ELEC 1100: Introduction to Electro-Robot Design

Lecture 2: DC Power Sources + Pulse Generation + PWM Control

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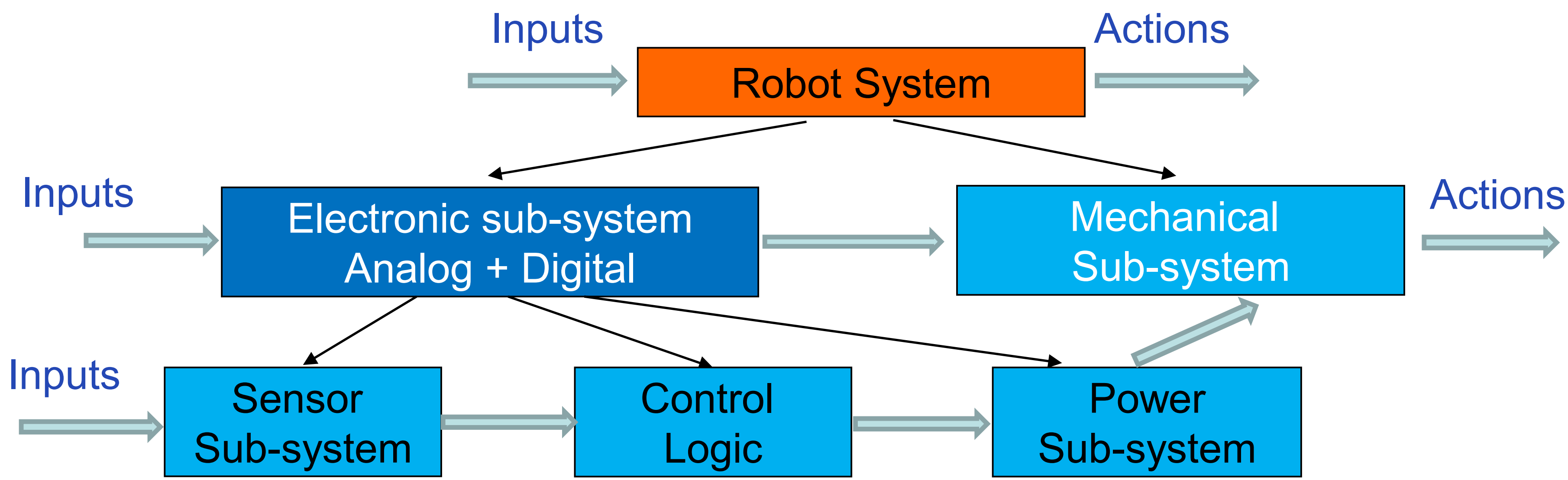
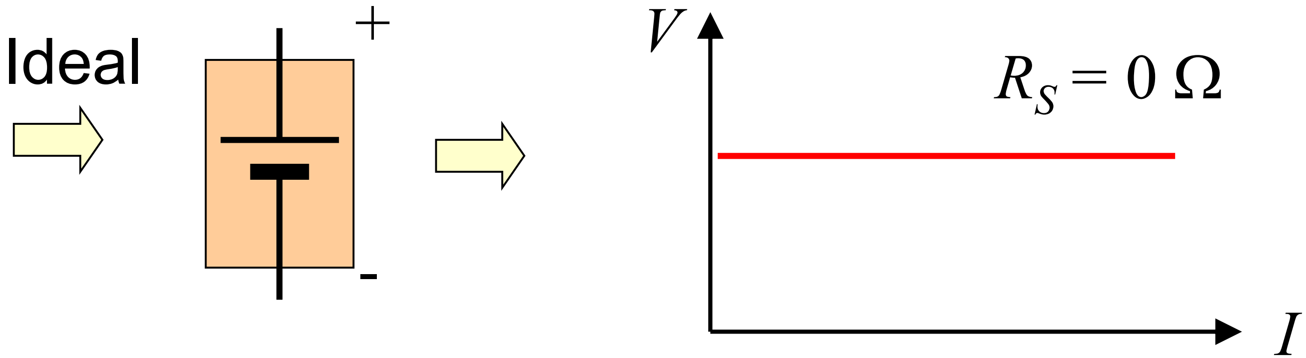
ELEC1100 ROADMAP

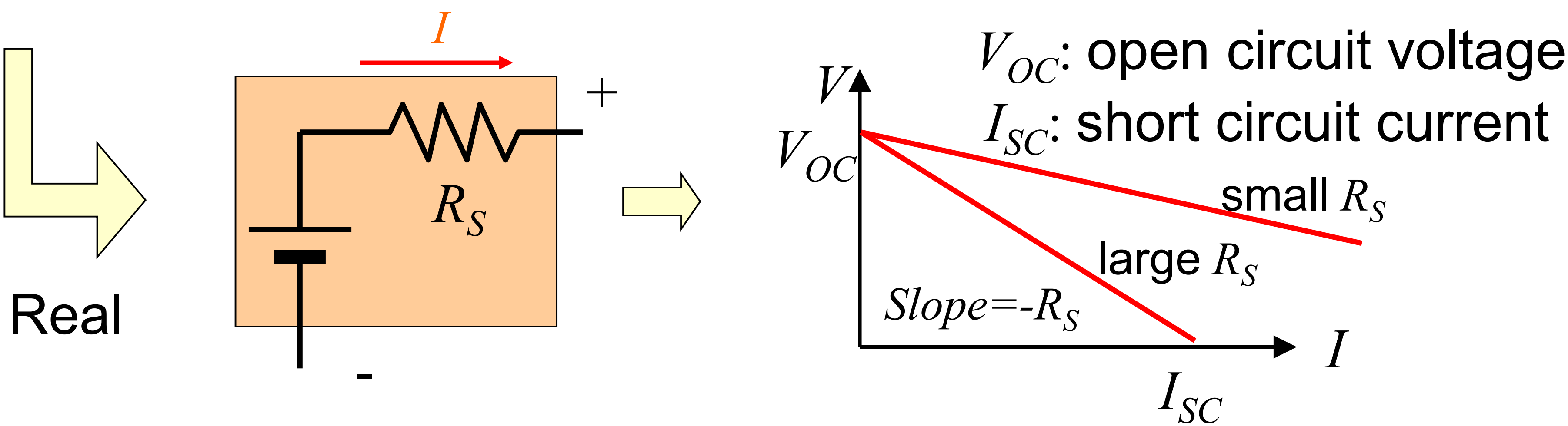


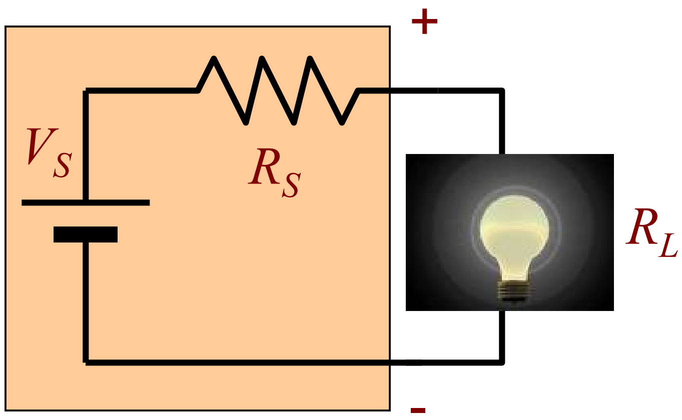
Basic electronics:
Wk1: Basic Electronics & DC Sources

Motor Power Supply:
Wk1: Pulse Signal & PWM Control

IDEAL AND NON-IDEAL BATTERY



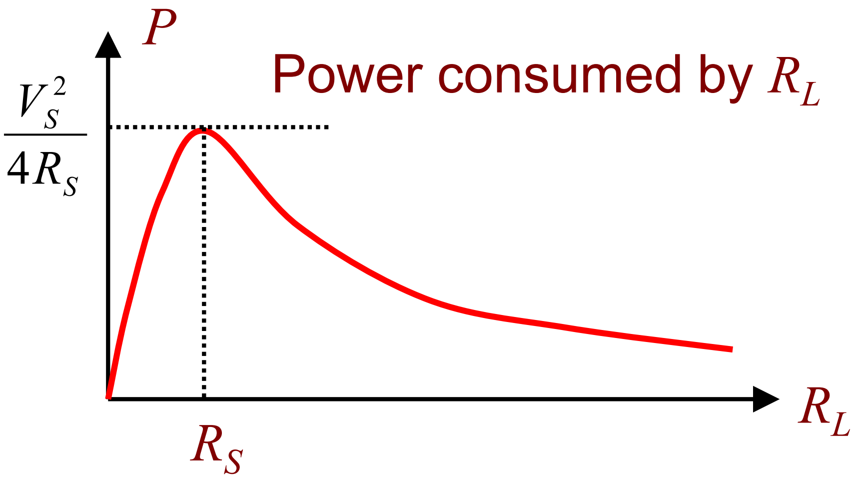


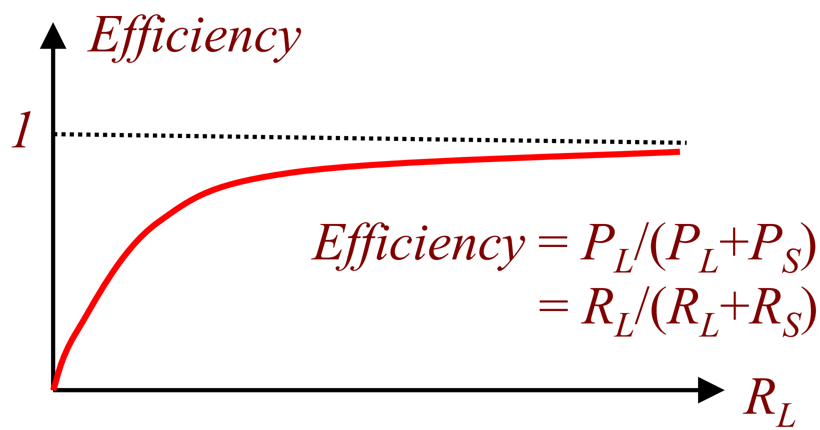


Current through the circuit = $\dfrac{V_S}{R_S + R_L}$

Power consumed by R_L = P_L = $R_L\left(\dfrac{V_S}{R_S + R_L}\right)^2$

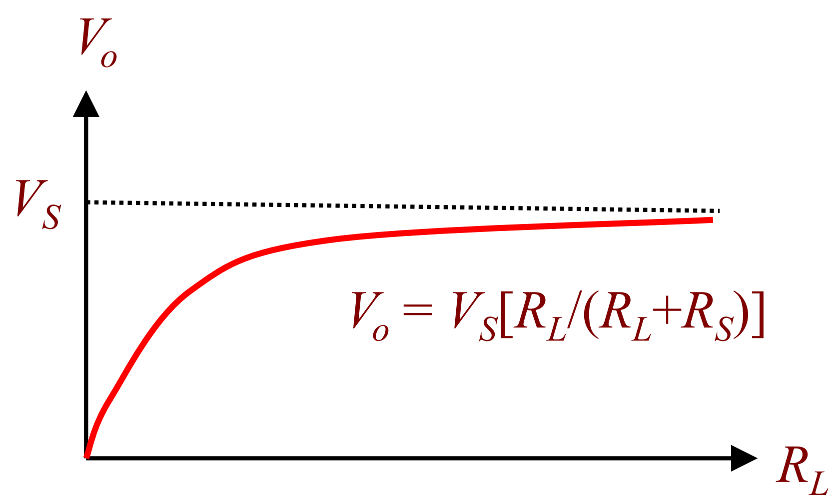
Power consumed by R_S = P_S = $R_S\left(\dfrac{V_S}{R_S + R_L}\right)^2$





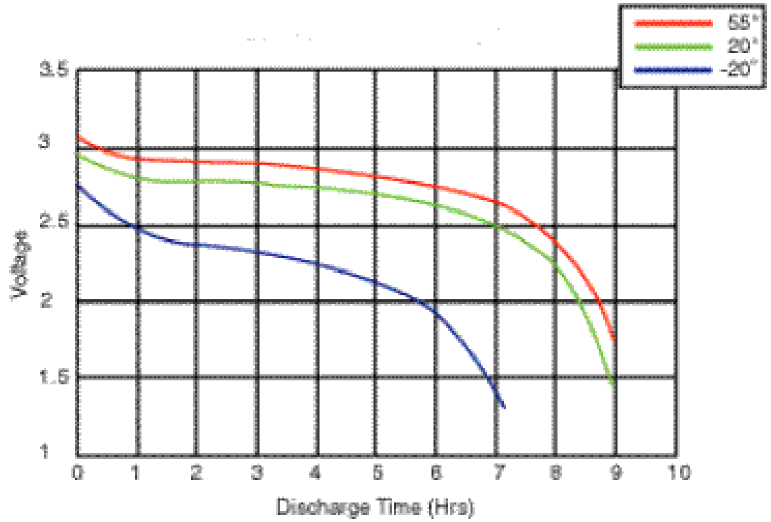
POWER EFFICIENCY - INTERPRETATION

- Observation
  - maximum deliverable power = $\dfrac{V_S^2}{4R_S}$
  - occurs when $R_L = R_S$
- Exercise: sketch the output voltage versus R_L
- Answer:



