SCS2113 – Electronics & Physical Computing

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UNIVERSITY OF COLOMBO SCHOOL OF COMPUTING

The Team

- Lectures
  - Dr. Hiran Ekanayake (HBE)
  - Mr. Isuru Nanayakkara (NHP)
- Practical Classes
  - Mr. Dushan Dinushka (HTD)
- Tutorial Classes
  - Mr. Thathsara Liyanage (KLT)




Course Outline

- Part 1 (Analog & Digital Electronics) - HBE
  - Basic concepts (V, I, Ω, W), signals, theories, analysis, components, filters, tools, measuring equipment, circuit modeling, power supply, etc.
- Part 2 (Physical Computing) - NHP
  - Microcontroller basics, arduino programming, IoT

Assessment

- Final Written Paper – 70%
- In-Course Assessment – 30%
  - Class Activities – 10%
  - Lab Sessions – 5%
  - Practical Tests – 15%

Electronics Lab of UCSC

Course Delivery

Lectures

- Activities, quizzes, interactions, breaks, etc.

Practical Classes

Tutorial Classes

ANALOG ELECTRONIC FUNDAMENTALS

Lesson Outline

- History
- Theory
- Components
- Applications
- Experiments
- Prototyping

References

- Maretzki, G. (2015), Electronics Fundamentals: An introductory course on electronics covering basic theory, DC and AC electrical circuits, electronic components, circuit design, and circuit construction methods.
- Horowitz, P., & Hill, W. (1989). The art of electronics. Cambridge [England]: Cambridge University Press.
- Electronics Tutorials, https://www.electronics-tutorials.ws/

HISTORY

Electricity in Nature

History

- Benjamin Franklin, 1972:
  - Observed electricity in clouds

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- Luigi Galvani, 1780:
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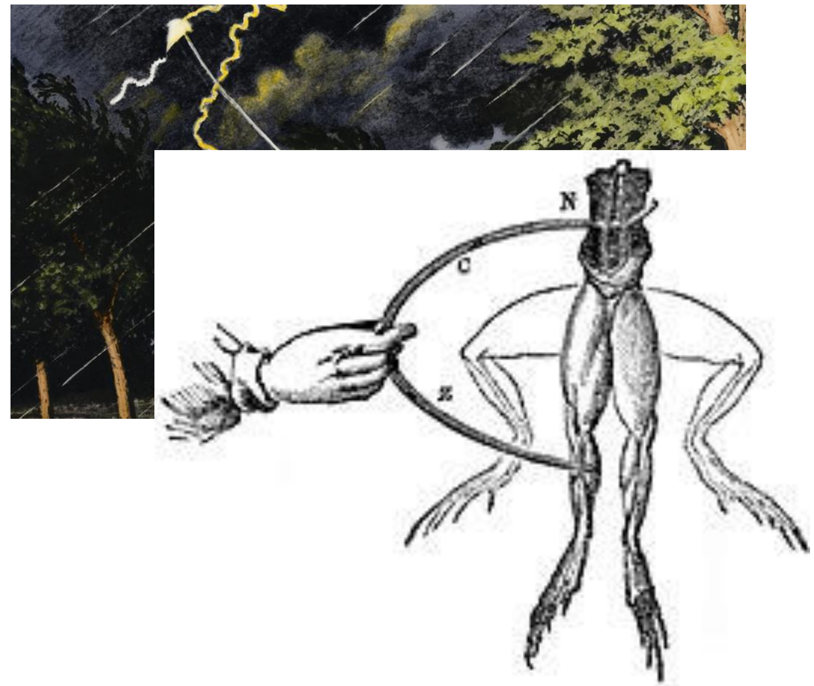
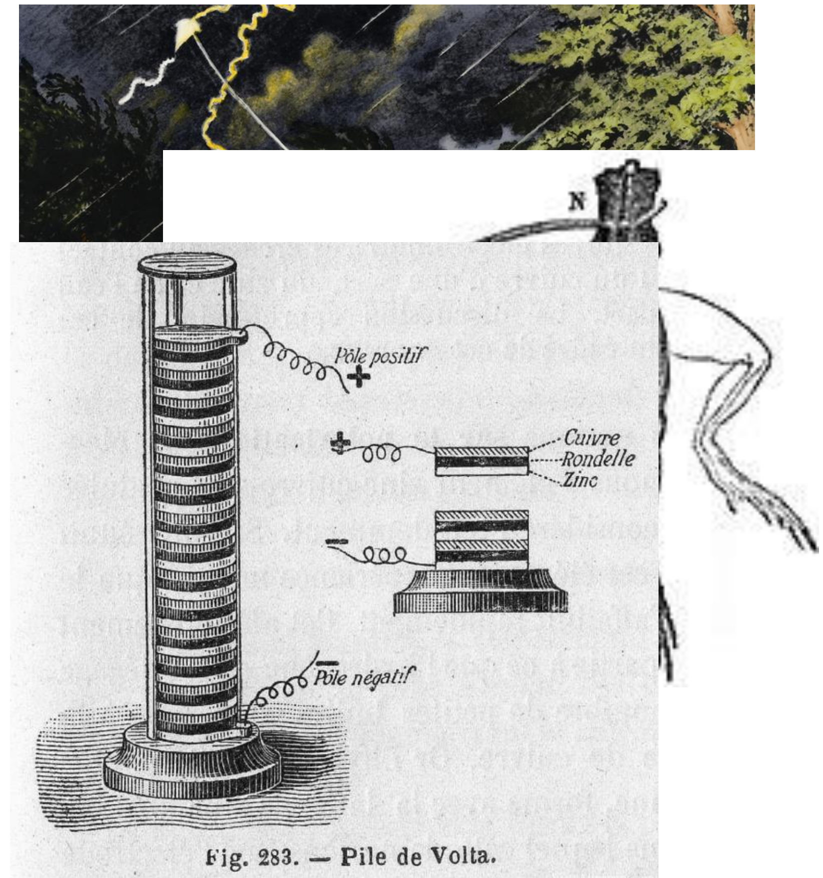


History

- Benjamin Franklin, 1972:
  - Observed electricity in clouds
- Luigi Galvani, 1780:
  - Dead frogs’ legs as source of electricity since they jump during dissection
- Alessandro Volta, 1800:
  - Electricity generated by dissimilar metals
  - Principle of a battery
  - ‘Volt’ to measure electrical potential



History

- André-Marie Ampère, 1820:
  - Electricity and electromagnetism
  - Principle of motors and generators
  - ‘Ampere’ to measure electrical current

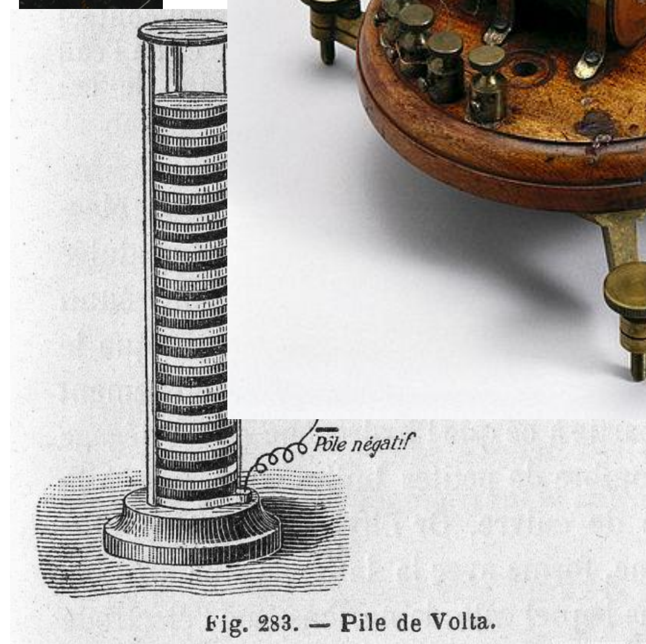
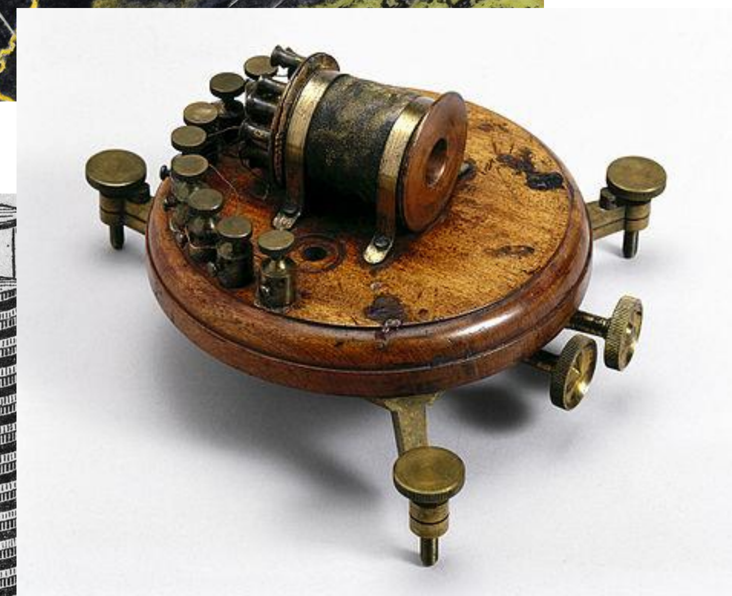
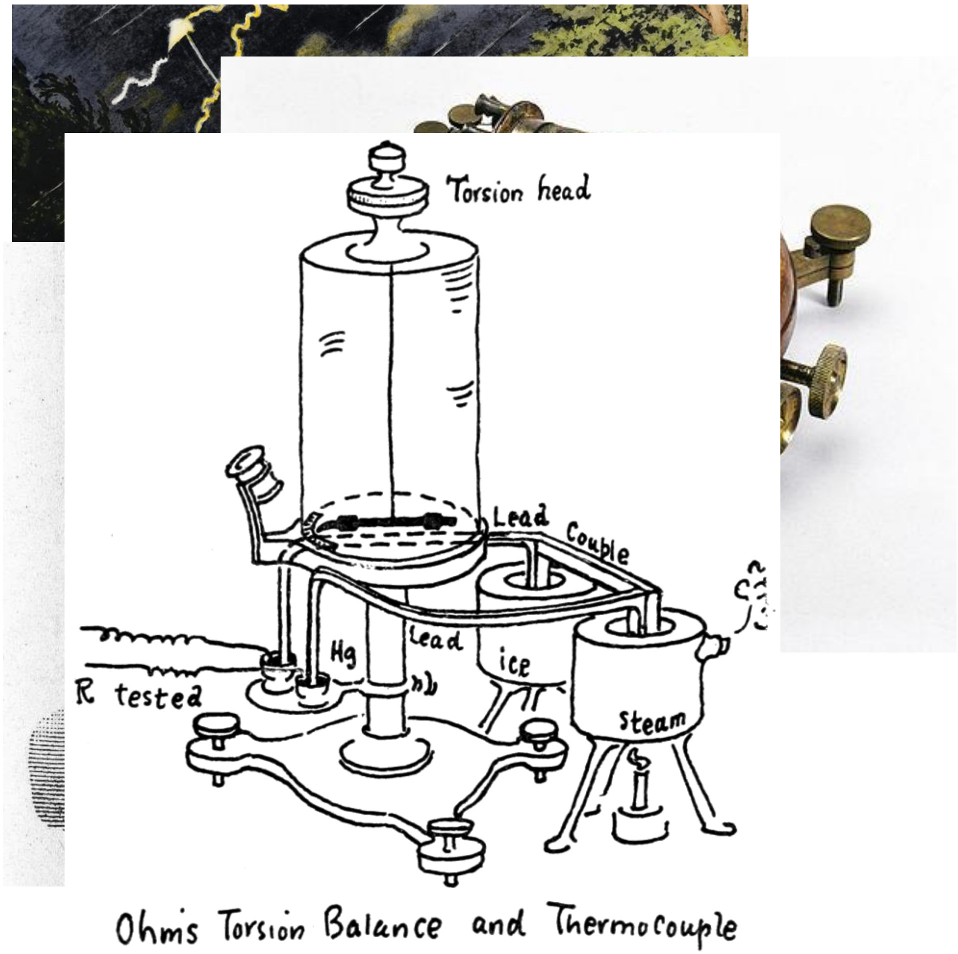


Fig. 283. — Pile de Volta.



