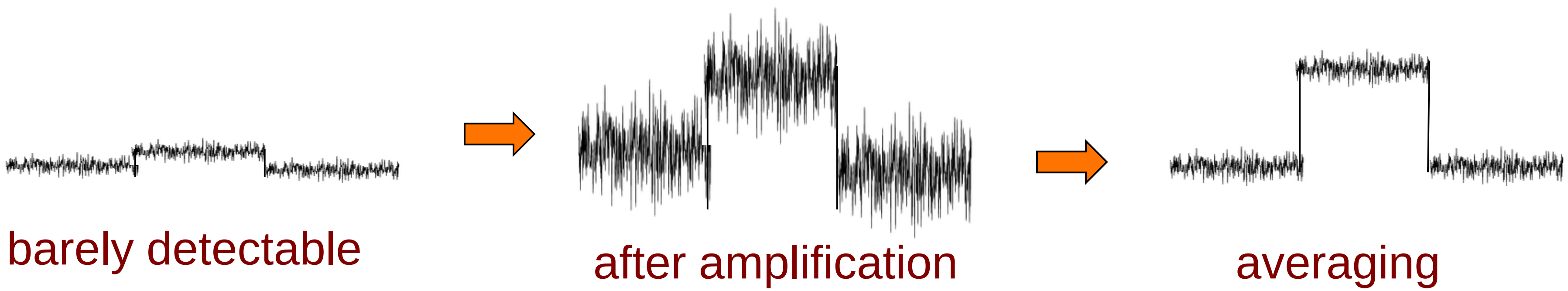
- Actual A/D process involve sampling, which represents the time domain resolution of the analog signal



- The more often you sample, the more accurate the data, but the more storage space required
- For example, CD music is sampled at 44.1kHz

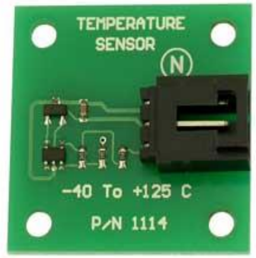
SIGNAL LEVEL AND NOISE

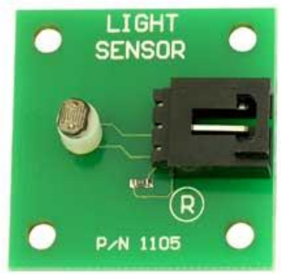
- Signal coming out directly from a sensor is usually very small and need to be amplified
- All signals contain noise that set the minimum detectable level

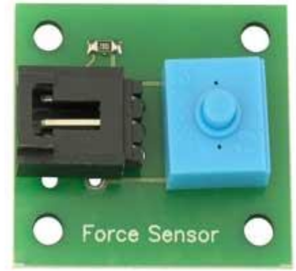


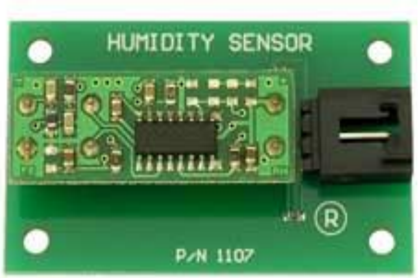
- Most signal from the sensor needs to be amplified
- For example, your line sensor composed of a sensor and a switch

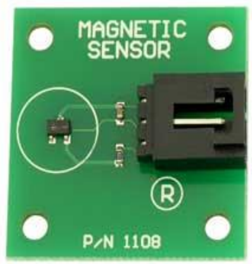
SUMMARY

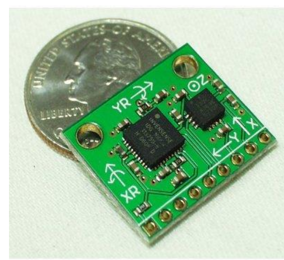


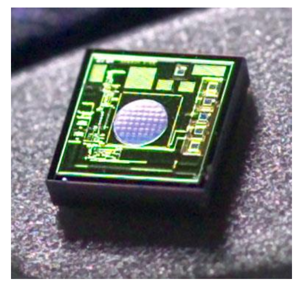









accelerometer


microphone


chemical sensor

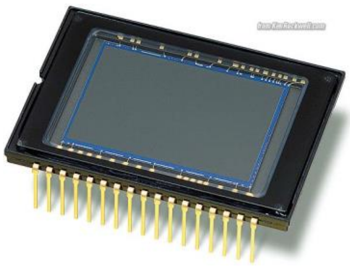
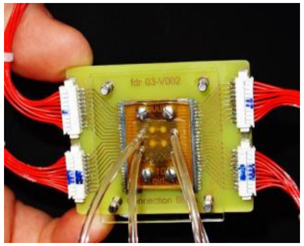


image sensor


biosensor


gyroscope

- Sensor signal is usually very small and need to be amplified
- Analog data is converted to digital data through sampling and A/D conversion
- After A/D, sensor data are digitally represented and stored

NEXT LECTURE

- Logics
- K-map
- Midterm Review

Questions ?!