BATTERY CHARACTERISTICS

- Battery voltage is not constant



Li battery characteristics at different temperature versus time

- Need to stabilize the voltage to provide predictable performance

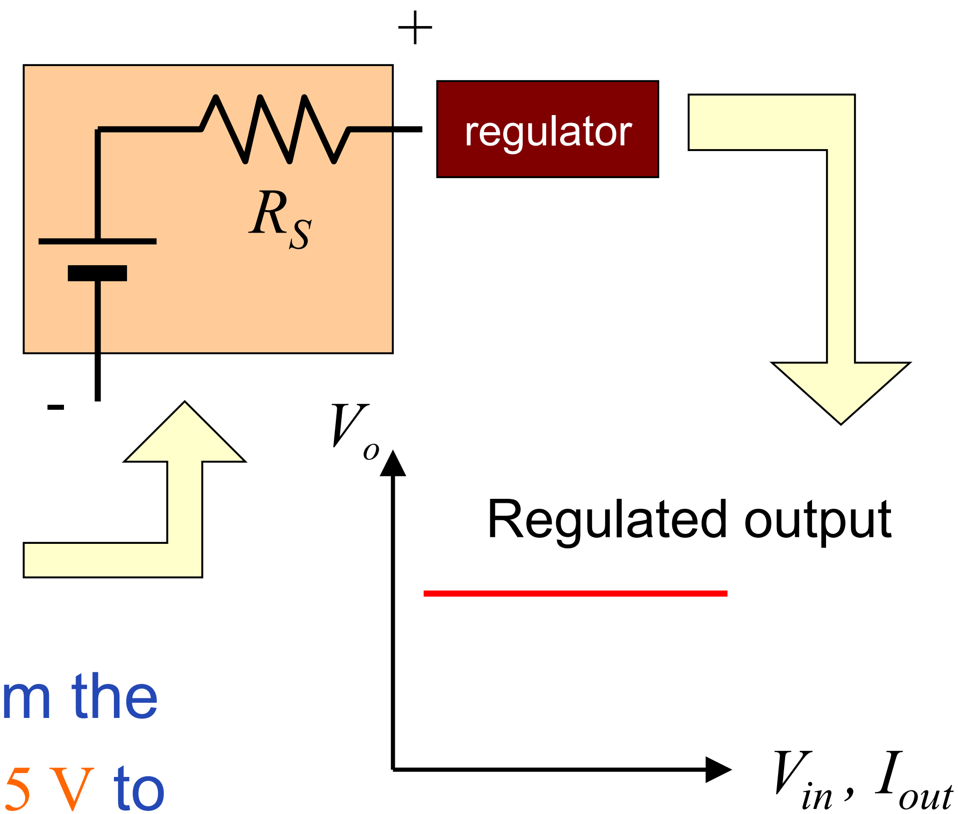
BATTERY TYPES

Primary Battery	Voltage	Energy (MJ/kg)	Remarks
Zinc chloride/carbon	1.5V	0.13	Inexpensive
Alkaline	1.5V	0.4-0.59	Most commonly used
Silver oxide	1.55V	0.47	Very expensive, only used in button cells
Lithium manganese dioxide	3.0V	0.83-1.01	Expensive and slow discharge For high drain usage only
Mercury oxide	1.35V	0.5	Constant voltage, but banned in most countries because of health concerns

Rechargeable	Voltage	Energy (MJ/kg)	Remarks
NiCd	1.2V	0.14	Inexpensive, but with “memory” effect
Lead–acid	2.1V	0.14	High discharge rate and environmental hazard
NiMH	1.2V	0.36	Heavy and high discharge rate
NiZn	1.6V	0.36	Newly introduced in 2009 and limited size only
Lithium ion	3.6V	0.46	Low discharge and volatile (explode if short circuit)

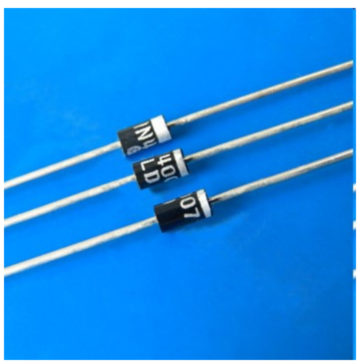
REGULATED OUTPUT

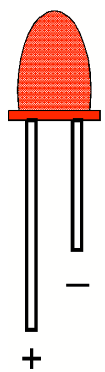
- Most battery-operated systems need a regulator to provide a constant voltage
- Regulators can also provide different voltages to different parts of a system
- Example: you will use 12 V from the battery to drive the motor and 5 V to drive the remaining circuits

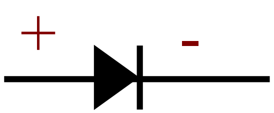


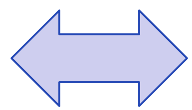
DIODE

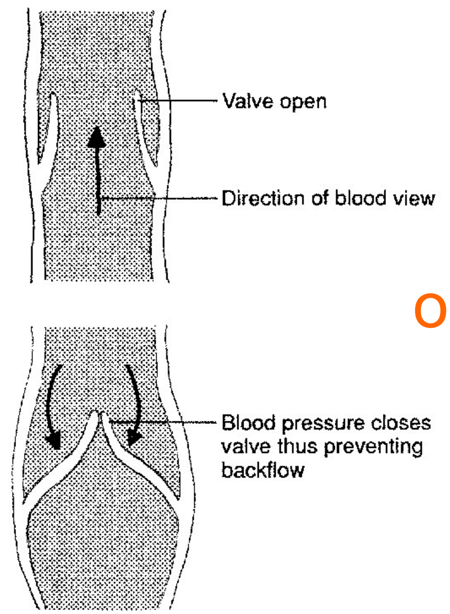
- A diode is a device that only allows current to flow in one direction (e.g. LED)
- Symbol and characteristics



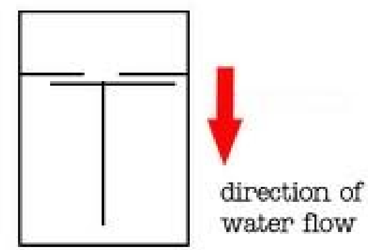




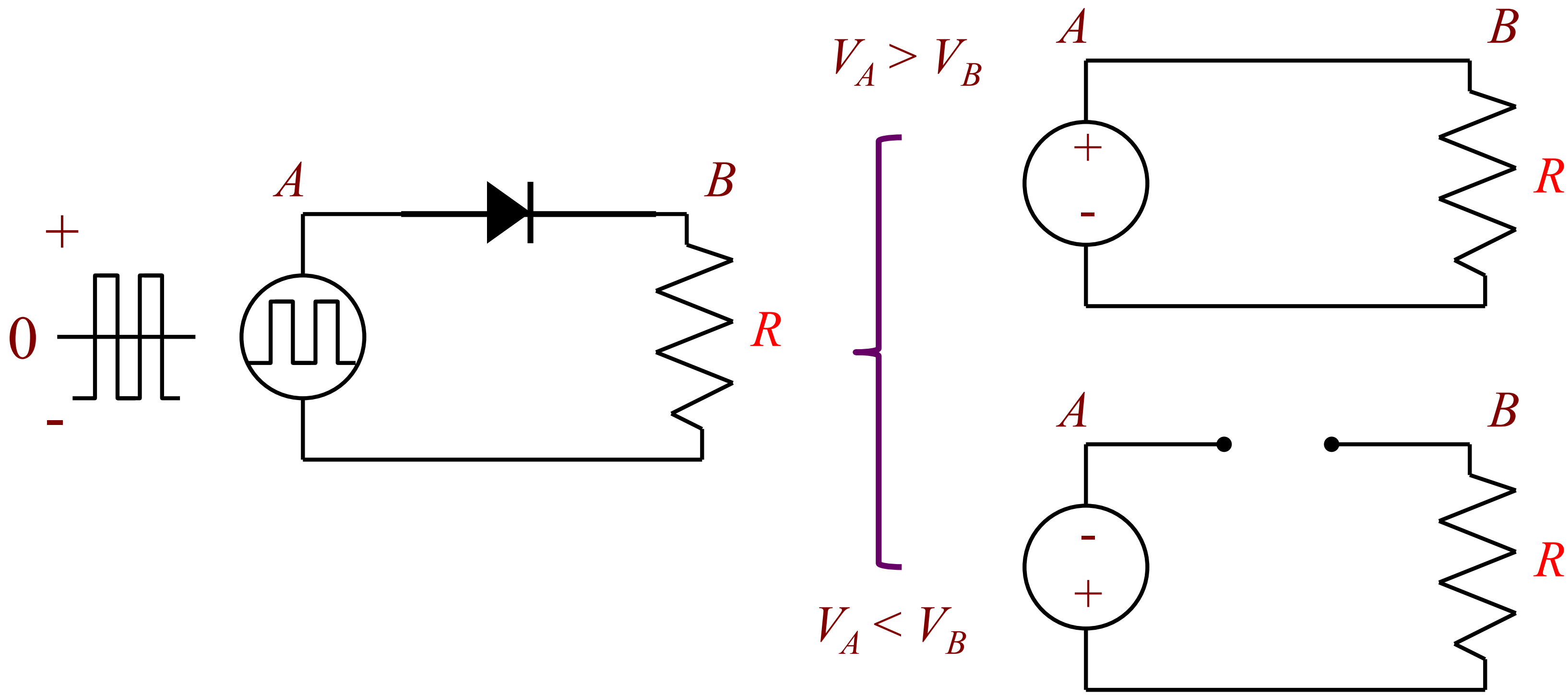




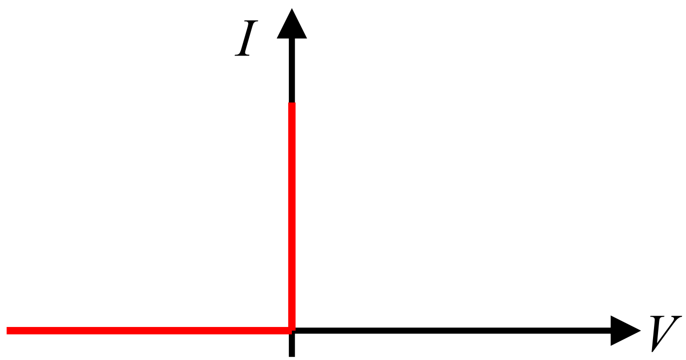
or

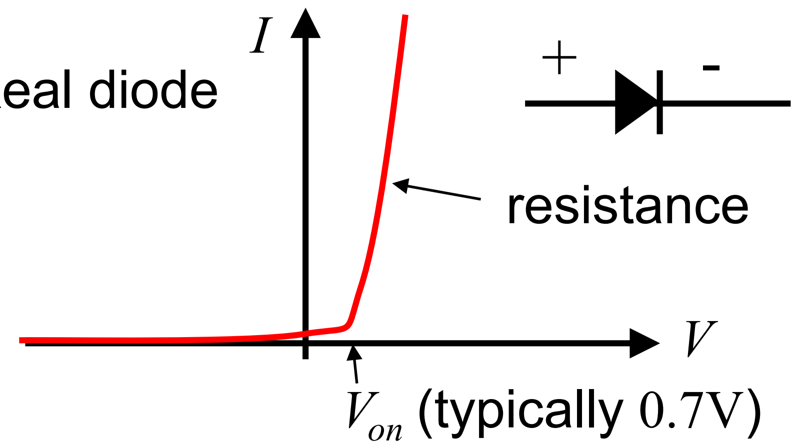


❖ A diode becomes a short circuit under forward bias and open circuit when reverse biased



❖ I-V characteristics of a typical diode



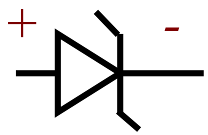


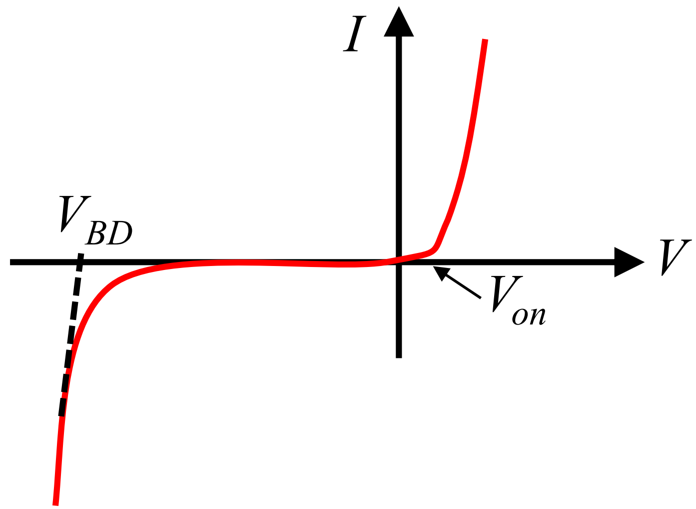
❖ At reverse voltage, current is zero (no current)

❖ At forward voltage, current is infinite (or any current)

- Similar to a diode, but it also allows current to flow when reverse voltage is larger than a certain value

- Symbol and characteristics



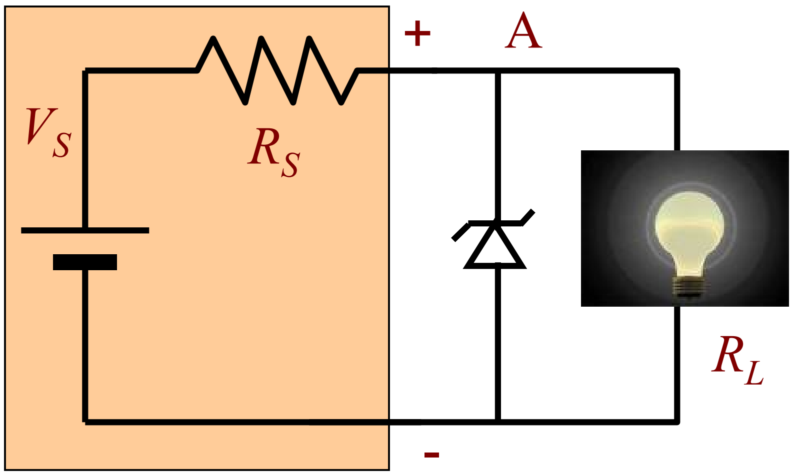


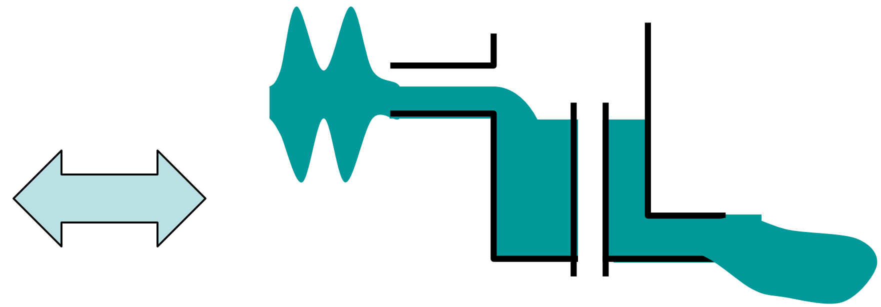
- Allow conduction when $V < V_{BD}$ or $V > V_{on}$