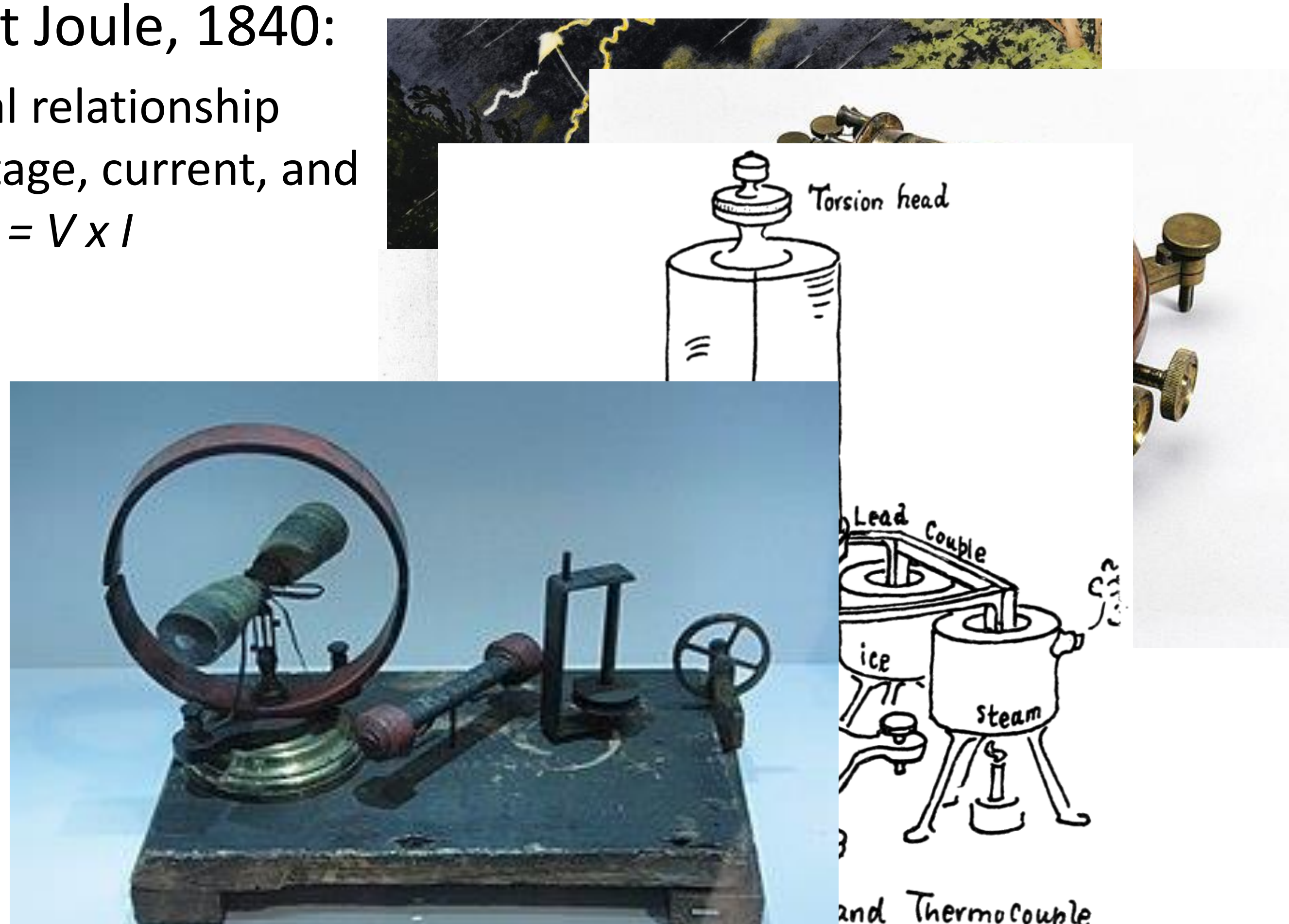
History

- André-Marie Ampère, 1820:
  - Electricity and electromagnetism
  - Principle of motors and generators
  - 'Ampere' to measure electrical current
- Georg Ohm, 1827:
  - Mathematical relationship between voltage, current, and resistance – Ohm's law
  - 'Ohm' to measure electrical resistance



History

- James Prescott Joule, 1840:
  - Mathematical relationship between voltage, current, and power, i.e., *P = V x I*



History

- Lee De Forest, 1906:
  - First amplifying device, triode

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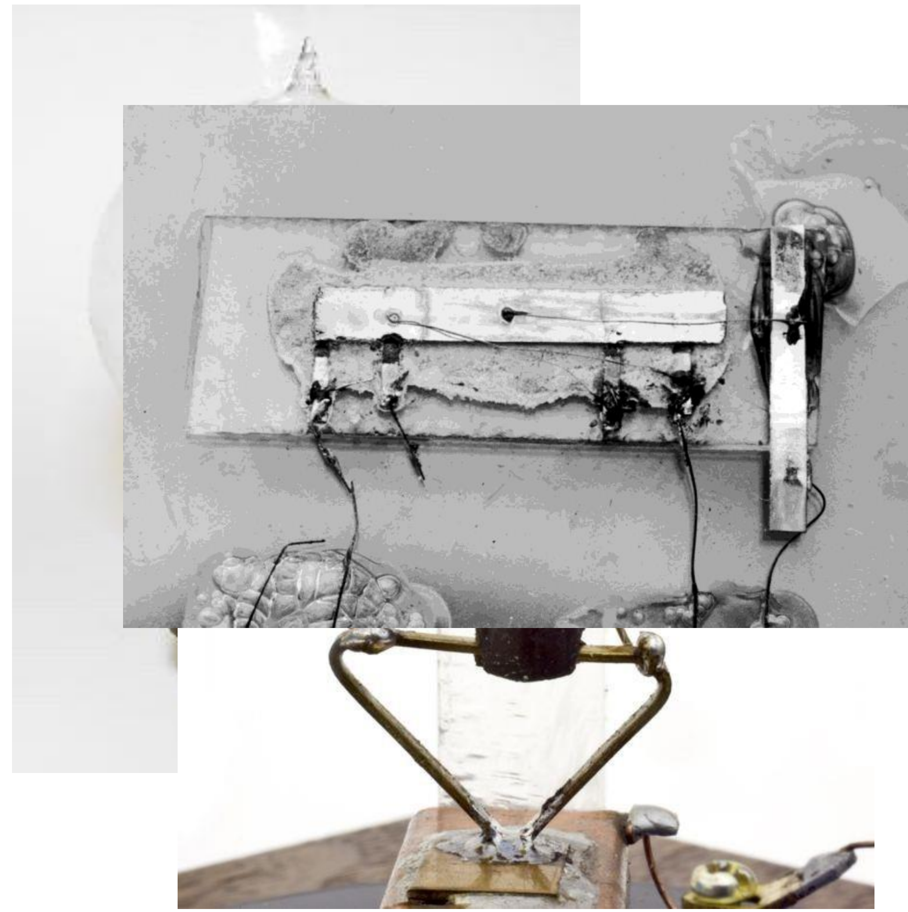
  - First amplifying device, triode
- John Bardeen, Walter Brattain, and William Shockley, 1947:
  - First semiconductor transistor
- Jack Kilby and Robert Noyce, 1958:
  - First integrated circuit (IC)

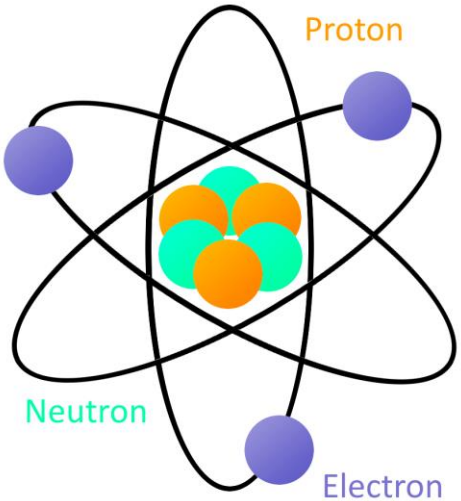


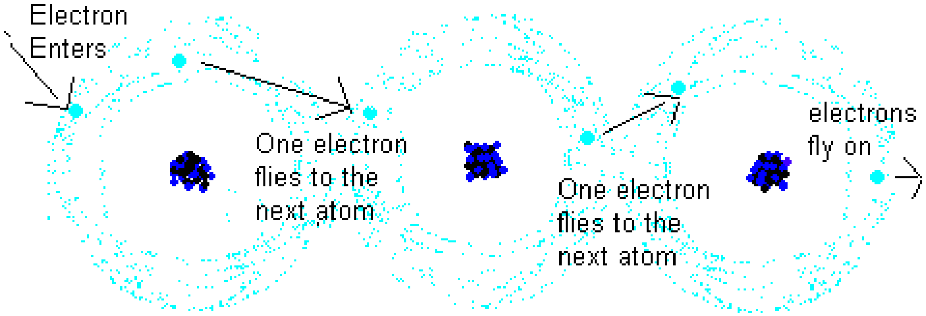
THEORY

Section Outline

- What is ‘Electricity’?
- Electric circuits
- AC vs. DC
- Voltage, current, resistance, and power
- Ohm’s law
- Power law

What is 'Electricity'?