- Typical value $V_{BD} = -5.7$ V or $V_{on} = 0.7$ V

CONNECTING A ZENER DIODE

❖ Circuit construction with Zener diodes

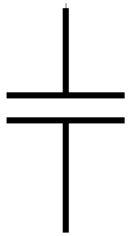




❖ When $V_A > |V_{BD}|$, the Zener diode becomes a short circuit to protect, clamp the voltage to V_{BD}

❖ Problem: power waste

- A capacitor is a charge storage element

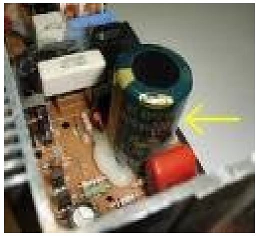


symbol

polyester film capacitor

ceramic capacitor

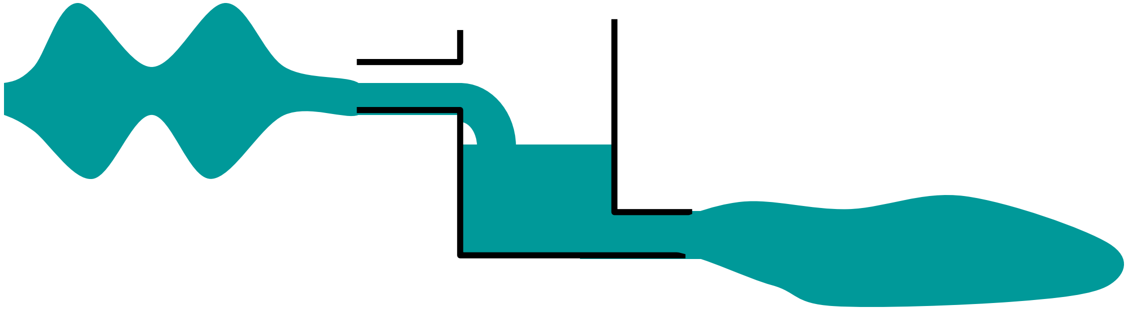
electrolytic capacitor



in circuit board

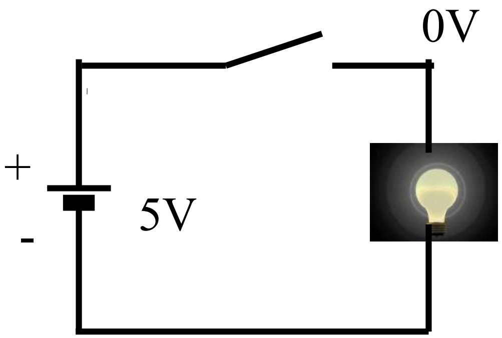
- Analogy

Pool

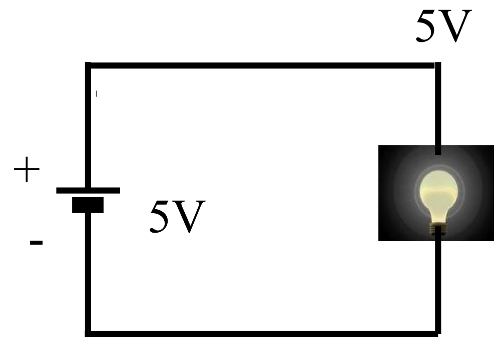


CAPACITOR ACTIONS

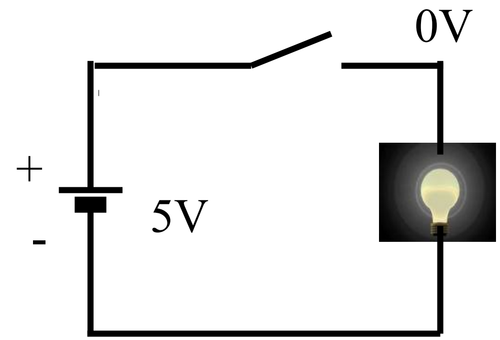
- Without capacitor



Switch is off; lamp is off

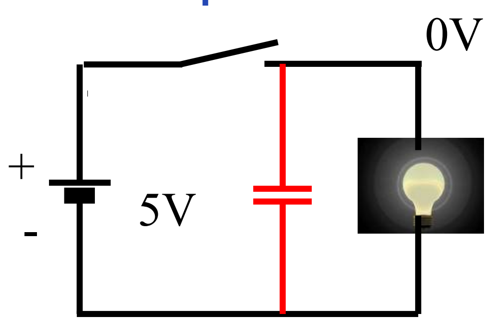


Switch is on; lamp is on

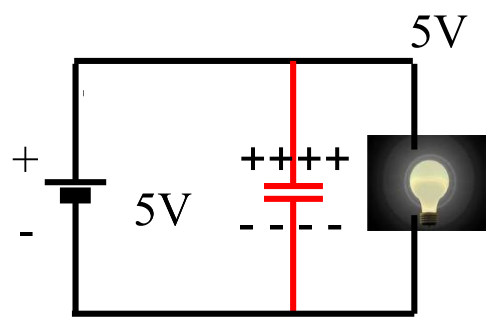


Switch is off; lamp is off

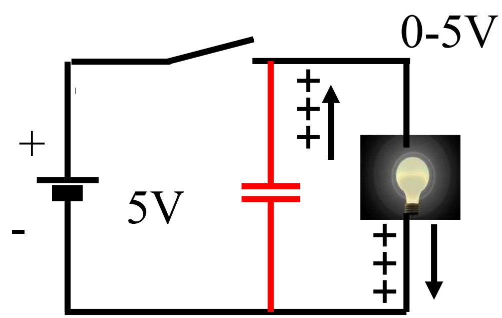
- With capacitor



Lamp is off; capacitor is electrically neutral



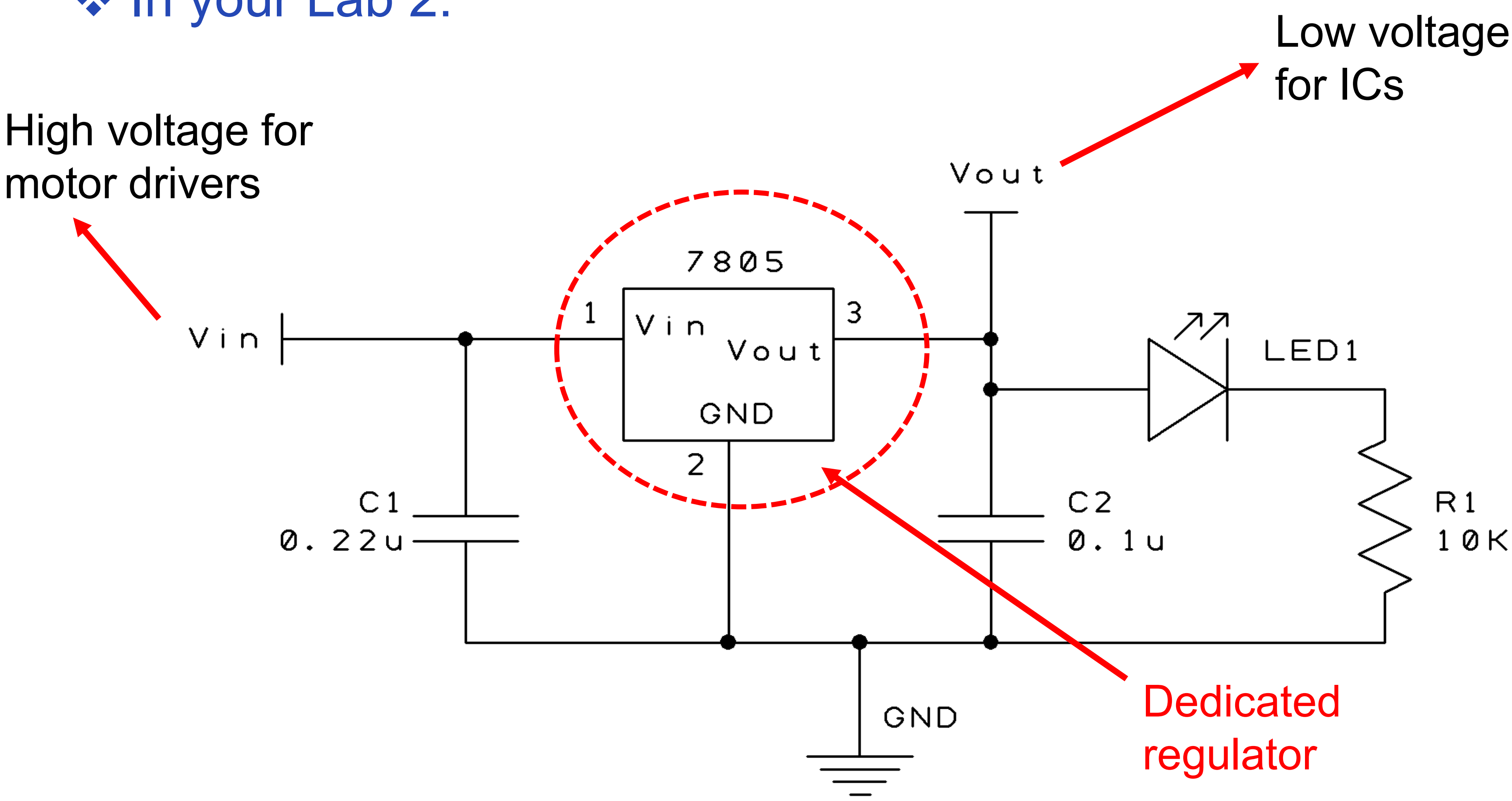
Lamp is on; capacitor is charged



Lamp keeps on for a while; capacitor is discharged

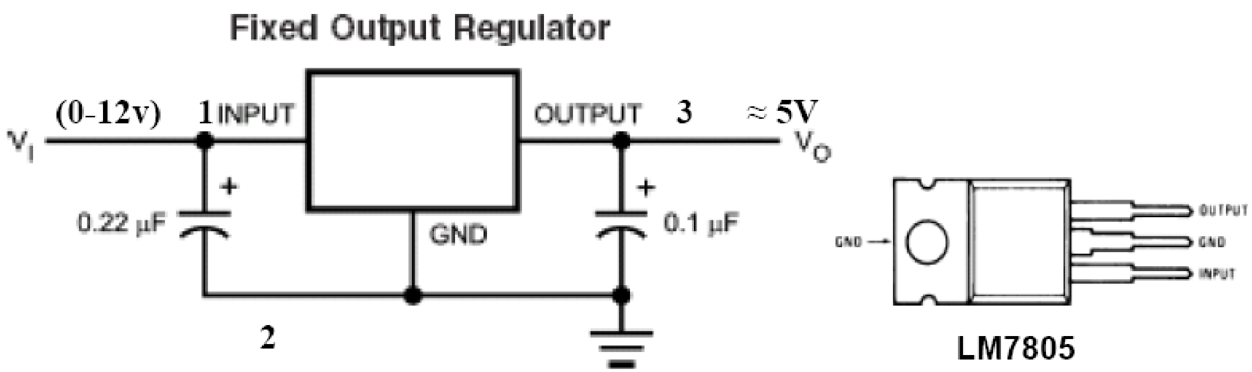
DEDICATED VOLTAGE REGULATOR

❖ In your Lab 2:



LM7805

- It is the Integrated Circuit (IC) to be used in your lab



- No need to understand the internal circuit (as you need to take more advanced courses)
- Only IC Function knowledge is needed
- A capacitor is commonly used to stabilize the input

MEASURE OF A REGULATOR PERFORMANCE

- Line regulation
  - It measures how stable the output voltage is with respect to the change of the input voltage

$$\text{Line regulation} = \frac{\Delta V_O}{\Delta V_I}$$

  - Ideally, it is equal to zero
- Load regulation
  - It measures how stable the output voltage is with respect to the change of output current

$$\text{Load regulation} = \frac{\Delta V_O}{\Delta I_O}$$

  - Ideally, it is equal to zero

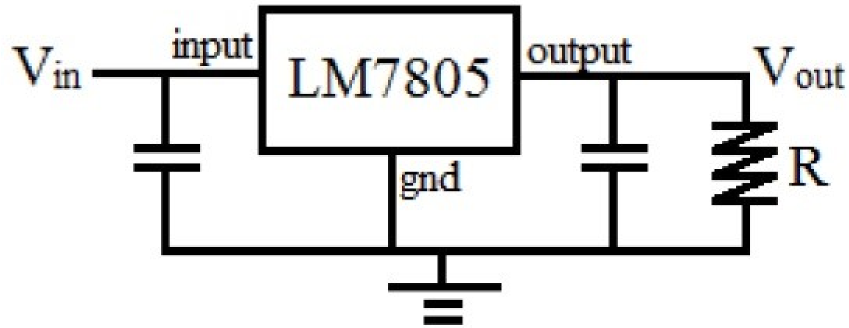
MEASURE OF A REGULATOR PERFORMANCE

❖ Example:

$7V \le V_{in} \le 25V$,

when $V_{in} = 7V$, $V_{out} = 4.9976V$;
when $V_{in} = 25V$, $V_{out} = 5.0016V$.

What's the Line regulation?

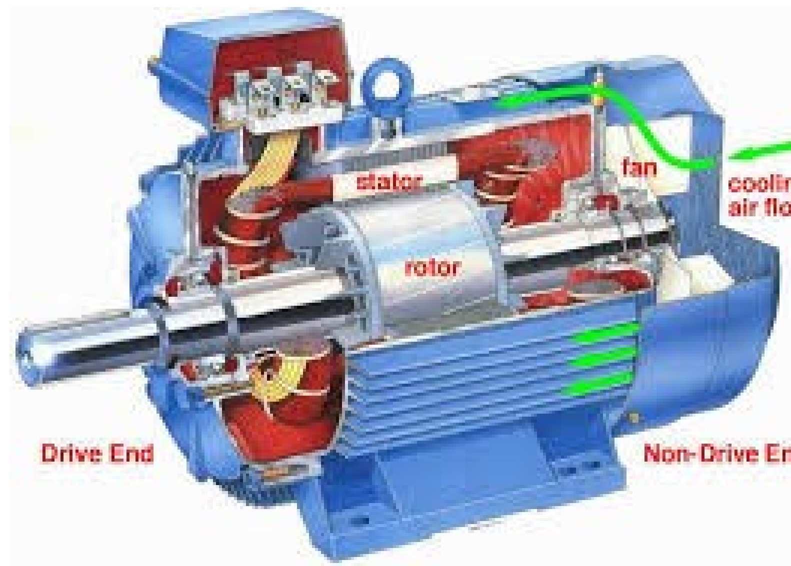


$$\text{Line regulation} = \frac{\Delta V_O}{\Delta V_I}$$

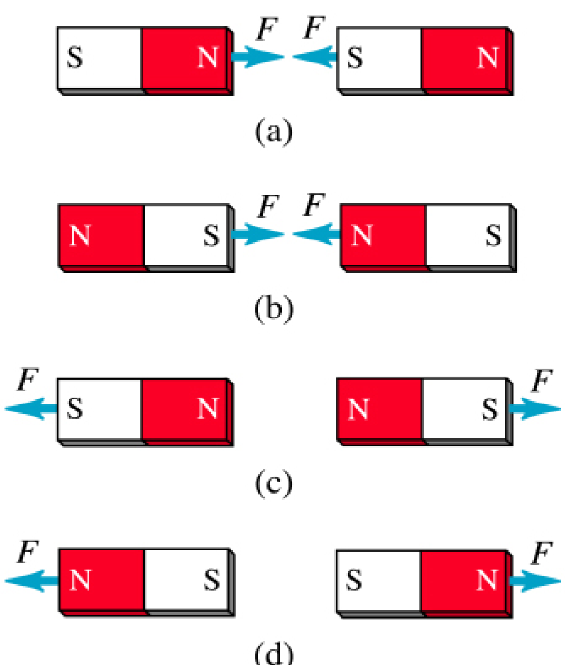
$$= \frac{5.0016 - 4.9976}{25 - 7} = \frac{0.004}{18} \cong 0.00022$$

WHAT ARE MOTORS?

- A motor is an electric-mechanical device, converting electricity to mechanical motion
- A revised energy conversion leads to a generator



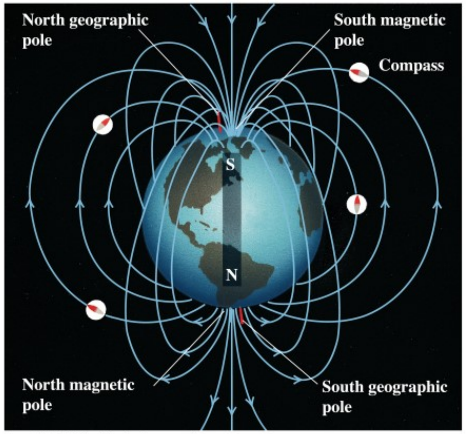
- A magnet has two poles: south and north
- Like poles repel, and opposite poles attract

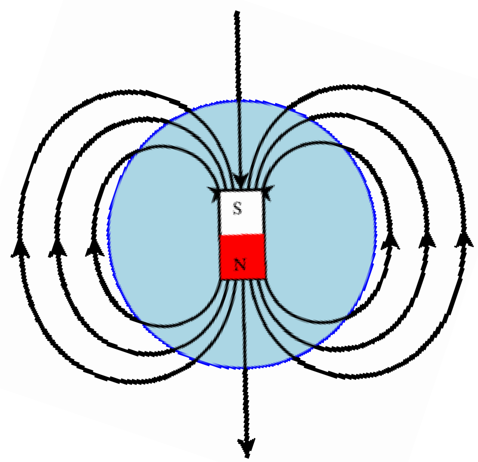


Magnetic poles always come in pairs

Magnetic monopoles are predicted to exists but with no experimental evidence yet

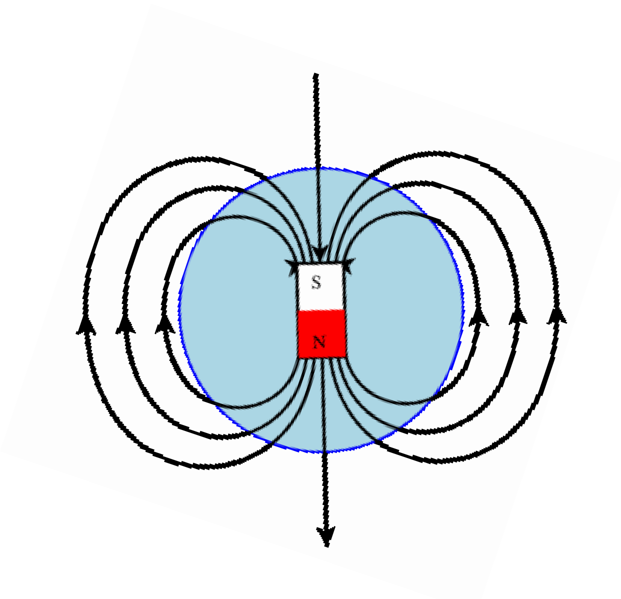
The Earth's magnetic field appears to come from a giant bar magnet, but with its south pole located up near the Earth's north pole

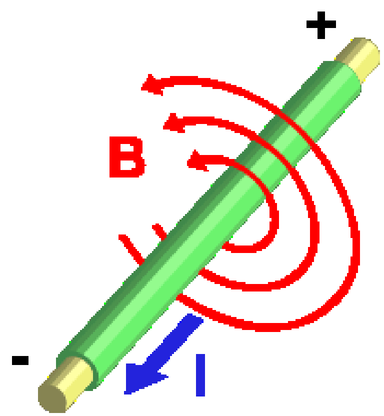


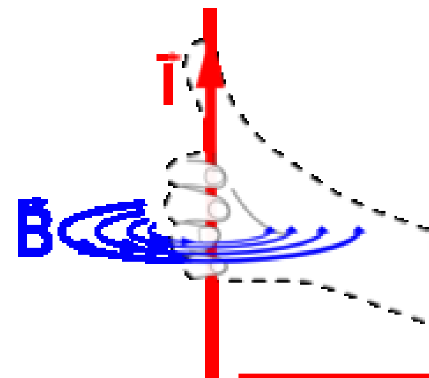


CURRENT AND MAGNETIC FIELD

- A magnet produces a magnetic field from N to S
- A current flow through a wire also creates or “induces” a magnetic field (denoted by B)
- Direction of a B-field can be found by the right-hand-rule

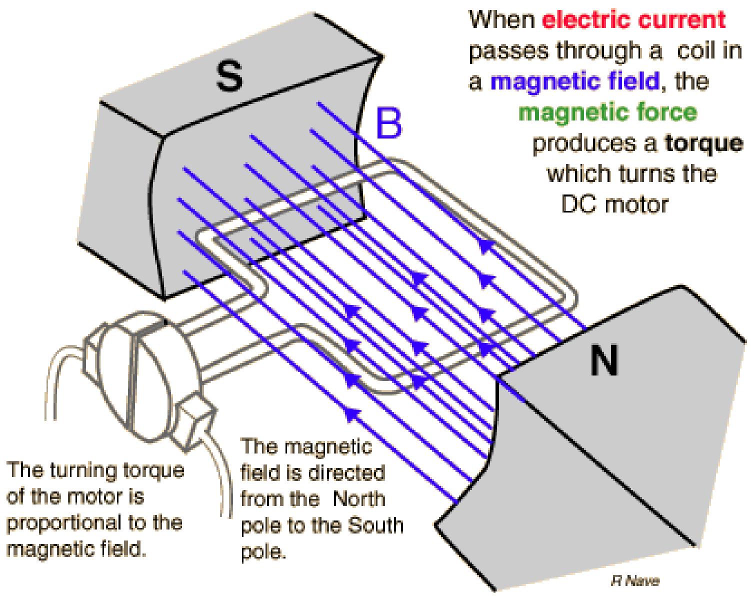


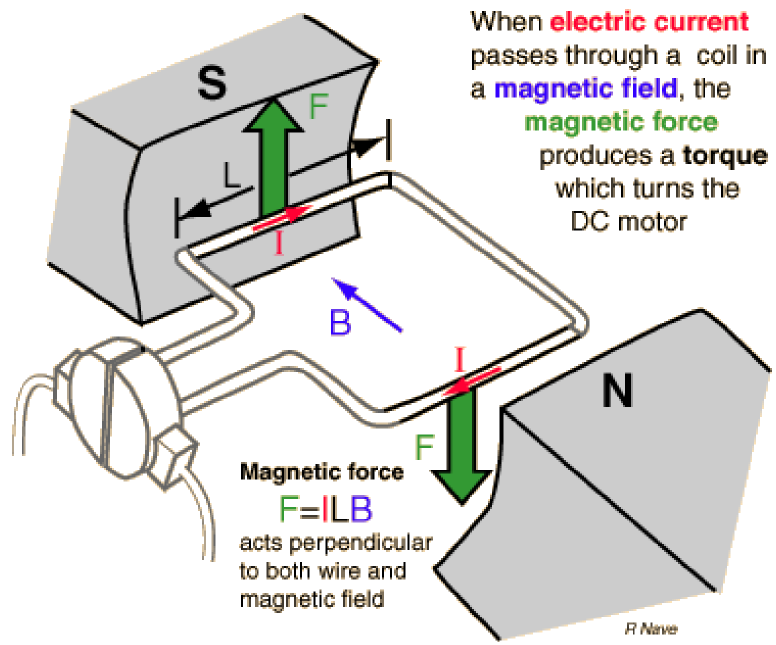




Right-Hand-Rule

- When a wire carrying an electric current (I) is placed in a magnetic field (B), the wire will experience the Lorentz force



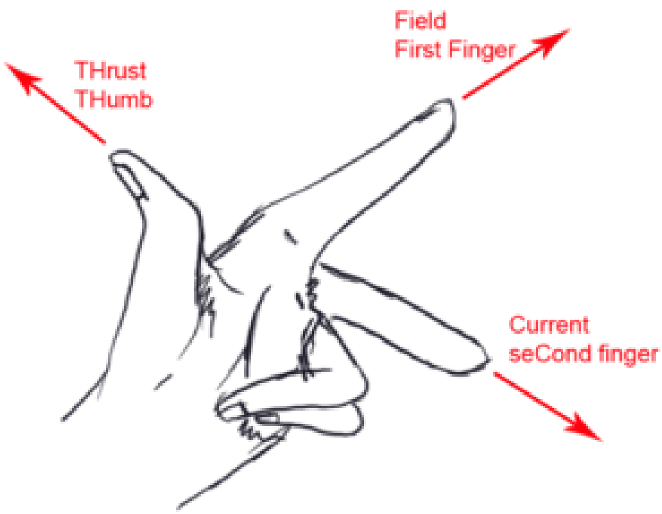


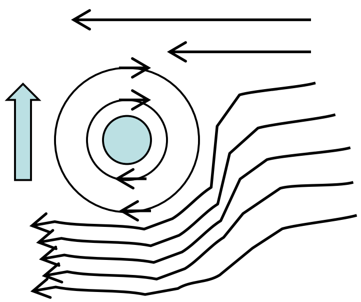
MAGNETIC FORCE TO A CURRENT CARRYING WIRE

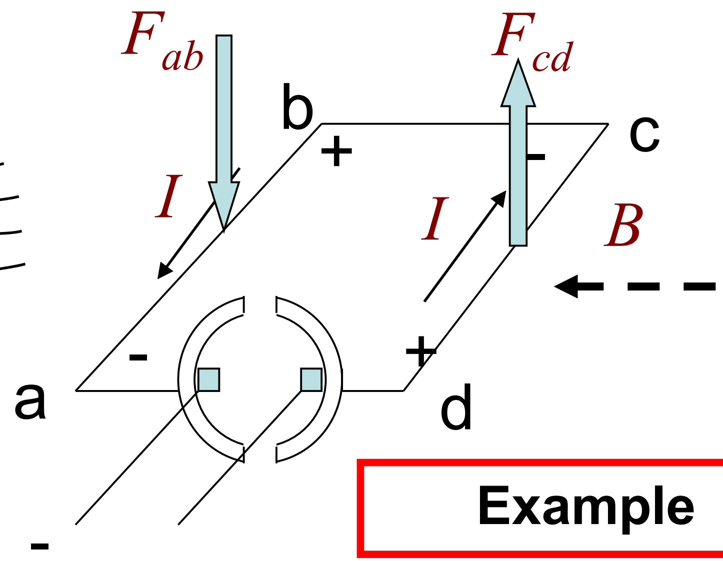
- Formula of the magnetic force on a current-carrying wire :

  $F = ILB$ (B : magnetic field L : wire Length I : current)