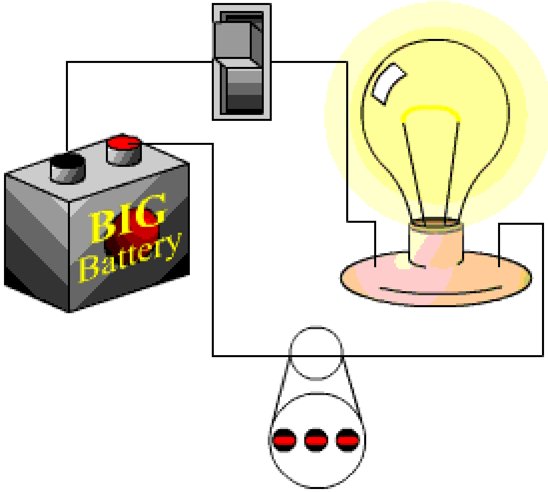


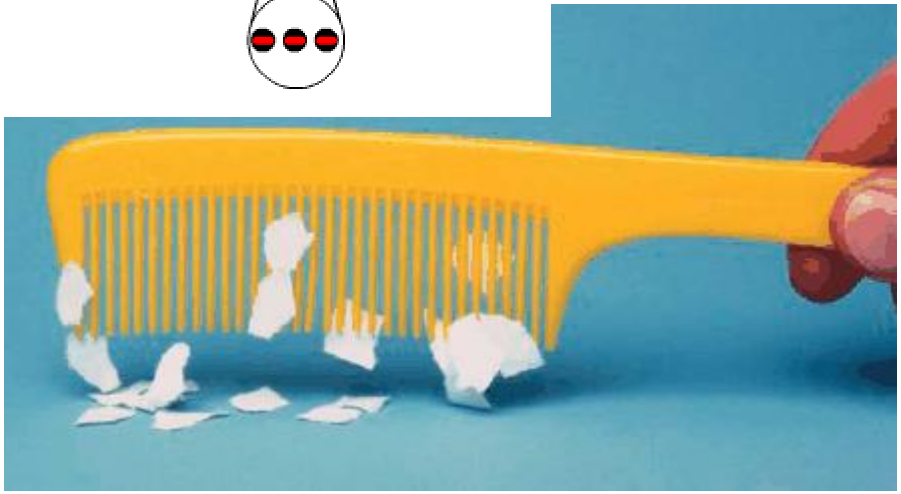
Flow of Electricity

- All matter is made of atoms
- All atoms are made of:
  - Neutrons – neutral charge
  - Protons – positive charged
  - Electrons – negative charge
- Electrons can easily move
- **Electricity** is about the behavior of electrons
- In electronics, we control the behavior of electrons

What is 'Electricity'? A Definition

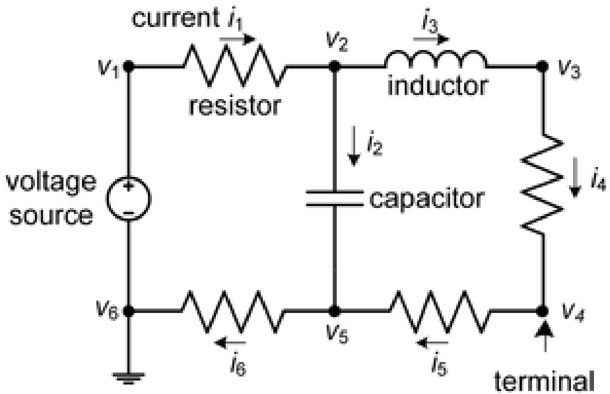
- A form of energy resulting from the existence of charged particles (such as electrons or protons), either **statically** as an accumulation of charge or **dynamically** as a current.





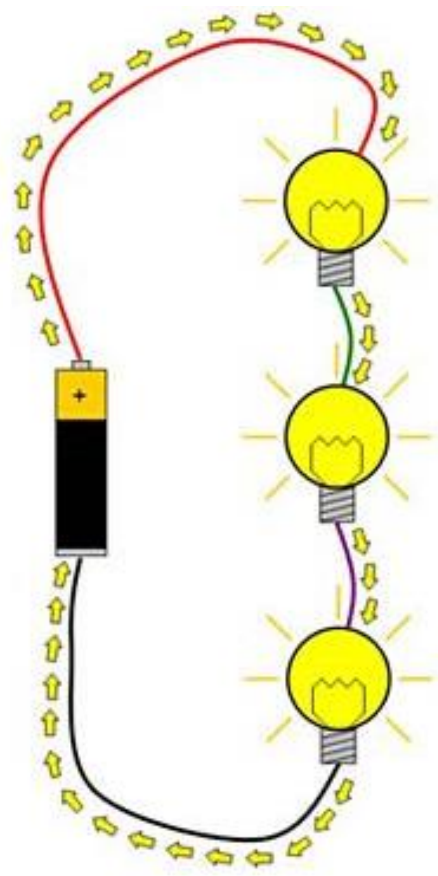
Electric Circuit

- An **electrical network** is an interconnection of electrical components (e.g., batteries, resistors, inductors, capacitors, switches, transistors) or a model of such an interconnection, consisting of electrical elements (e.g., voltage sources, current sources, resistances, inductances, capacitances);
- An **electrical circuit** is a network consisting of a closed loop, giving a return path for the current (Wikipedia).



Types of Circuits

- Series circuit:
  - All the elements/components/devices are connected in series.
  - All the current flows through every device and a break at any point will interrupt the current flow.



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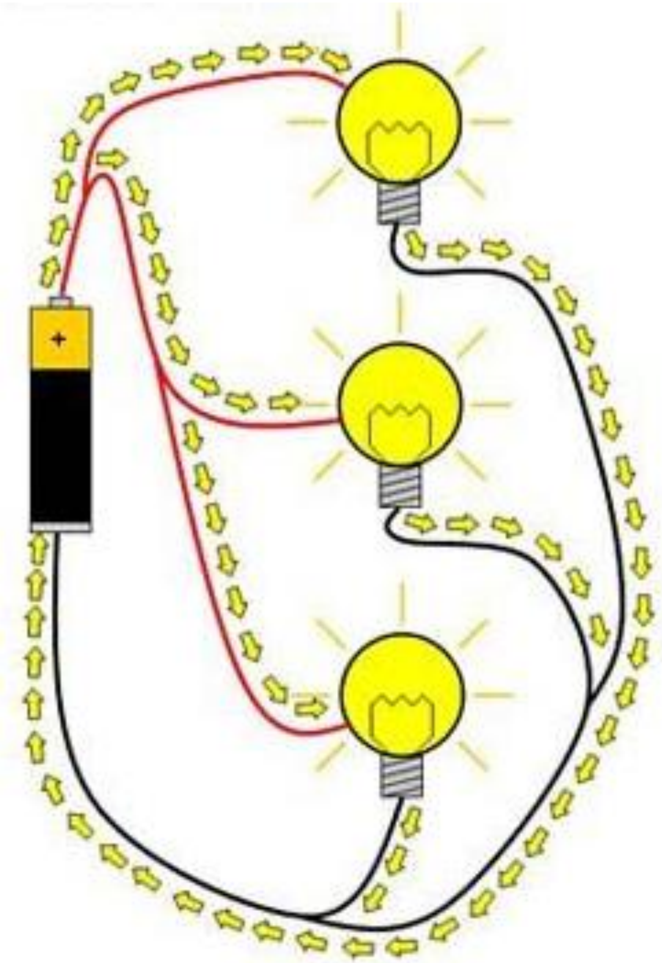
  - There are multiple paths for the current to flow.

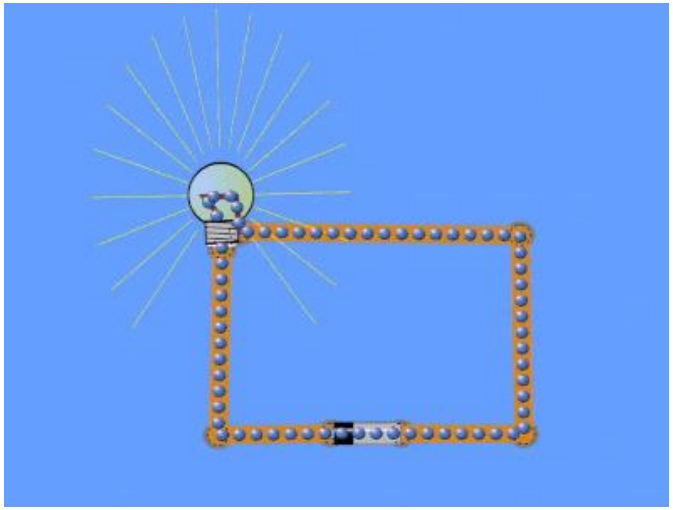


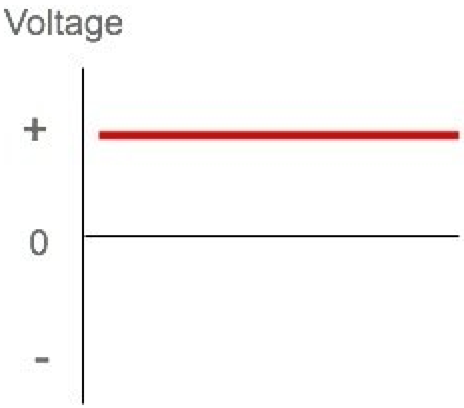
Types of Circuits

- Series circuit:
  - All the elements/components/devices are connected in series.
  - All the current flows through every device and a break at any point will interrupt the current flow.
- Parallel circuit:
  - There are multiple paths for the current to flow.
- Complex circuit

Types of Circuits

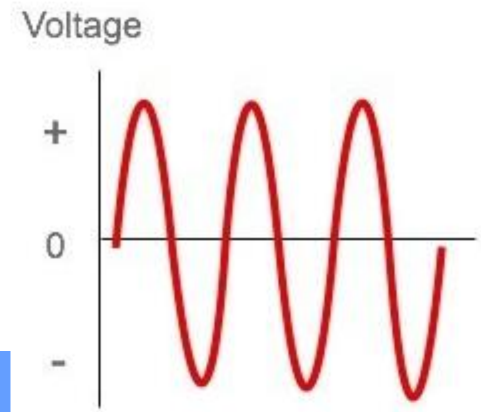
- Direct Current (DC):
  - Generated by DC sources, e.g., batteries
  - Current flows only in one direction

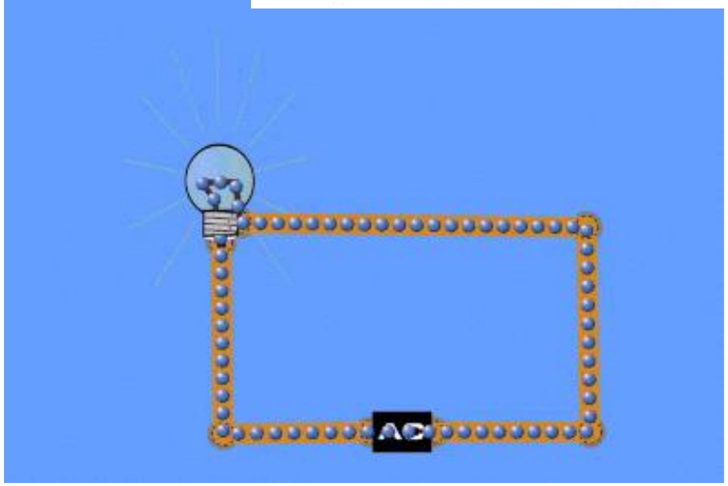




Types of Circuits

- Direct Current (DC):
  - Generated by DC sources like batteries
  - Current flows only in one direction
- Alternating Current (AC):
  - Generated by AC sources like generators and inverters
  - AC alternates directions in a repetitive pattern, e.g., house current alternates 50 cycles per second