- Direction of the force can be determined by the Fleming's Left-Hand-Rule



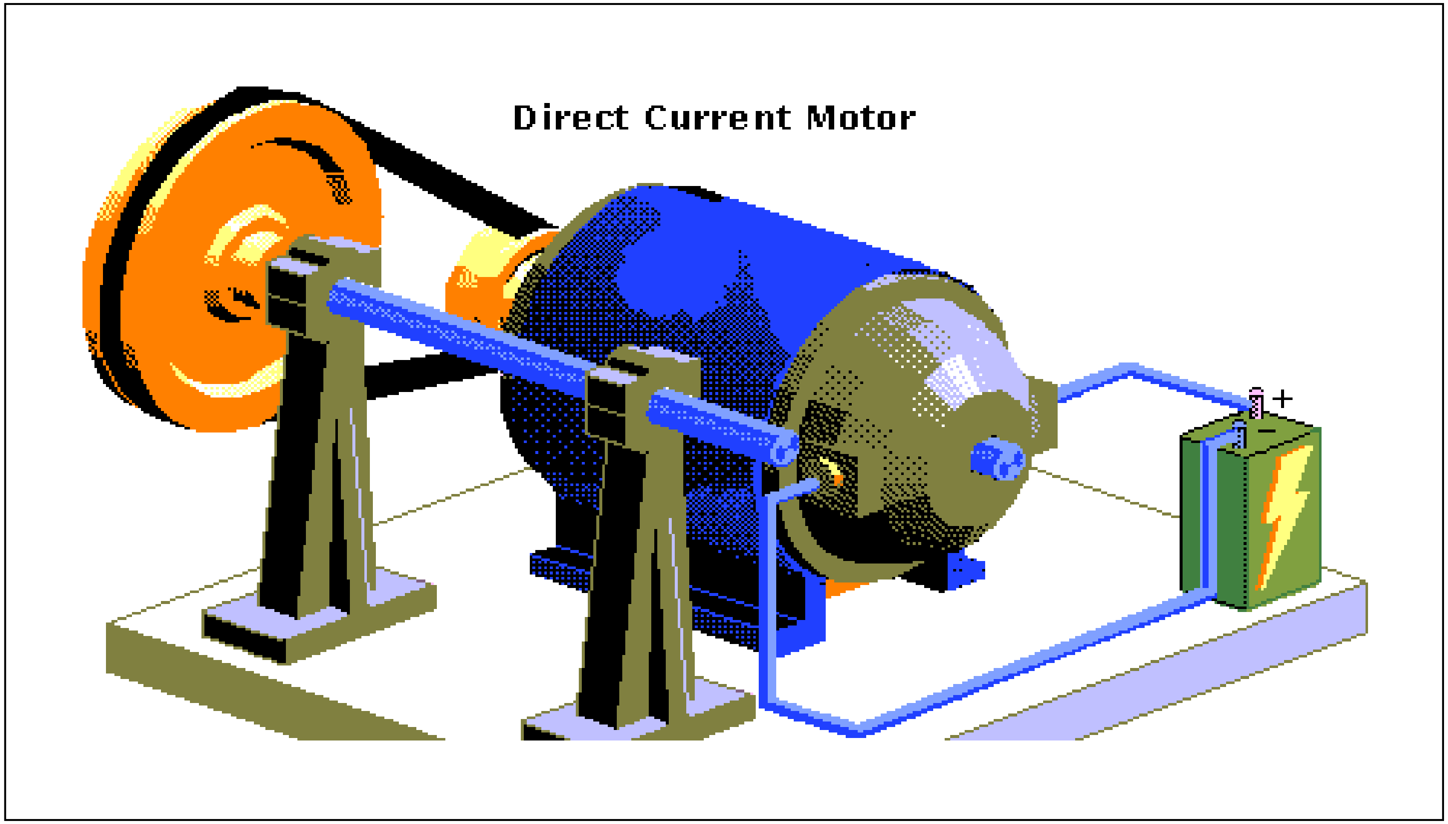




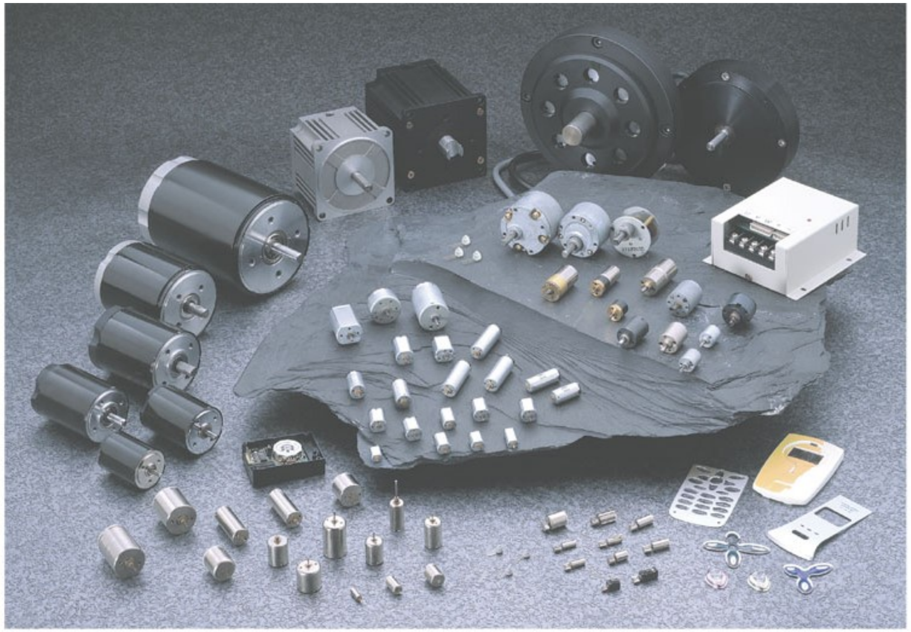
Example

ELECTRIC MOTOR

- **An electric motor uses electrical energy to produce mechanical energy**

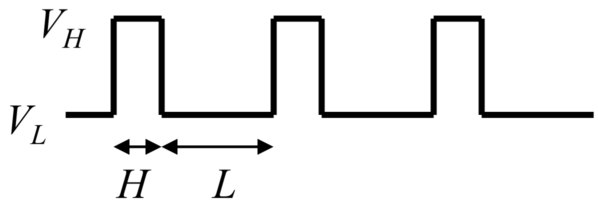


- Electric motor consists of two parts
  - Stator: composed of two permanent magnet poles
  - Rotor: composed of windings which are connected to a mechanical commutator
- Types of electric motors
  - Brushed DC motor
  - Brushless DC motor
  - Stepper DC motor
  - Micro motor
  - …



PULSE GENERATION

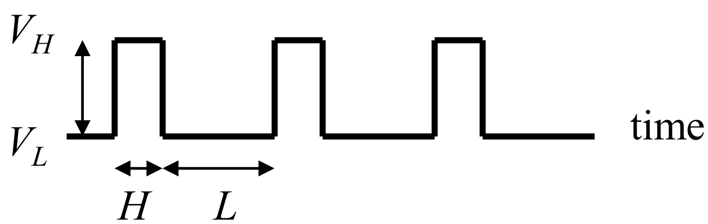
- Mobile robots usually have DC voltage as power source
- Pulse voltage signal also has many applications that will be described in later lectures
- Can we generate pulses with desired timing out of a DC power supply?



PULSE CHARACTERISTICS

❖ Definition of terms

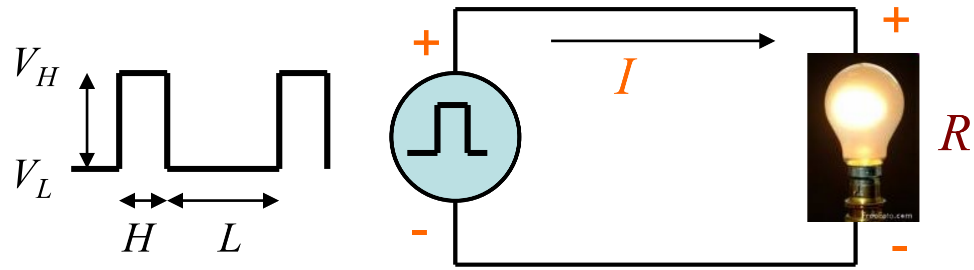
- A continuous well defined train of pulses sometimes also called a clock
- Clock high time = H
- Clock low time = L
- Clock period = $T = H + L$
- Frequency = $1/T$
- Duty cycle = H/T
- Pulse height = $V_H - V_L$



AVERAGE VOLTAGE

- If you use a pulse to drive a load, what is the result?
- Average voltage

$$V_{ave} = \frac{H}{H+L} V_H + \frac{L}{H+L} V_L$$



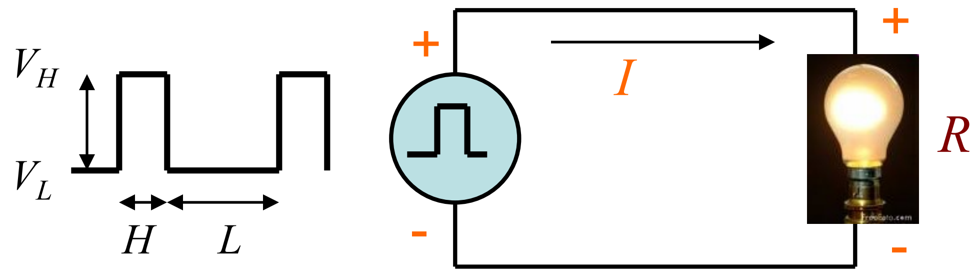
  - If $V_L = 0$, we have

$$V_{ave} = \frac{H}{H+L} V_H$$

- Is the brightness of the light equal to the circuit with the pulse voltage replaced by a battery with $V = V_{ave}$?

- Average Power

$$P_{ave}=\frac{H}{H+L}\frac{V_H^2}{R}+\frac{L}{H+L}\frac{V_L^2}{R}$$



- If the pulse voltage source is replaced by an equivalent DC voltage source with $V=V_{eq}$, we have:

$$P_{ave}=\frac{V_{eq}^2}{R}$$

- Equating the average power, we have

$$\frac{V_{eq}^2}{R}=\frac{H}{H+L}\frac{V_H^2}{R}+\frac{L}{H+L}\frac{V_L^2}{R}\Rightarrow V_{eq}=\sqrt{\frac{H}{H+L}V_H^2+\frac{L}{H+L}V_L^2}$$

or if $V_L=0$

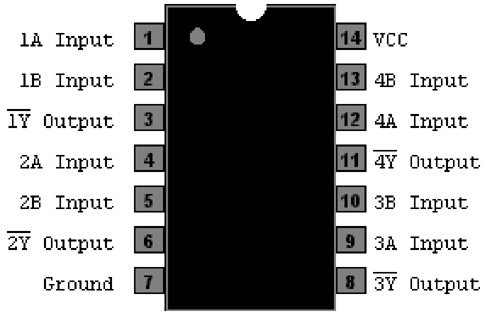
$$V_{eq}=\sqrt{\frac{H}{H+L}}V_H$$

INTEGRATED CIRCUIT

- To generate pulses, you need to use a new component called Integrated Circuit (IC)
- ICs can be made very compact in a fingernail size chip, having up to several billion transistors and other electronic components such as capacitors, resistors, diodes and etc.
- The particular IC you will use is NE555
- The characteristics of an IC is given by the datasheet provided by the manufacturer
- You will learn more ICs in future

IC CONNECTION

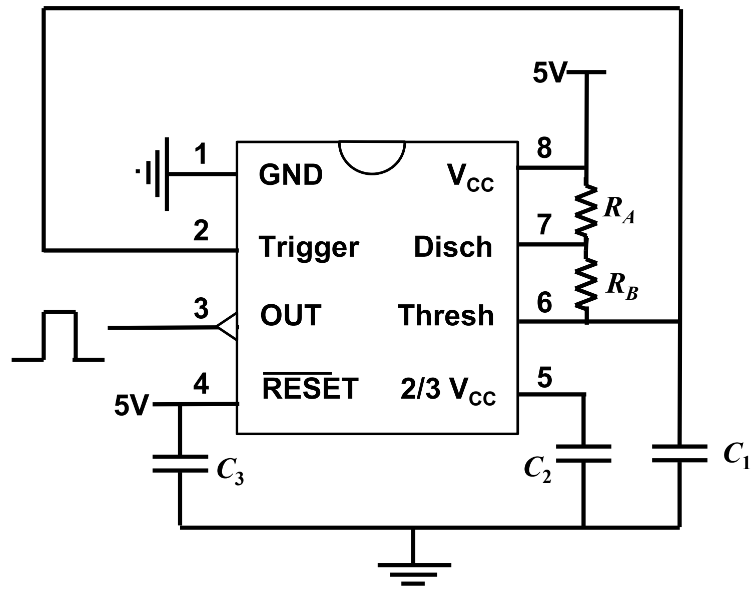
- Each IC has a U-shape mark or a circle to indicate its top



- After you identify the top of an IC, the pins are labeled starting with 1 from the top left corner going downward, then from the bottom right corner going upward

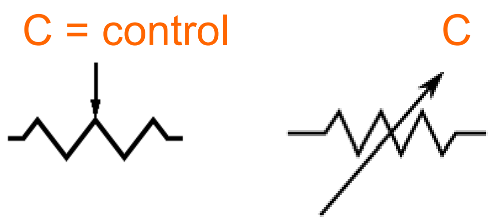
CONSTRUCTING AN NE555 CIRCUIT

- NE555 application schematic
- Based on the datasheet, we have
  - Clock high time = $0.7(R_A+R_B)C_1$
  - Clock low time = $0.7R_BC_1$
  - Clock period = $0.7(R_A+2R_B)C_1$
  - Frequency = $1/[0.7(R_A+2R_B)C_1]$
  - Duty cycle = $(R_A+R_B)/(R_A+2R_B)$

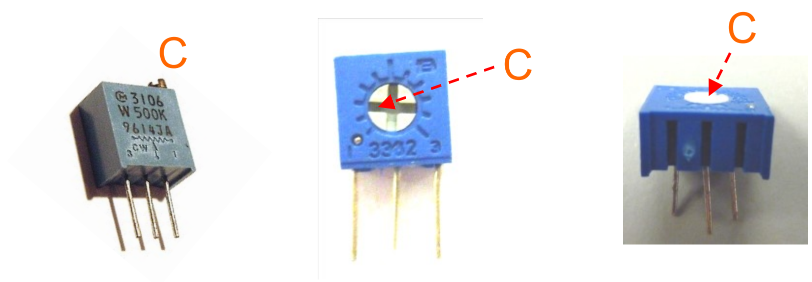


RESISTOR TUNING

- Sometimes we want to adjust the value of a resistor to achieve certain power deliver
- A variable resistor can be used



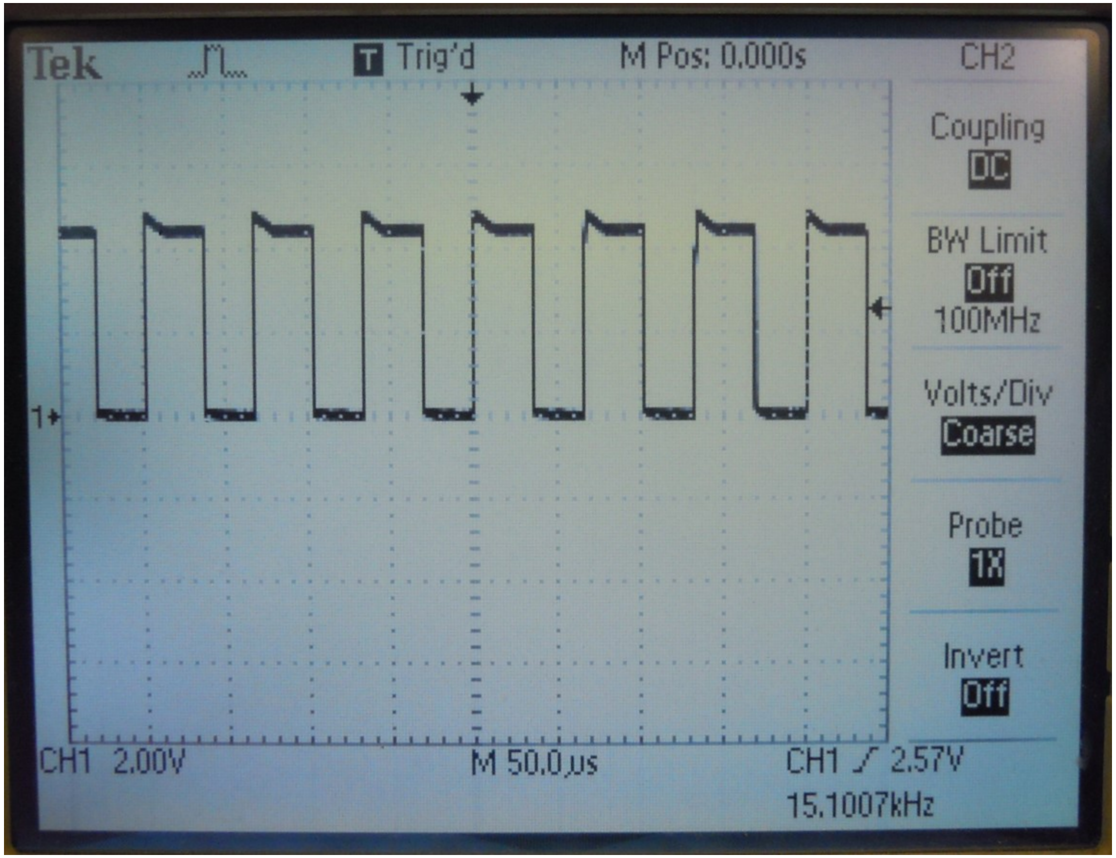
Symbol



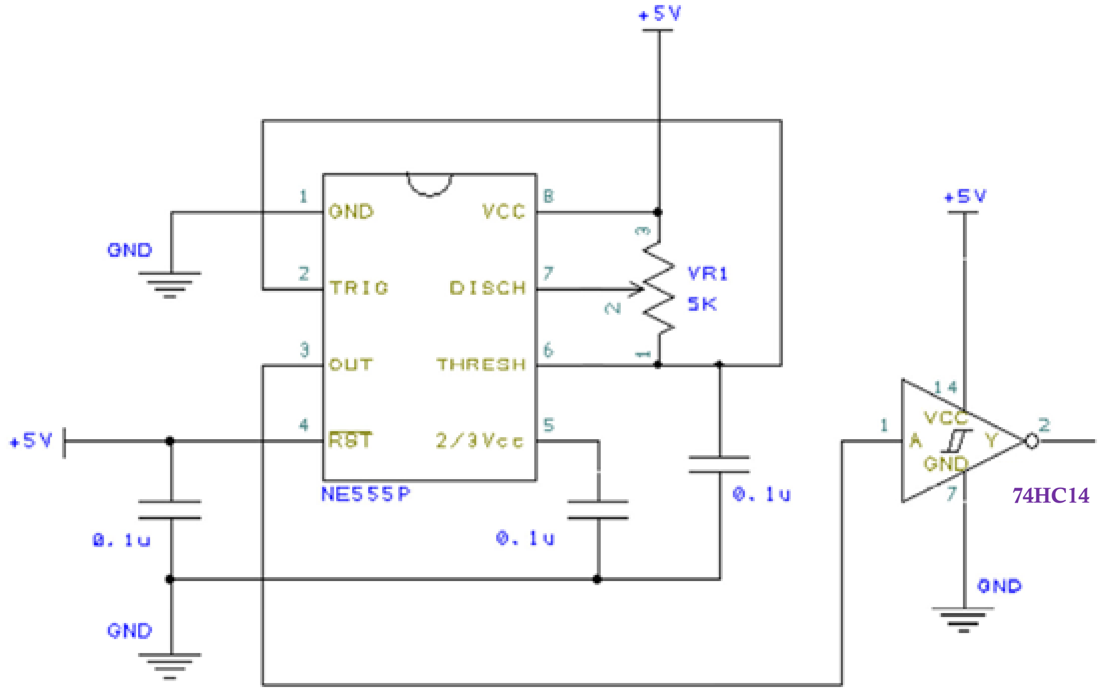
Real Object

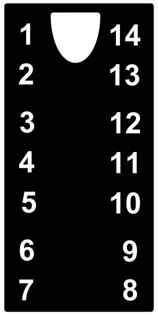
- You will be using one of these in Lab 2

❖ Unfortunately, the output of the pulse signal from NE555 is not always perfect.



- We can use Schmitt Trigger (74HC14) to rectify the waveform

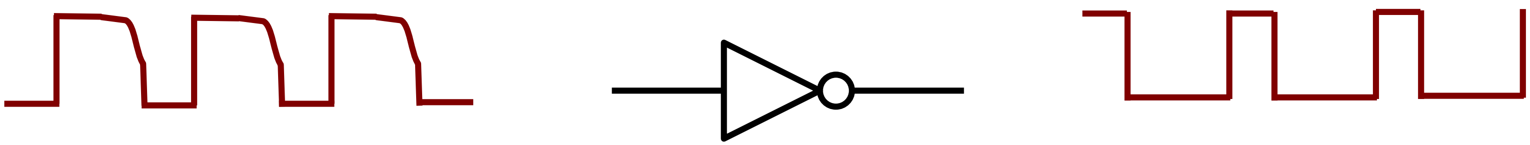


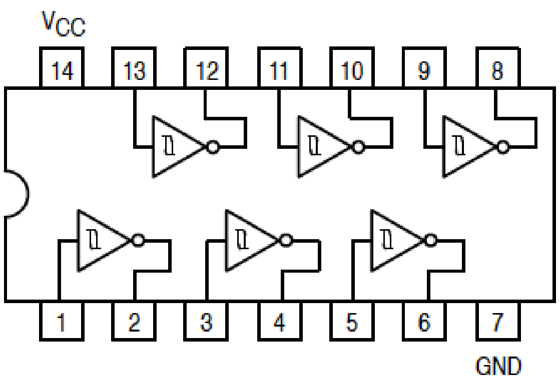


74HC14

SCHMITT TRIGGER

❖ The output of the 555 timer may not be a perfect square wave and it is re-shaped by the Schmitt Trigger (74HC14)





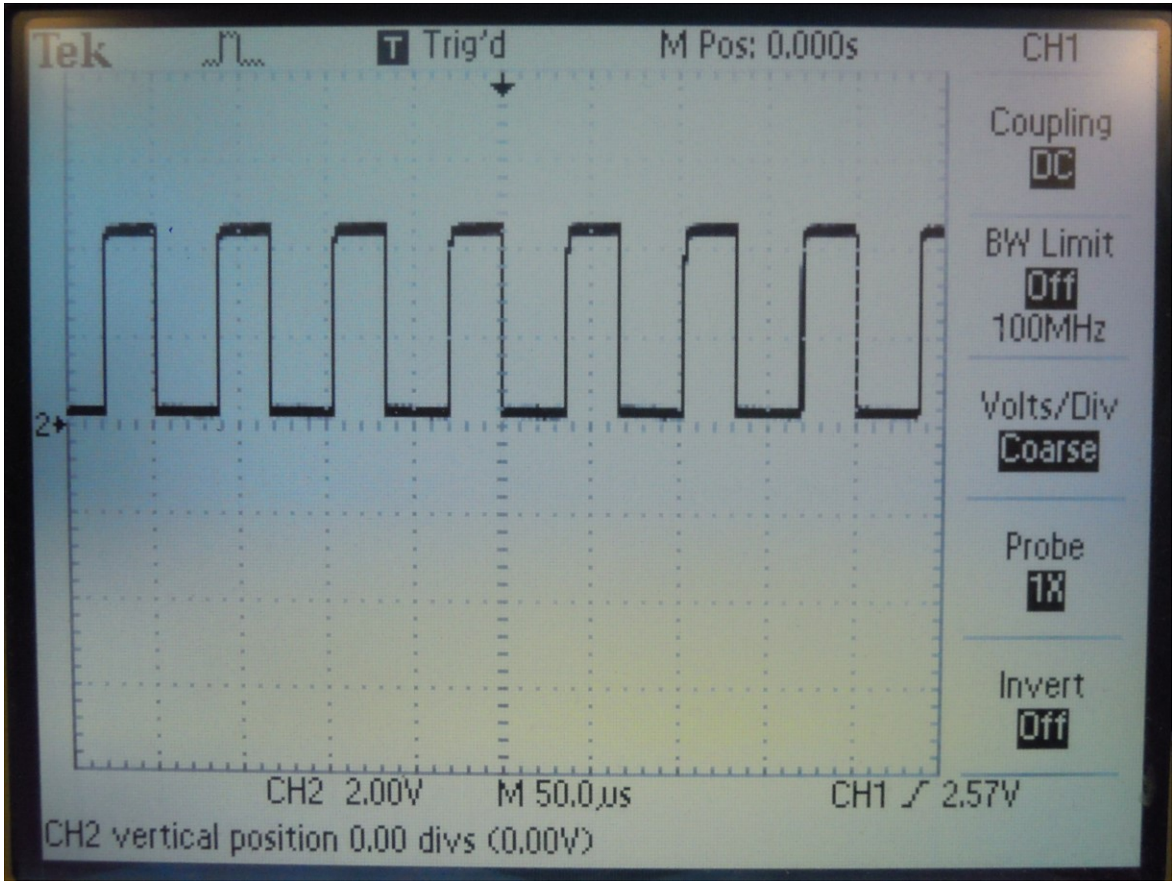
➢ The output is inverted

➢ There are 6 Schmitt Triggers and you only need to use one

➢ Even not shown, the V_{CC} (positive supply) and GND has to be connected to power for proper function

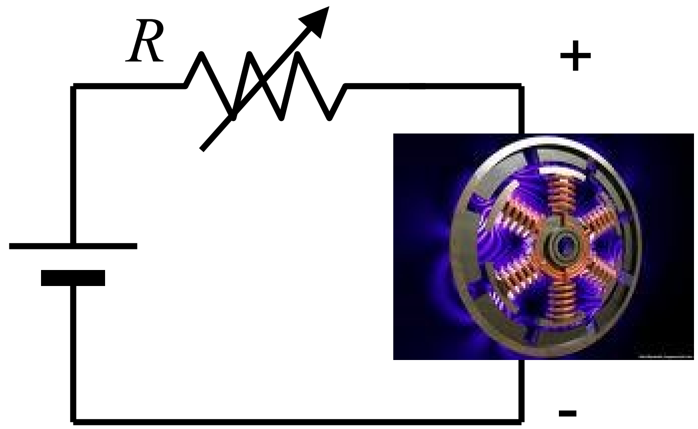
SCHMITT TRIGGER

❖ After going through the Schmitt trigger, the waveform is clean.

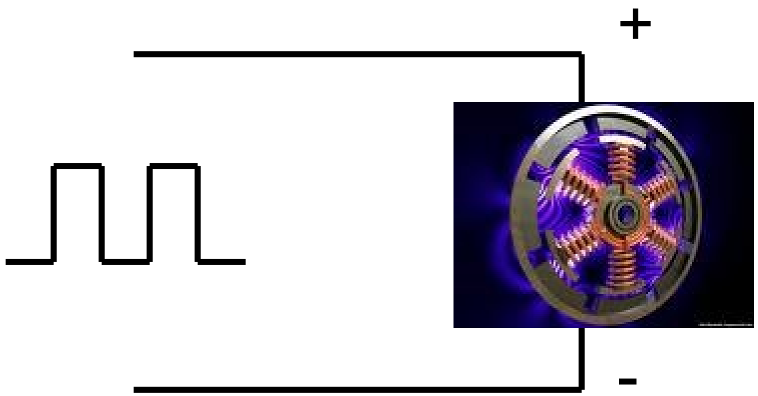


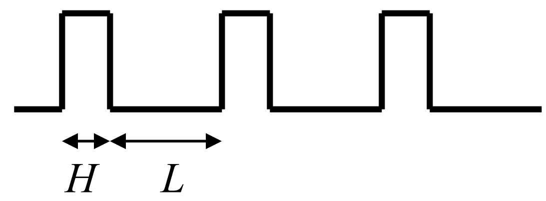
GENERIC MOTOR SPEED CONTROL

- Higher voltage leads to larger current, higher power and faster rotation
- Different voltages can be obtained by using a variable resistor
- Disadvantages:
  - It is difficult to control the speed precisely
  - Need mechanical motion to tune the resistor and not computer friendly



- Turning the motor on/off quickly and repeatedly





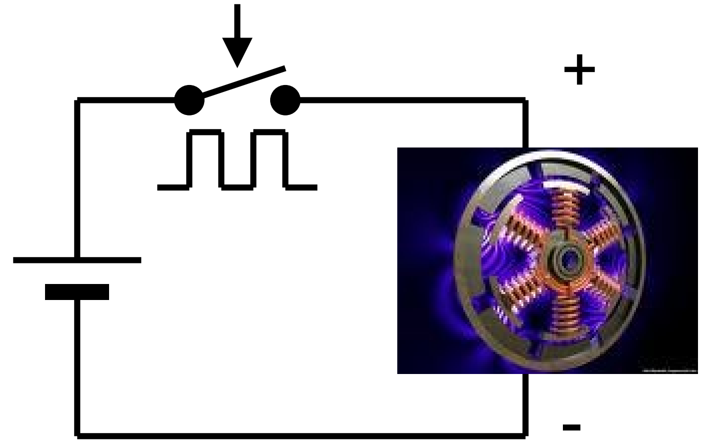
Period = $H + L$

Duty cycle = $\dfrac{H}{H+L}$

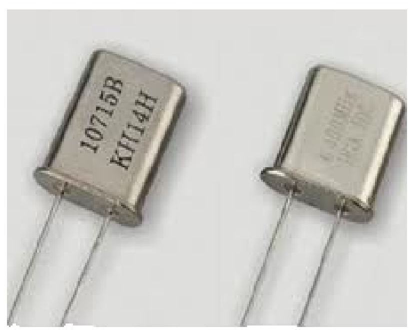
- By adjusting the duty cycle, the speed of the motor can be controlled