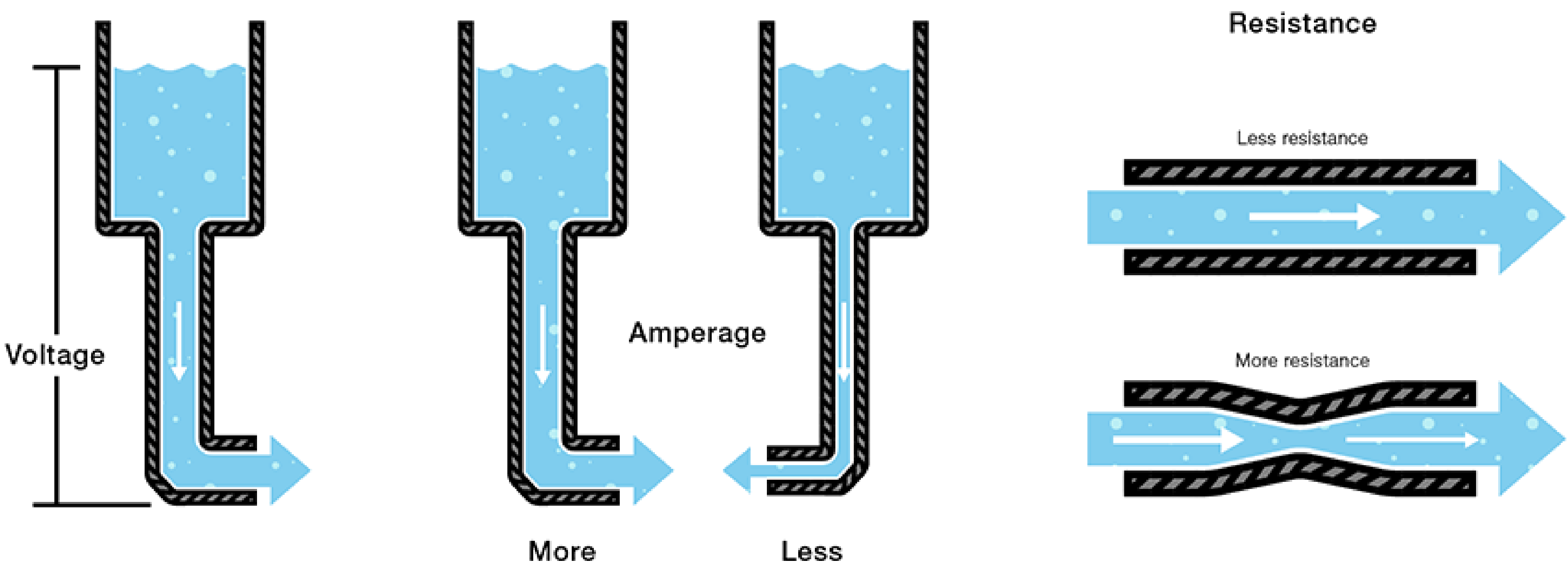




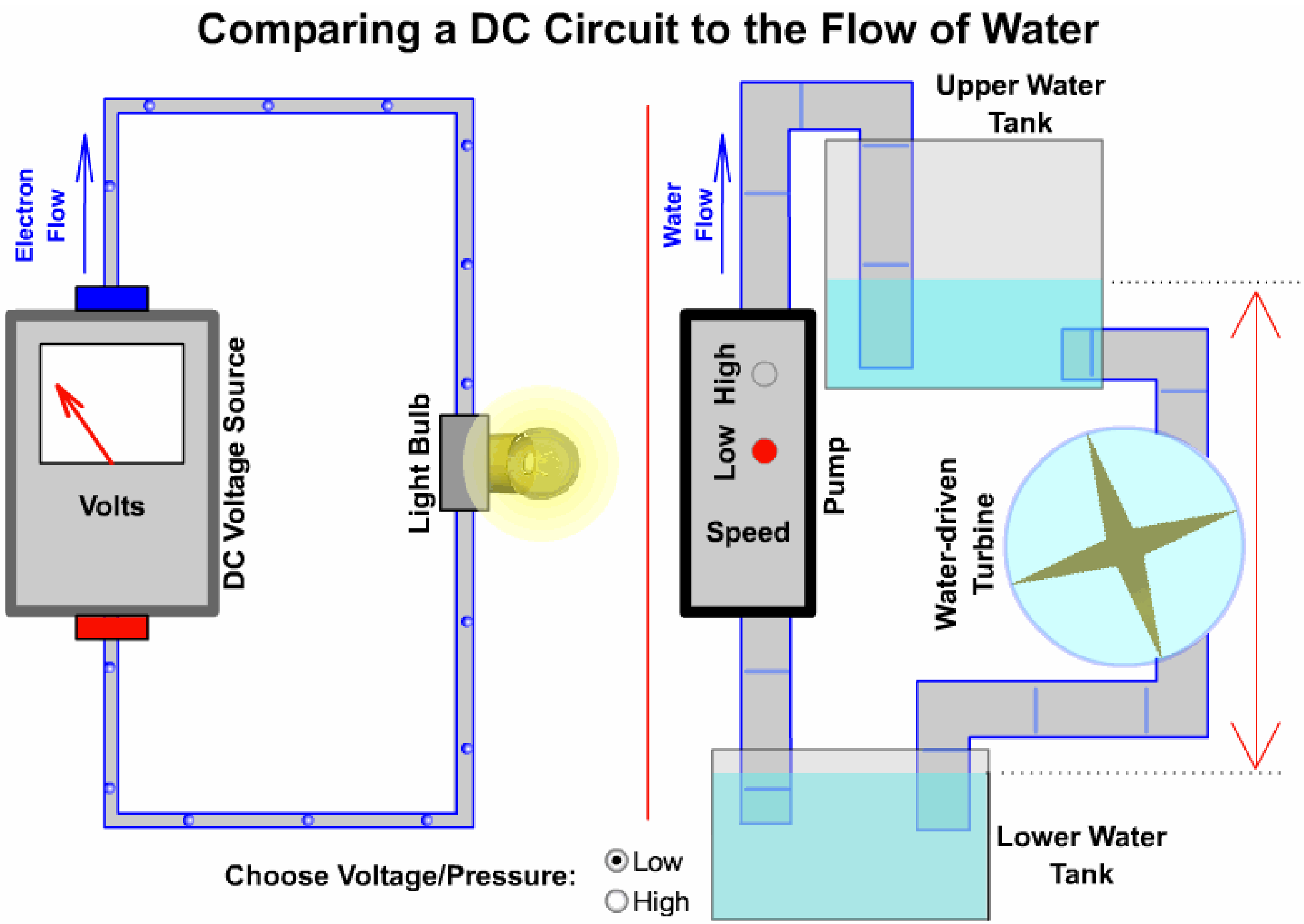
Understanding Current, Voltage, Resistance, and Power

- Current (I):
  - Flow of electrons in a given amount of time
  - Measures in amperes or amps (A)
- Voltage (V):
  - Electrical potential or pressure
  - Measures in volts (V)
- Resistance (R):
  - Resistance to current flow
  - Measures in Ohms (Ω)
- Power (P):
  - Amount of work being done by current and potential in a given amount of time
  - Measures in Watts (W)

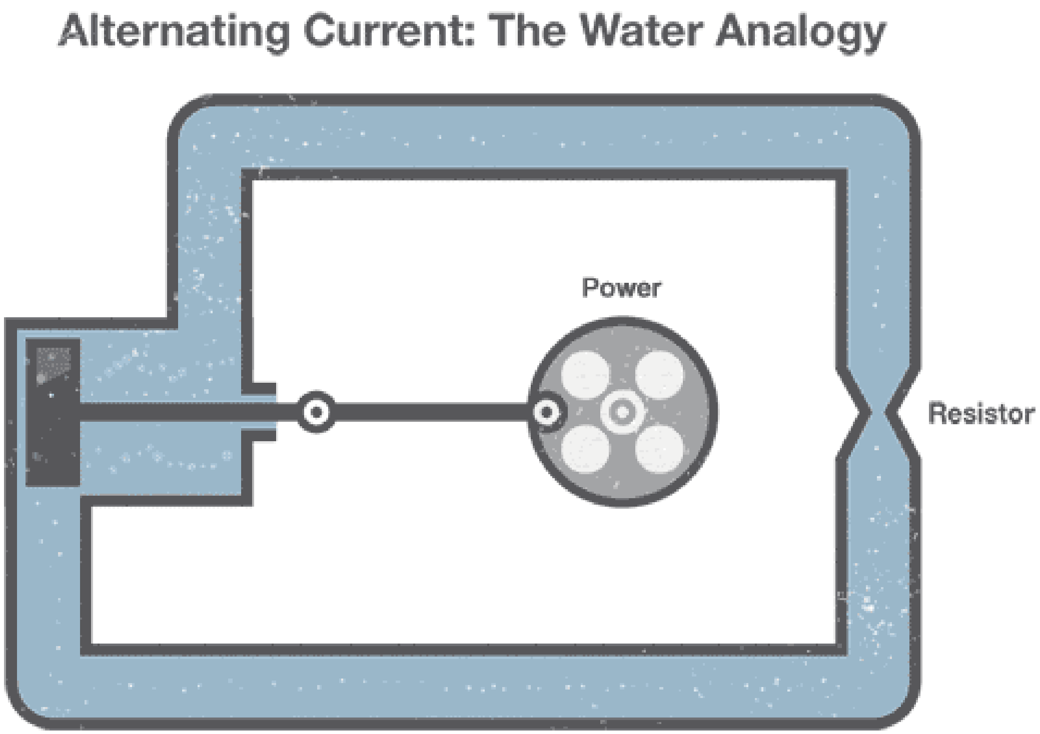
Water Analogy 1



Water Analogy 2

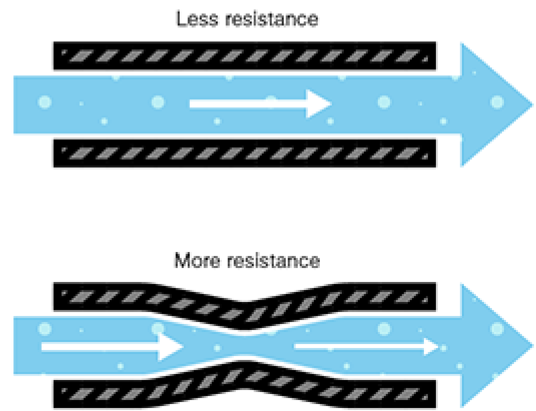


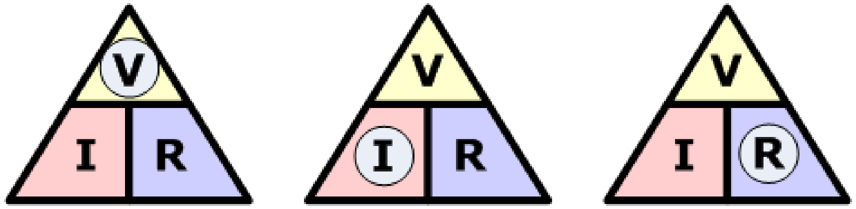
Water Analogy 3



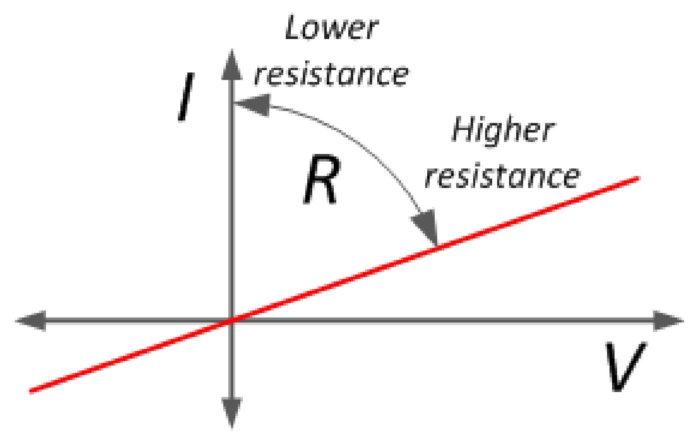
Ohm’s Law

- The current through a conductor between two points is directly proportional to the voltage across the two points (Wikipedia).