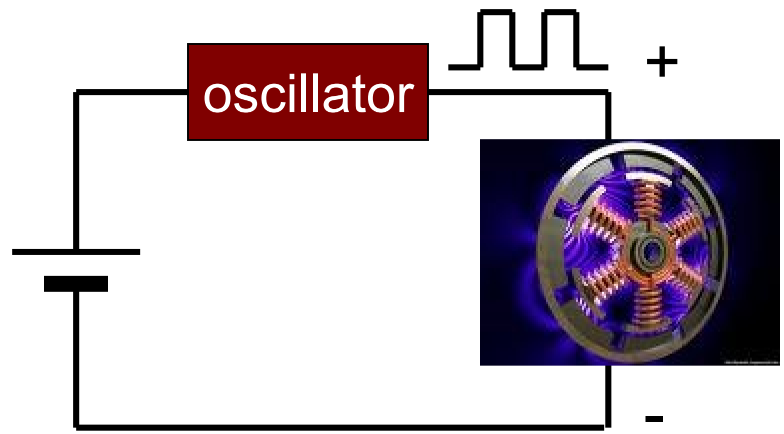
GENERATING PULSES

- By mechanically pressing a switch quickly

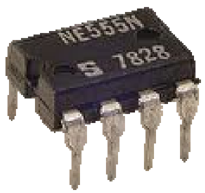


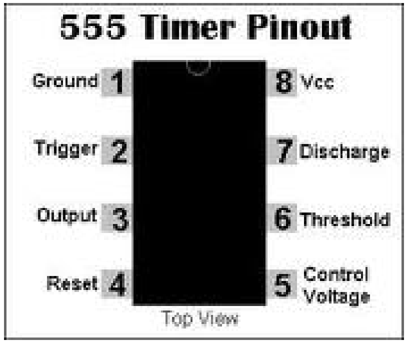
- By electrical means using an oscillator

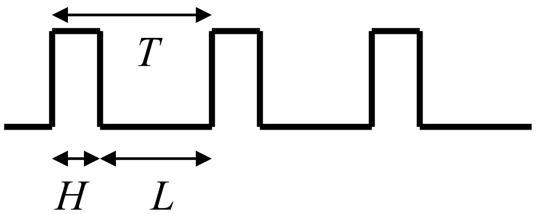


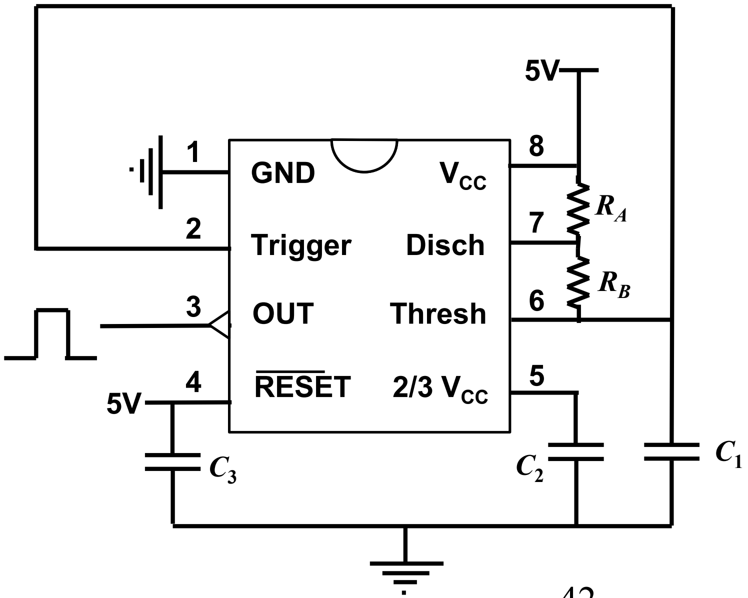


- Oscillators can also be constructed using a 555 Timer IC (will be used in your project)
- The frequency of this clock signal depends on the values of R_A, R_B and C_1 according to the formulas below







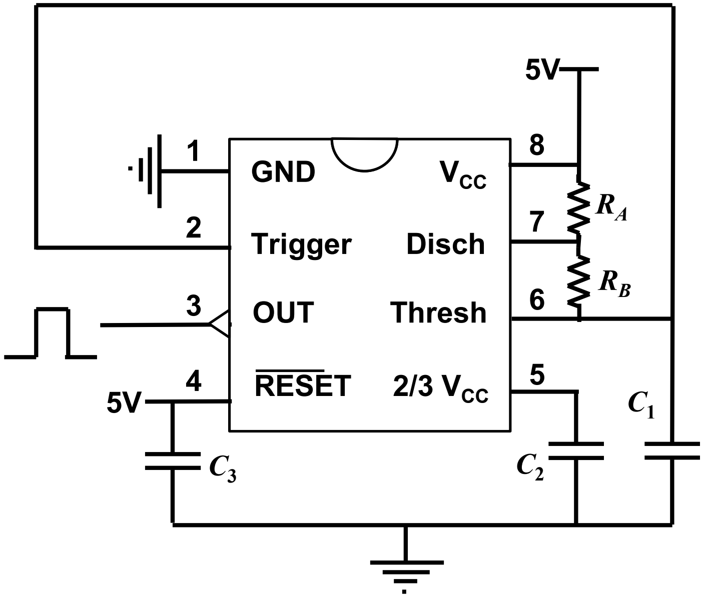


$$H = 0.7(R_A + R_B)C_1$$

$$L = 0.7 R_B C_1$$

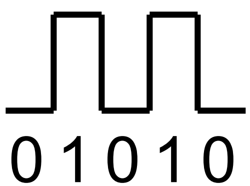
$$T = H + L = 0.7(R_A + 2R_B)C_1$$

- Controlling the pulse width with R_A, R_B and C_1 also requires mechanical intervention
- Analog control also difficult to obtain the required speed precisely



- We will develop a method to control the pulse width digitally

- Decimal number system – base 10, each digital is coming from the set {0,1,2,3,4,5,6,7,8,9}
- Binary number system – base 2, each digital is coming from the set {0,1}
- Why using binary system?

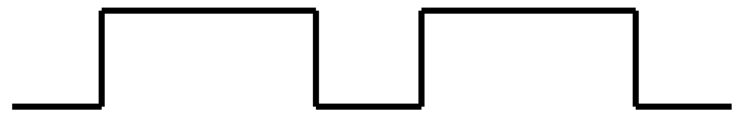


  - It can be represented by two level of voltages

Base 10	Base 2
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010

PULSE AND BINARY REPRESENTATION

❖ You may use pulses to transmit binary numbers … but



Is it 0 1 0 1 0

or 0 0 1 1 0 0 1 1 0 0

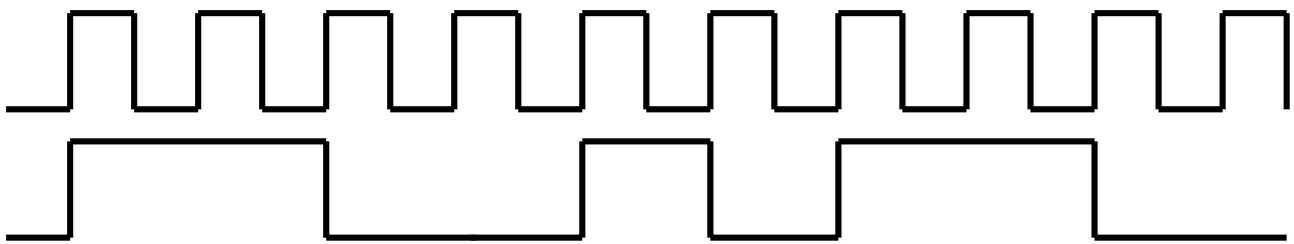
Is it 0 1 1 0 1 1 0

or 0 0 1 1 1 1 0 0 1 1 1 1 0 0

❖ A synchronization signal called a “clock” is needed

Clock

Data



Number 1 1 0 0 1 0 1 1 0 0

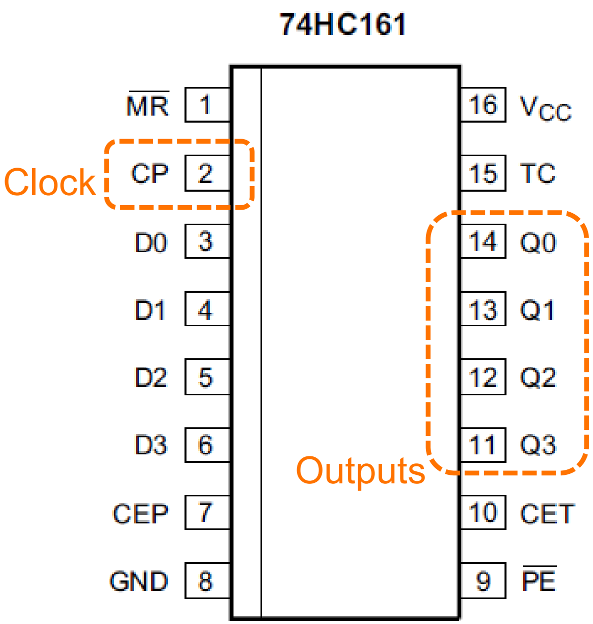
Q: how can you transmit more bits in the same time slot?

CLOCK

- A clock is a series of pulse transmitted at constant frequency for synchronization
- Clock speed usually represents the fastest rate data that can be handled or transmitted
- Most electronic systems require clocks
- Example: Intel Core i7 3.4GHz Quad-Core represents the fastest signal is at 3.4GHz (or 3,400,000,000 pulses per second)

COUNTER (74HC161)

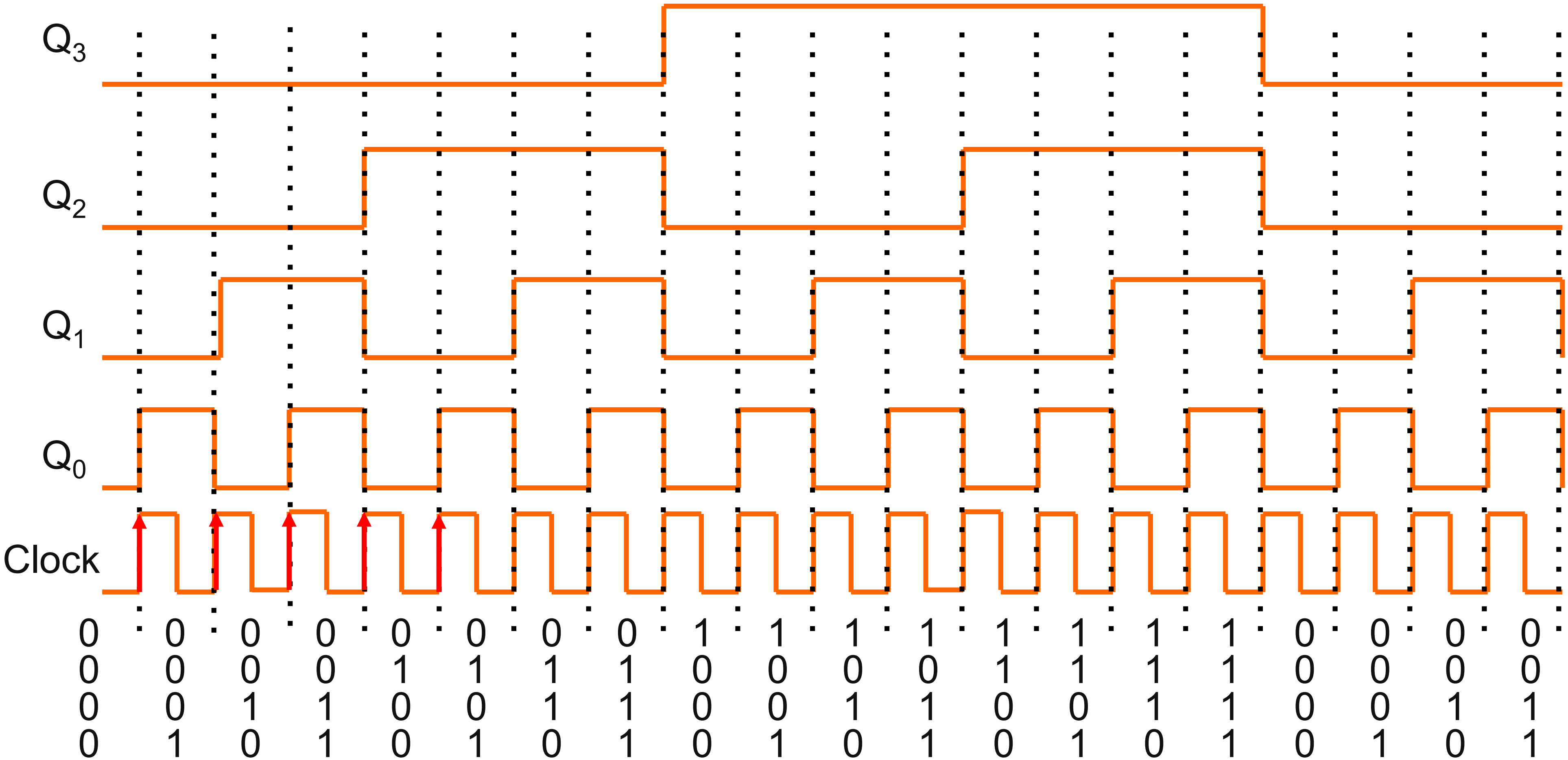
- A counter is an IC that counts the number of rising edges of input clock (for example, 74HC161)
- Its output is a binary number $Q_3Q_2Q_1Q_0$
- Binary number consists of only "0" and "1" and the equivalent decimal number is given below



- In circuit, "1" represents high and "0" represent low

Dec	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bin	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111

OUTPUTS OF 74HC161



BIT VALUE IN BINARY NUMBER

- Digit value in decimal number

$$\ldots \; \underline{x} \quad \underline{x} \quad \underline{x} \quad \underline{x} \quad \underline{x}$$

$$\ldots \; 10^4 \; 10^3 \; 10^2 \; 10^1 \; 10^0$$

- Digit value in binary number

$$\ldots \; \underline{x} \quad \underline{x} \quad \underline{x} \quad \underline{x} \quad \underline{x}$$

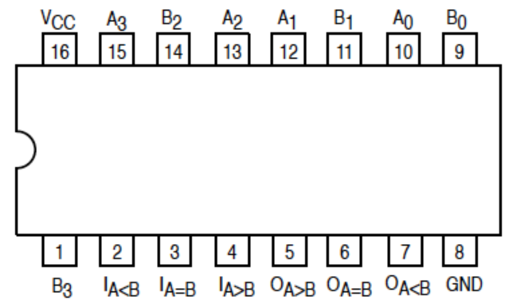
$$\ldots \; 2^4 \quad 2^3 \quad 2^2 \quad 2^1 \quad 2^0$$

$$\ldots \; 16 \quad 8 \quad 4 \quad 2 \quad 1$$

- For n binary digits, what is the largest number it can represent?