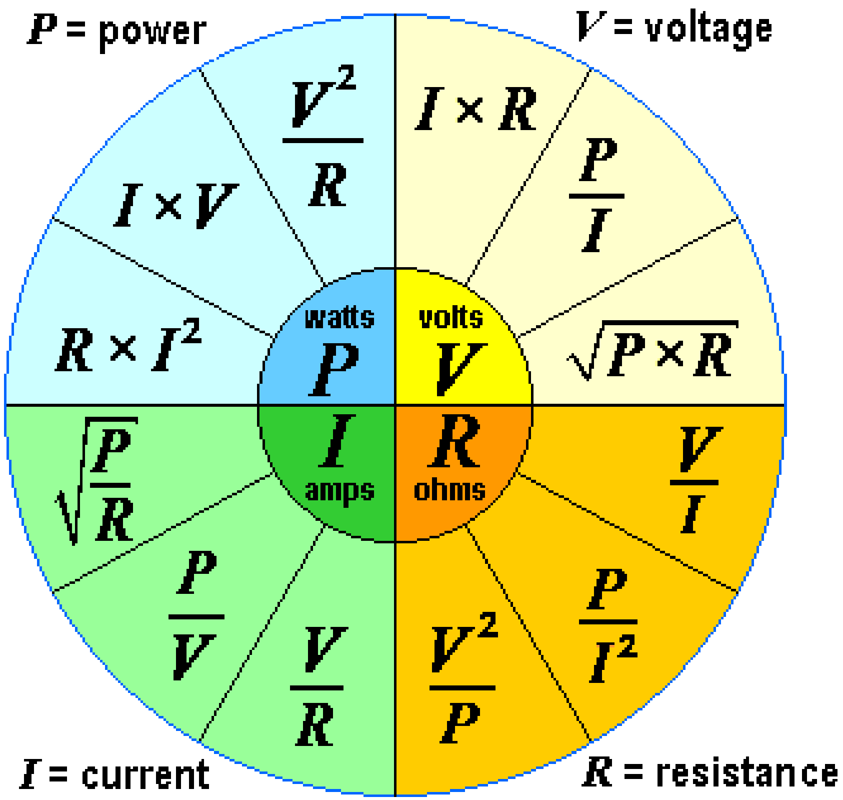




$$V = I \times R \qquad I = \frac{V}{R} \qquad R = \frac{V}{I}$$



Power Law



P = power
V = voltage
I = current
R = resistance
watts
P
volts
V
I
amps
R
ohms
$\frac{V^2}{R}$
$I \times V$
$R \times I^2$
$I \times R$
$\frac{P}{I}$
$\sqrt{P \times R}$
$\sqrt{\frac{P}{R}}$
$\frac{P}{V}$
$\frac{V}{R}$
$\frac{V}{I}$
$\frac{P}{I^2}$
$\frac{V^2}{P}$

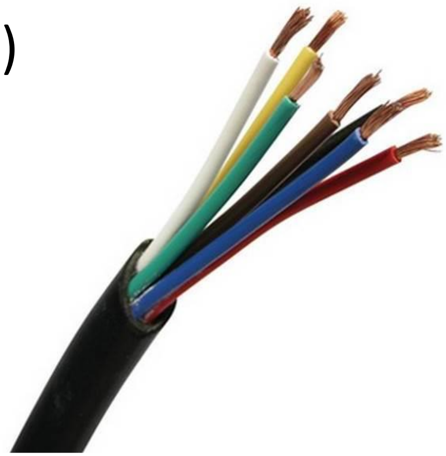
COMPONENTS

Types of Components

- Passive Components:
  - Doesn't require energy to operate, except for the available current from the circuit that it is connected to.
  - E.g., wires & cables, switches, relays, resistors, capacitors, RC circuits

Wires & Cables

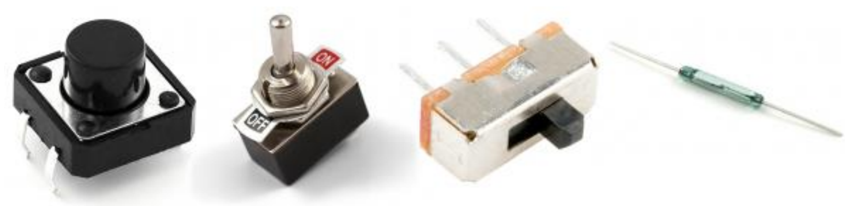
- Wire:
  - A conductor (e.g., copper) covered by an insulator
  - Solid or stranded
  - Diameter determines the current
  - Gauge determines the diameter
- Cable:
  - Multiple wires
- Other factors:
  - Capacitance and shielding in wires carrying data

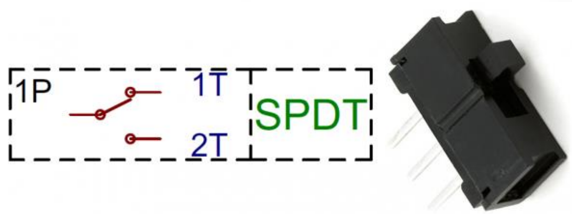


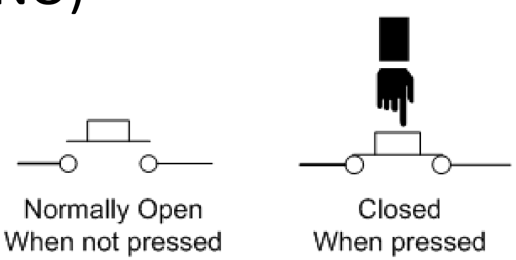
Wire Gauge and Breaker Rating		
Wire Gauge	Approximate Wire Diameter Inch / Millemeter	Breaker Rating
14	0.111 / 2.819	15 Amp
12	0.130 / 3.302	20 Amp
10	0.164 / 4.166	30 Amp
8	0.216 / 5.486	40 Amp

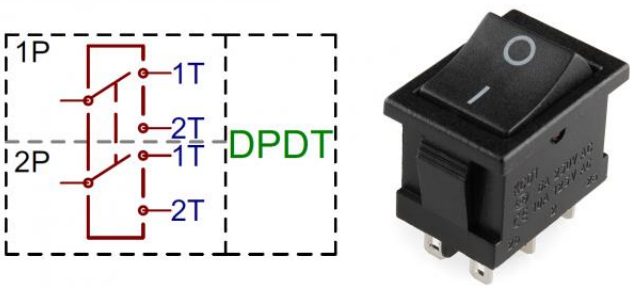
Switches (Mechanical)

- Used to interrupt/permit or direct/select current flow/signal in a circuit
- Types:
  - Single pole / multiple pole
  - Toggle / push button / slide / rotary
  - Normally closed (NC) / normally open (NO) contacts



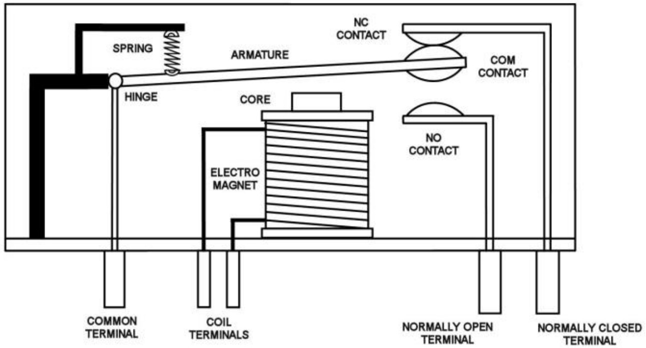


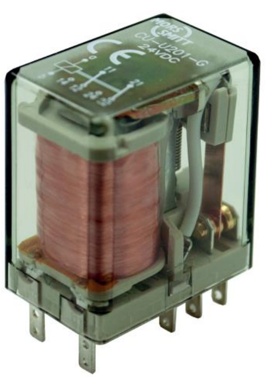


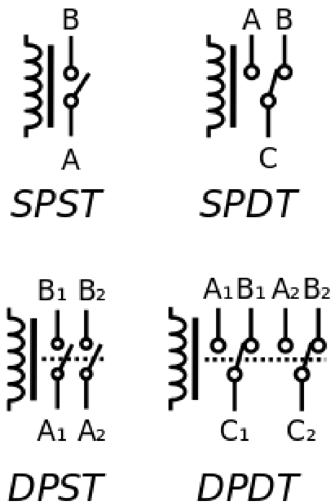


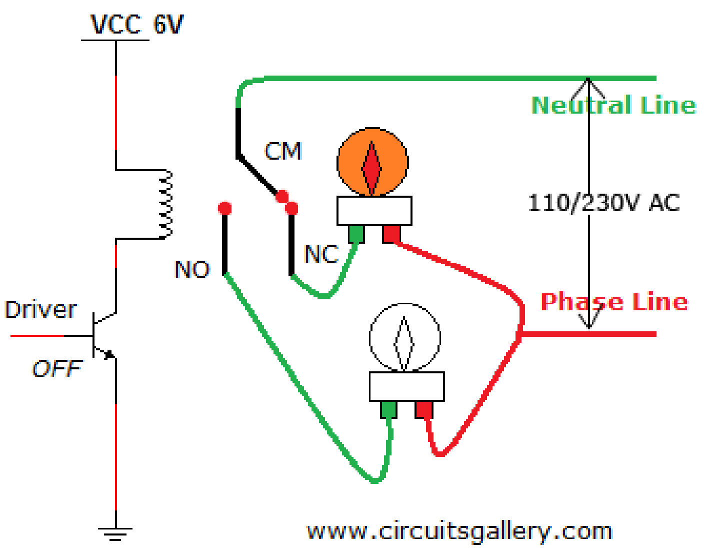
Relays

- A special kind of switch or an electromechanical amplifier which can switch larger currents
- Interface device



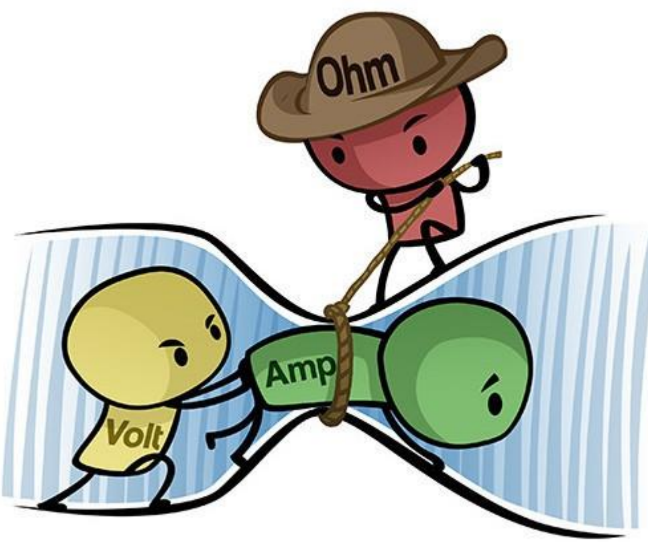


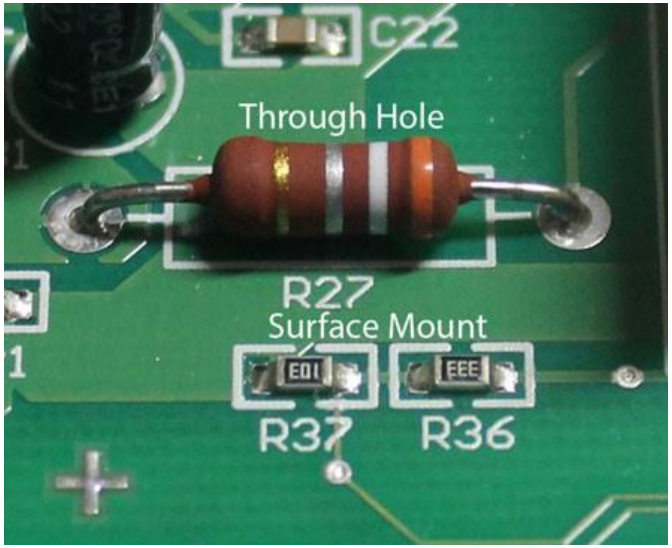


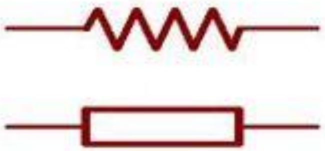


Resistors

- Limit or resist current flow
- Measures in ohm or Ω
- Many shapes and sizes

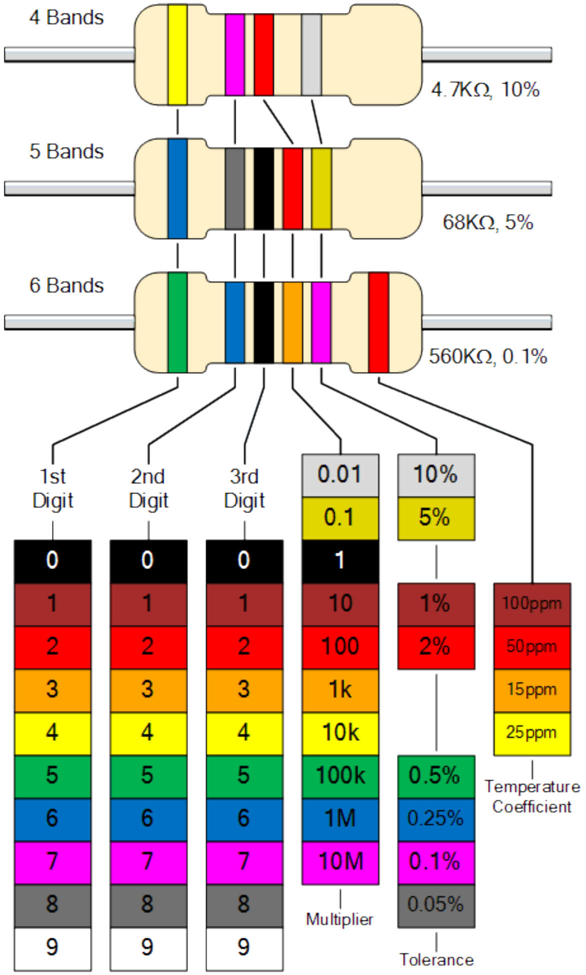






Resistors

- Limit or resist current flow
- Measures in ohm or Ω
- Many shapes and sizes
- Many resistance values
- Tolerance, e.g., 10%, 5%, 1%



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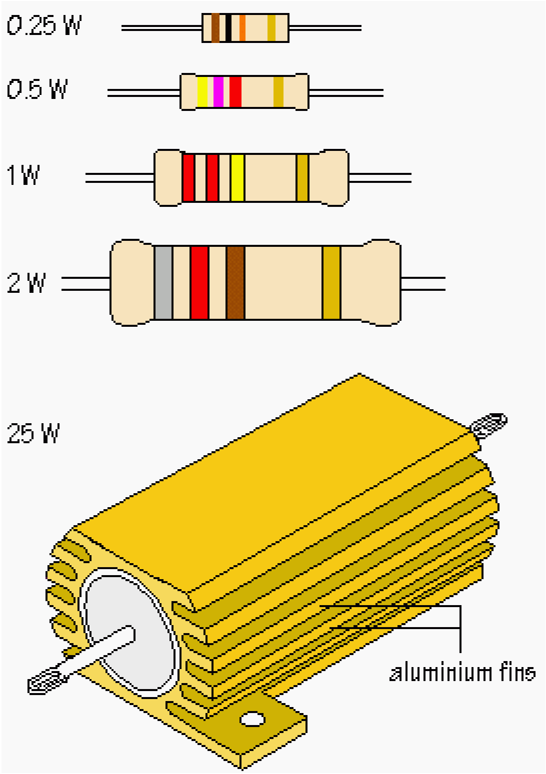
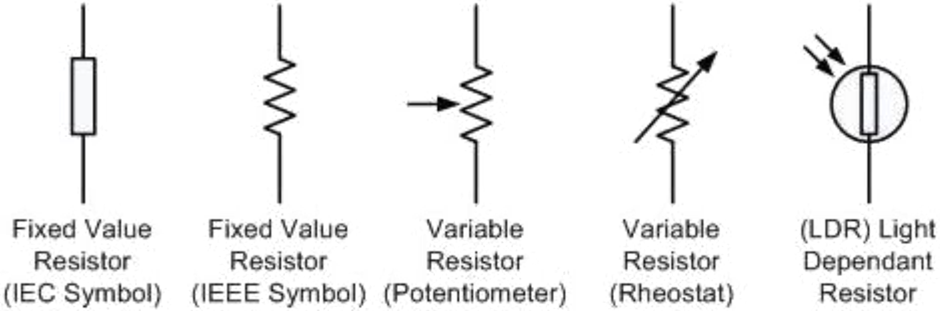


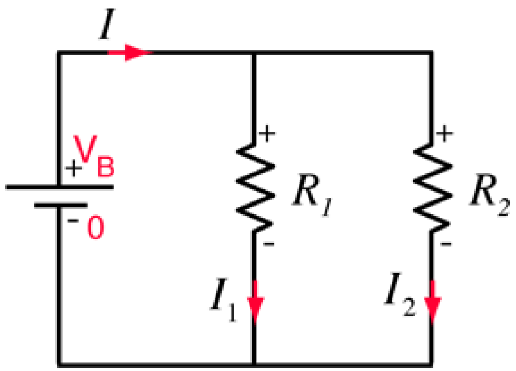
Resistors

- Limit or resist current flow
- Measures in ohm or Ω
- Many shapes and sizes
- Many resistance values
- Tolerance, e.g., 10%, 5%, 1%
- Power ratings in Watts
- Fixed vs variable values



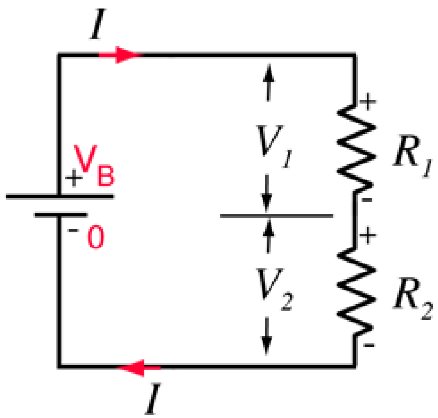
Connecting Resistors

- Series
- Parallel



Parallel resistors

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$

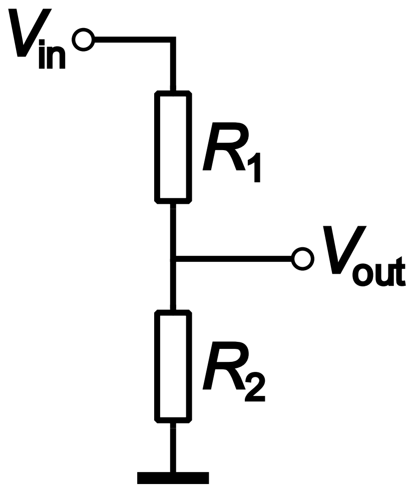


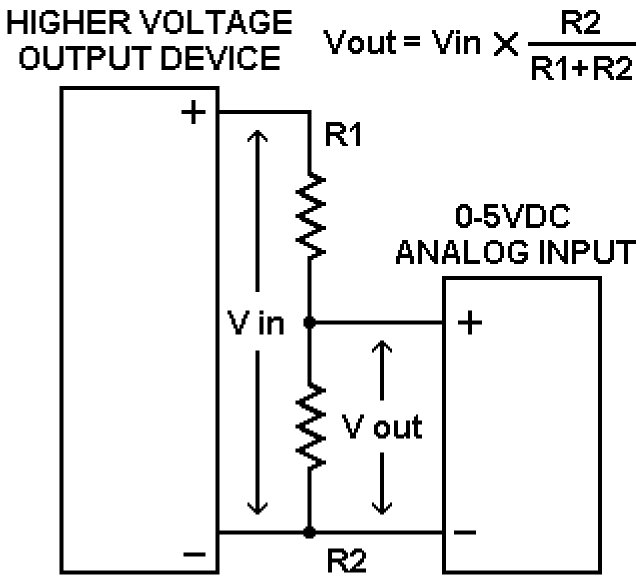
Series resistors

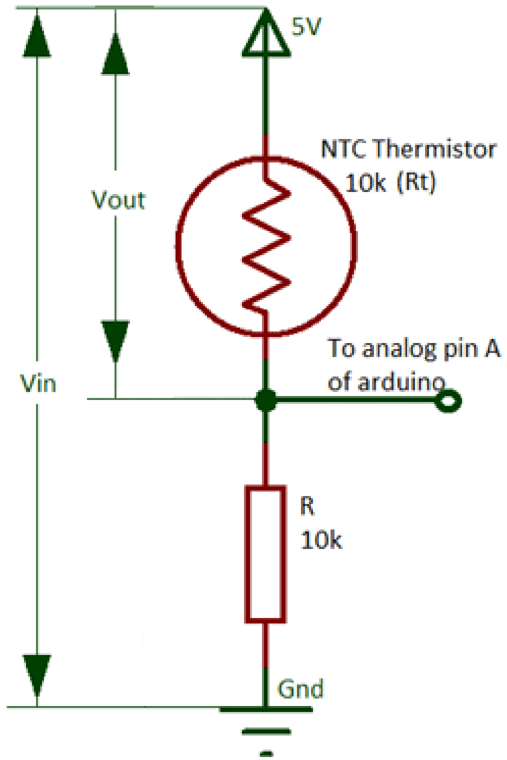
$$R_{equivalent} = R_1 + R_2$$

Voltage Division/Divider

- Signal matching between the output of one circuit to input of another circuit, voltage reference, sensor conditioning, etc.

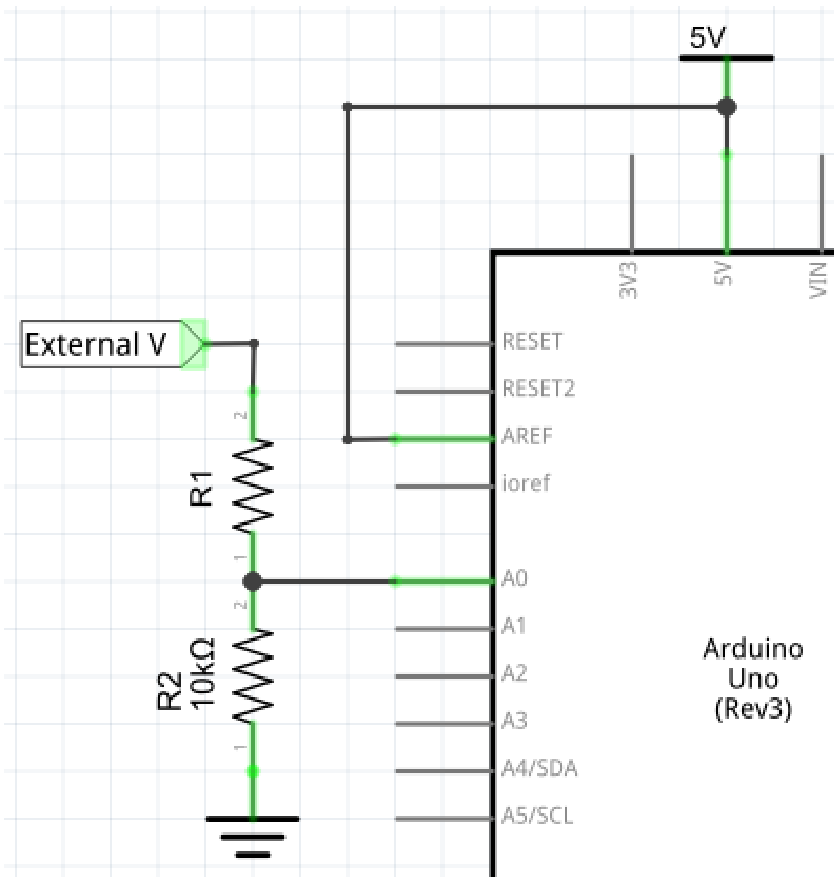






Exercise

- A student has constructed the given circuit to measure an external voltage using the Arduino Uno microcontroller board.
  - Determine the value of R1 if the student wants to measure a maximum voltage of 25V using the above circuit.
  - What is the resolution (voltage per bit) of the above circuit? Note: Arduino uses a 10-bit analog-to-digital converter.
  - If the analogRead(A0) returns 785, what is the corresponding input voltage?