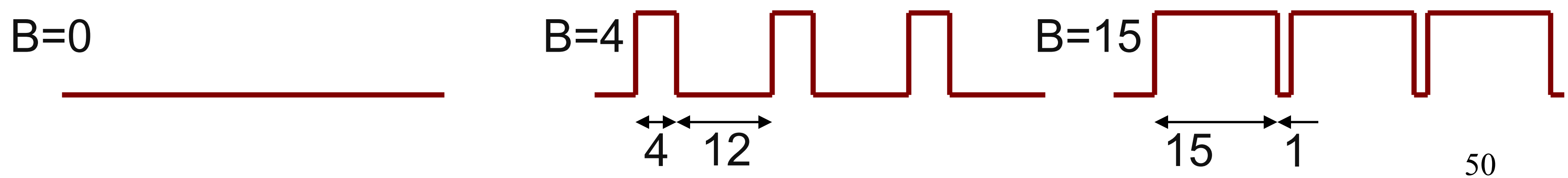
Answer: 2^n-1

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



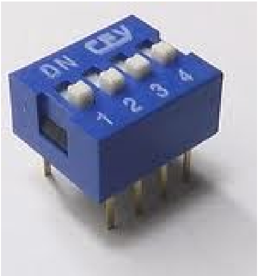
- If A < B, the pin A<B will go high and so on
- Suppose the number A comes from the counter 74HC161 and starting from 0000
- By inputting a fixed number to B, we can control the duty cycle at output of A < B

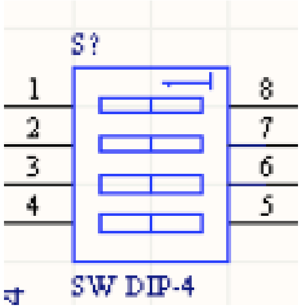
$O_{A<B}$ output



INPUTING TO THE COMPARATOR

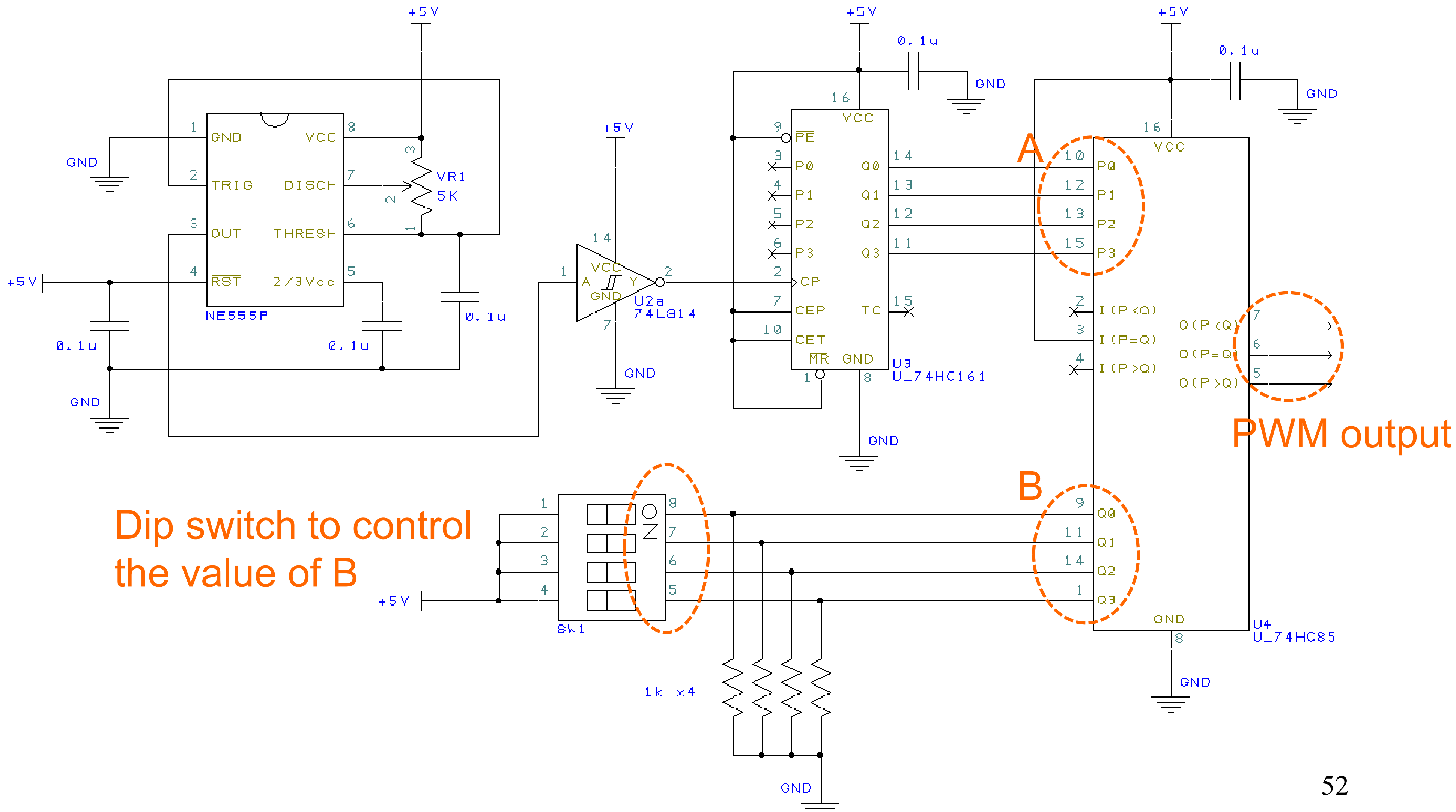
- The input to the B value of 74HC85 is done by a dip switch to either connect it to ground or power supply





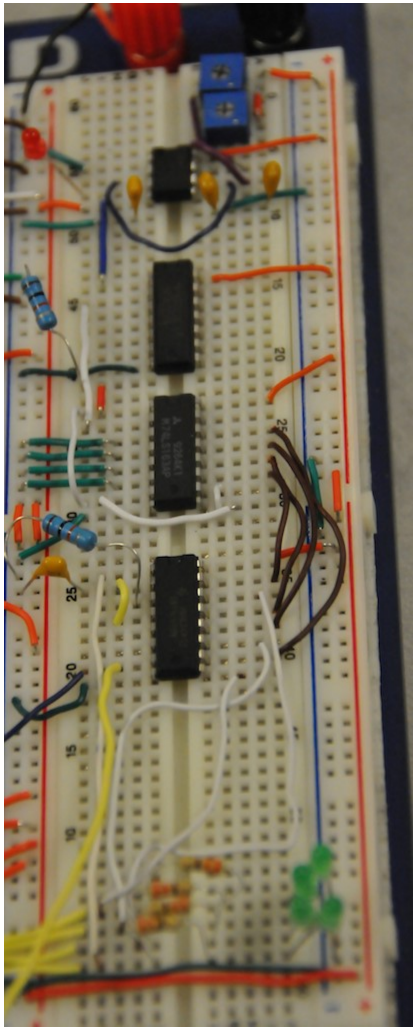
- Now you have a vague idea of the method to control pulse width (which you will do in Lab 3)
- It is time to put everything together

PUTTING EVERYTHING TOGETHER



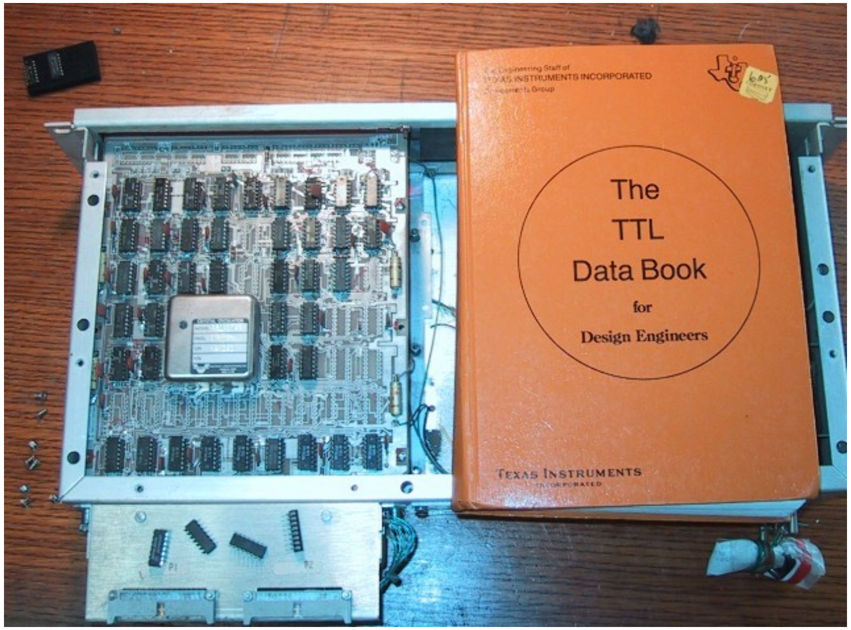
FINAL CIRCUIT

- Even though the circuit diagram is a bit complicated, the final circuit is not that difficult to construct
- Be patient and work carefully, you will be able to get the circuit working



THE TTL IC (7400 SERIES)

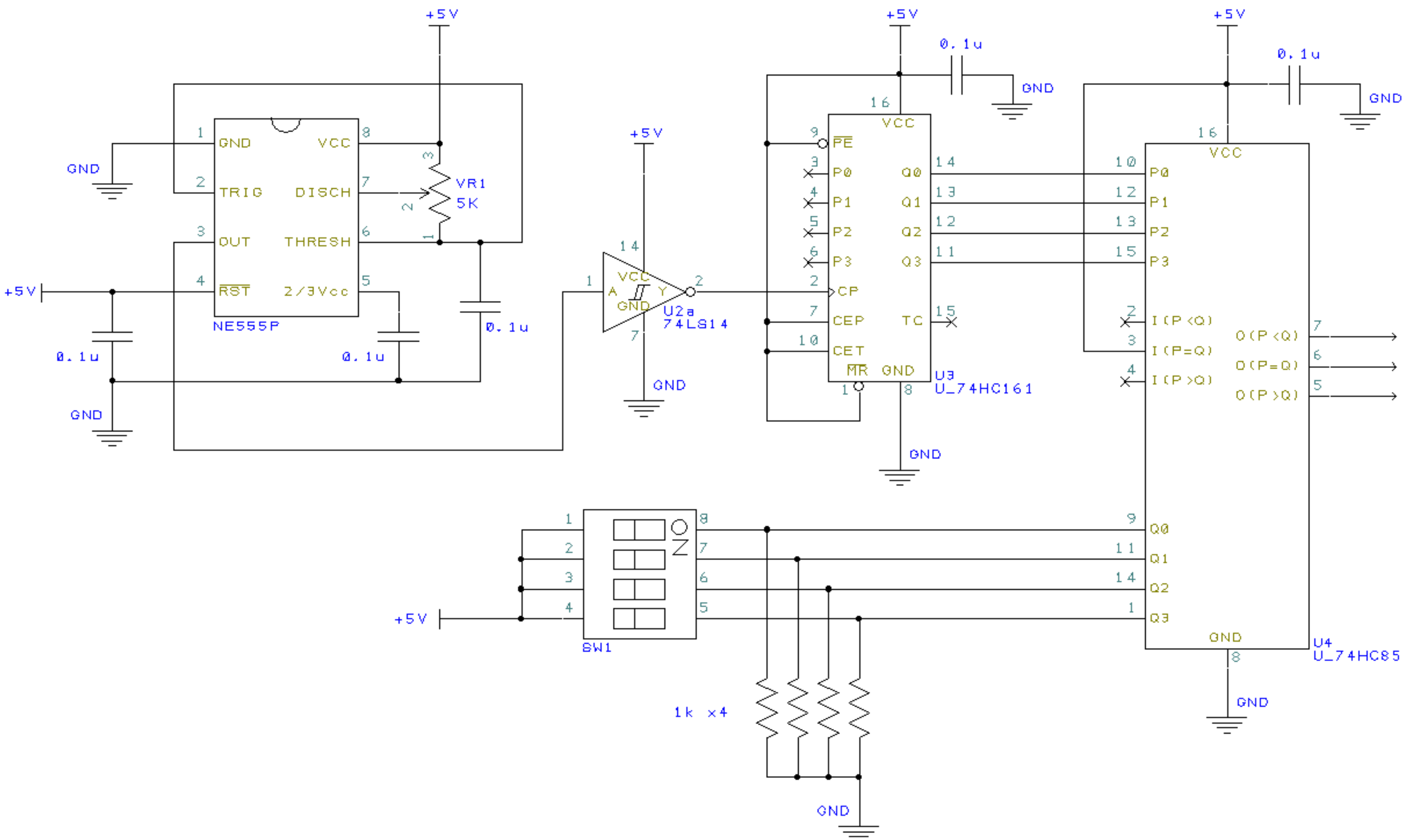
- The most widely used series to provide various functions to handle digital pulses
- Mainly developed by Texas Instruments (TI) with many compatible parts from AMD, Fairchild, Intel, Intersil, etc.



- Number with 74*xx*, 74L*xx*, 74H*xx*, 74S*xx*, 74LS*xx*
- Functionality can be easily found from the internet

LECTURE SUMMARY

❖ You are going to construct the following circuit in Lab 3



NEXT LECTURE

- ❖ Transistors and switches
- ❖ H-bridge Motor driver
- ❖ Sensors

Questions ?!