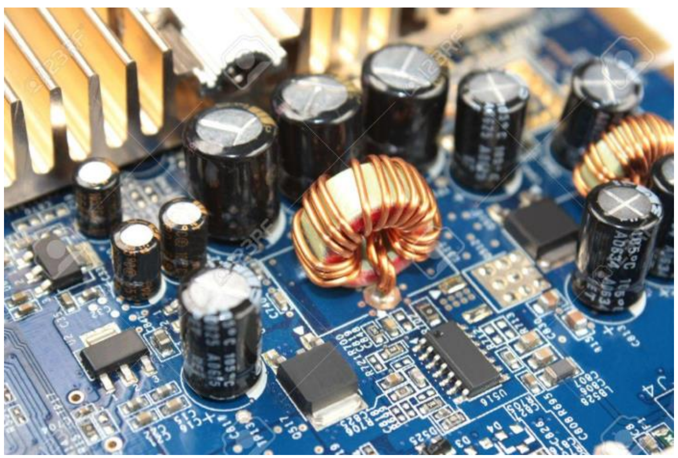


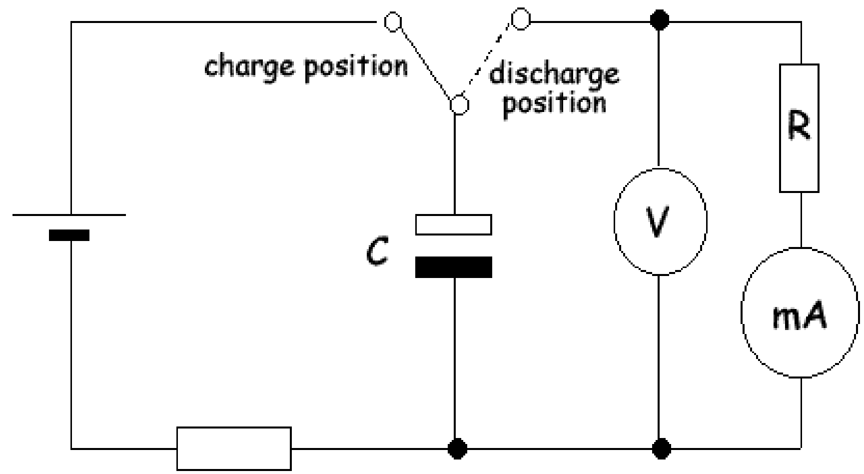
Exercise: Answers

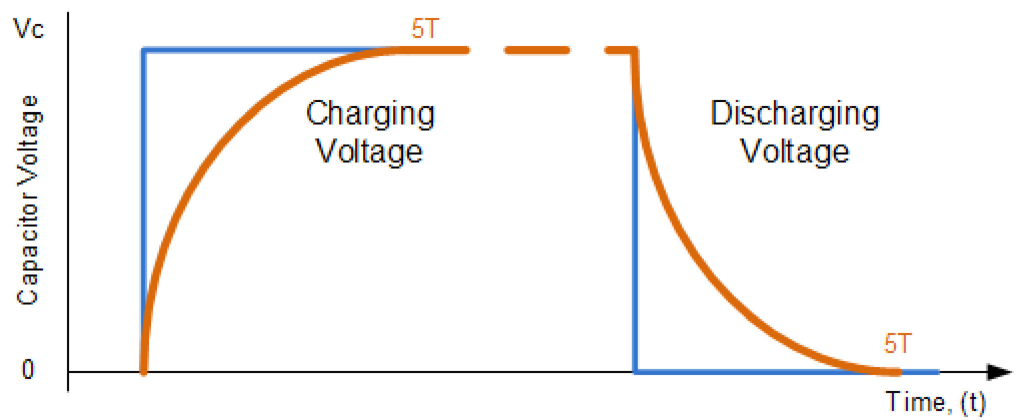
- Part 1:
  - (R1+R2)/R2 = 25/5 => R1 = 40kΩ
- Part 2:
  - 10-bit A/D → it will map input voltages between 0 and 5 volts into integer values between 0 and 1023
  - Therefore, resolution for 5V = 5/1024 = 0.0049V per unit
  - However, since a voltage divider is used, the resolution = 0.0049 * 5 = 0.0245V, Or, 25/1024
- Part 3:
  - Vin = 785 * 5/1024 * 5 = 19.16V

Capacitors

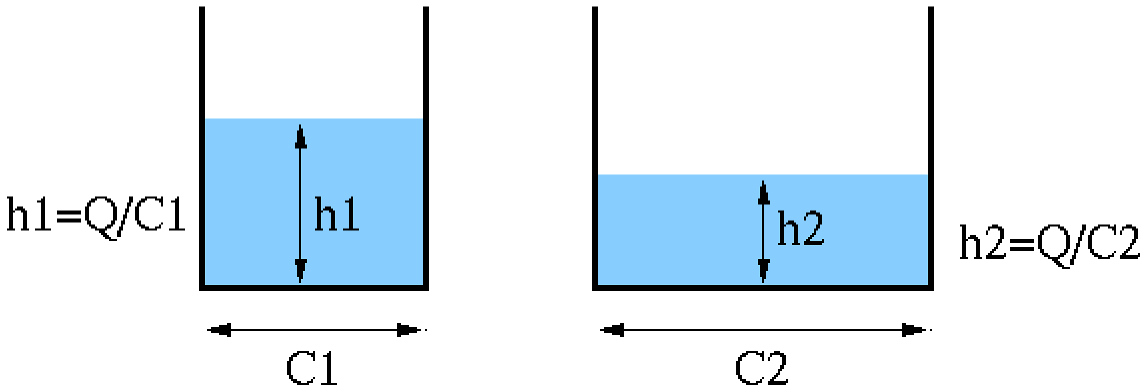
- Stores an electrical charge
- Measures in 'Farad'





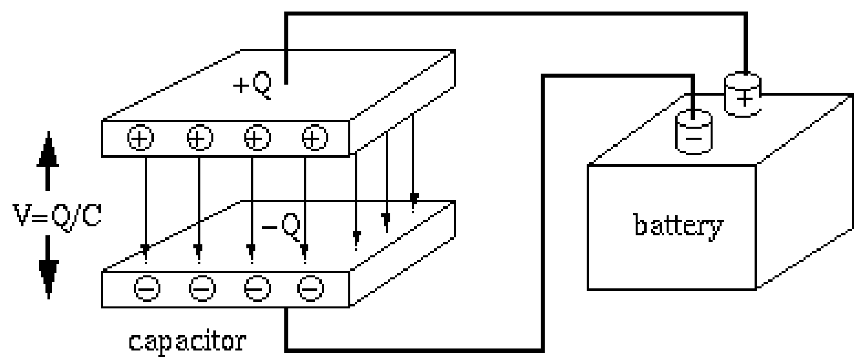


Capacitors – Water Analogy 1



water tank analogy of V=Q/C

$$V = \frac{Q}{C}, \qquad Q = VC, \qquad C = \frac{Q}{V}$$



Coulomb

Units of charge

One way to count charge is in units of the electron's charge:

1 electron has charge	$-1\,e$
5 electrons	$-5\,e$
18 protons	$+18\,e$

Another unit – the official SI unit of charge – is much, much bigger:

$$1 \text{ Coulomb (C)} = 6.25 \times 10^{18}\ e$$

Therefore,

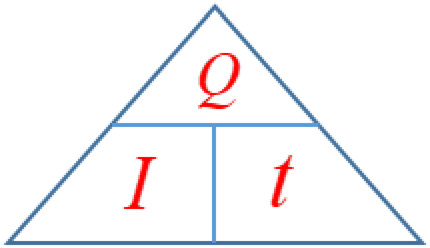
$$1 \text{ electron} = \frac{-1\,C}{6.25 \times 10^{18}} = -1.602 \times 10^{-19}\ C$$

$$1 \text{ proton} = +1.602 \times 10^{-19}\ C$$

A current of 1 Ampere = 1 Coulomb of charge flowing in 1 second

$$I = \frac{Q}{t}$$

$$Q = It$$



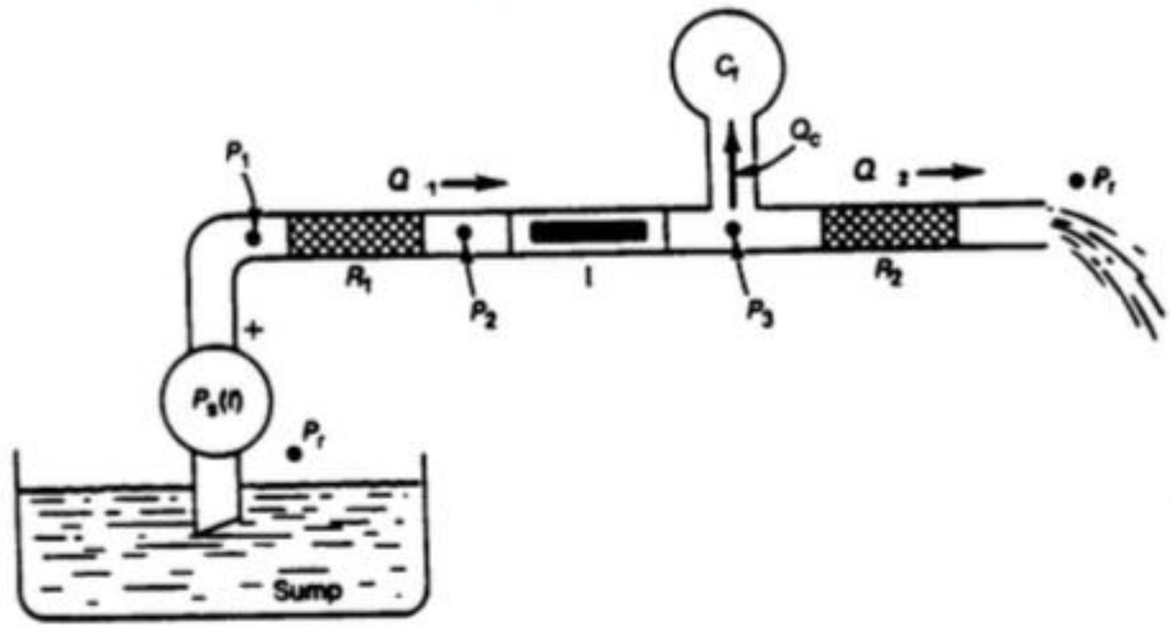
I = Current in amperes (A)

Q = Charge in coulombs (C)

t = time in seconds (s)

Capacitors – Water Analogy 2

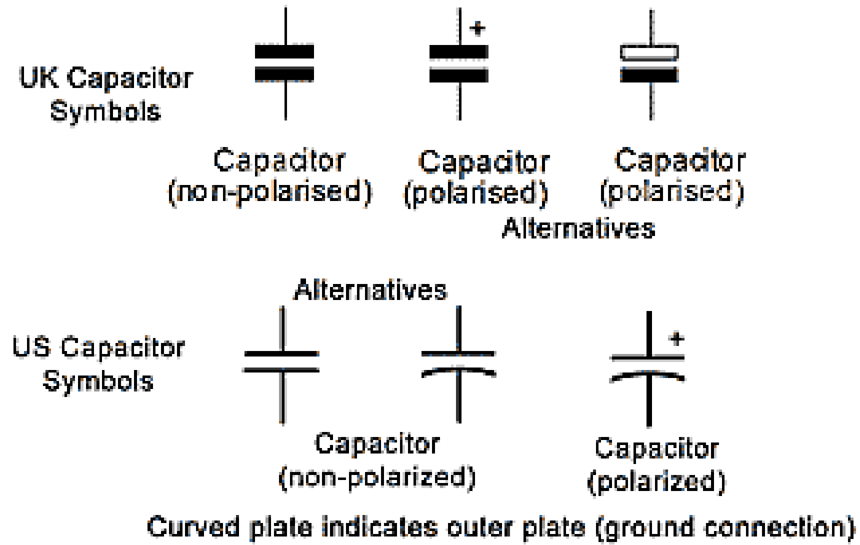
The figure below shows a second-order hydraulic filter:

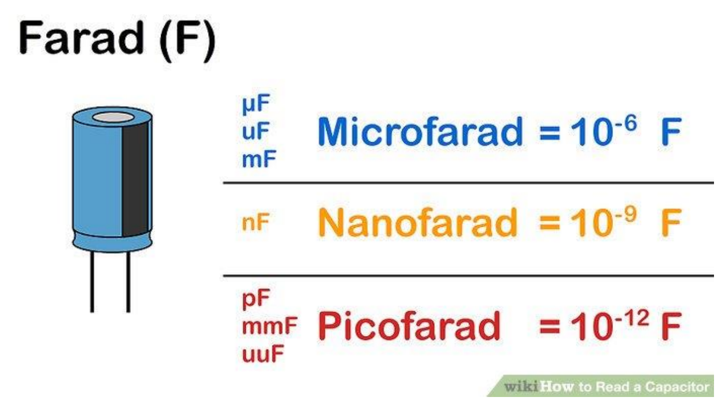


The fluid capacitance C_f is actually a hydraulic accumulator that uses an air bag to store hydraulic pressure inside the can. It operates very much like an open tank except that the energy is stored via the compression of the air bag rather than as a height of fluid in a gravity field. You can assume that the pressure inside the air bag is reference pressure P_r.

Capacitors

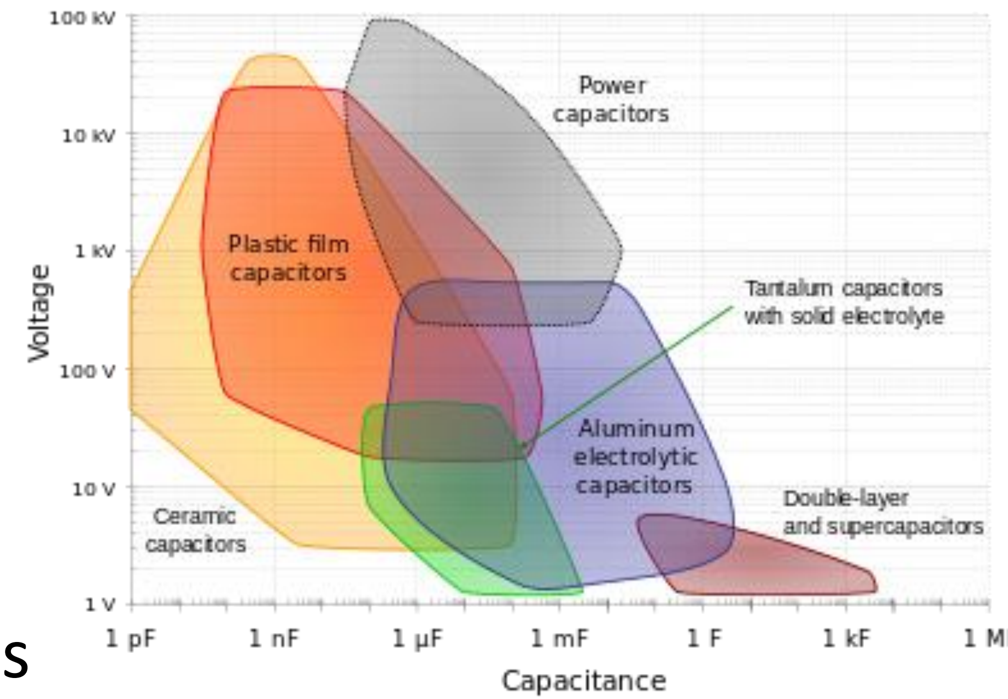
- Stores an electrical charge
- Measures in ‘Farad’
- Many types, shapes, sizes, and values

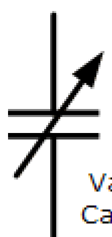




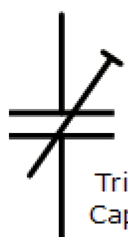
Capacitors

- Stores an electrical charge
- Measures in 'Farad'
- Many types, shapes, sizes, and values
- Voltage ratings
- Fixed and variable types





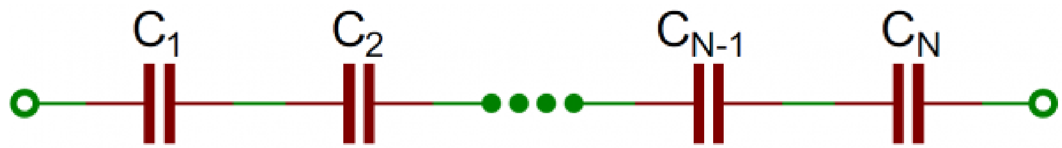
Variable Capacitor Symbol



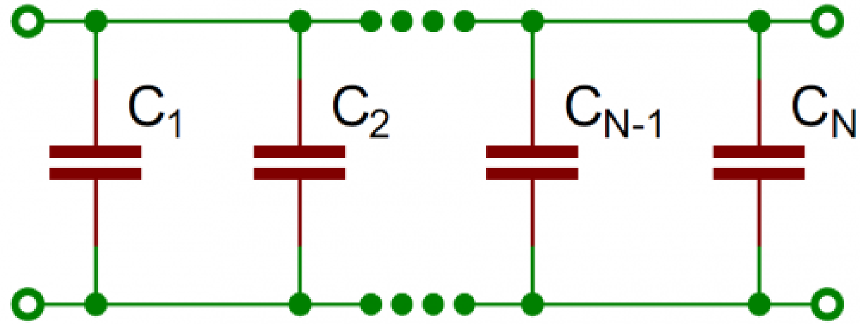
Trimmer Capacitor Symbol

Connecting Capacitors

- Series
- Parallel

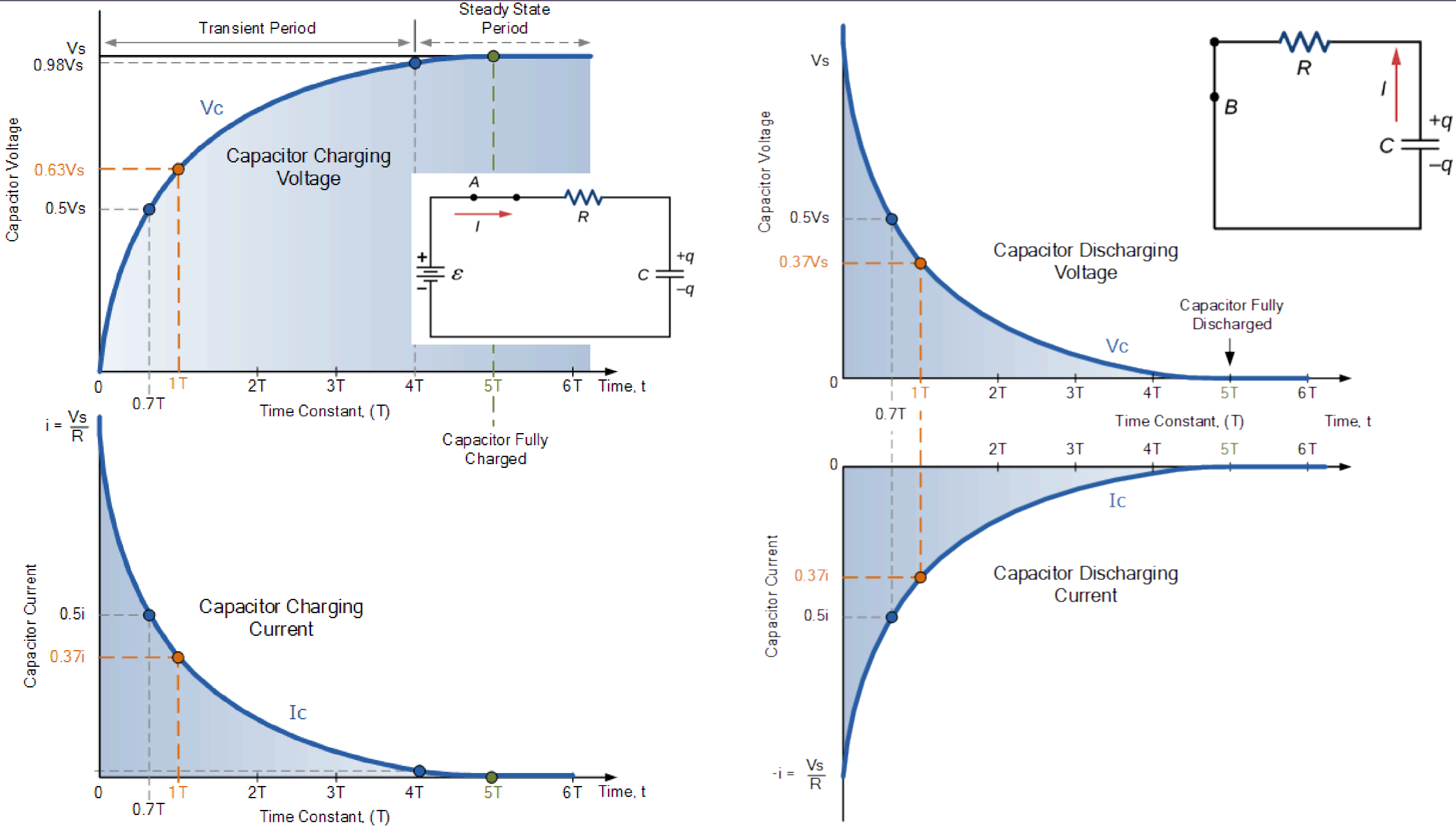


$$\frac{1}{C_{Tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_{N-1}} + \frac{1}{C_N}$$



$$C_{Tot} = C_1 + C_2 + \ldots + C_{N-1} + C_N$$

Resistor Capacitor (RC) Circuits

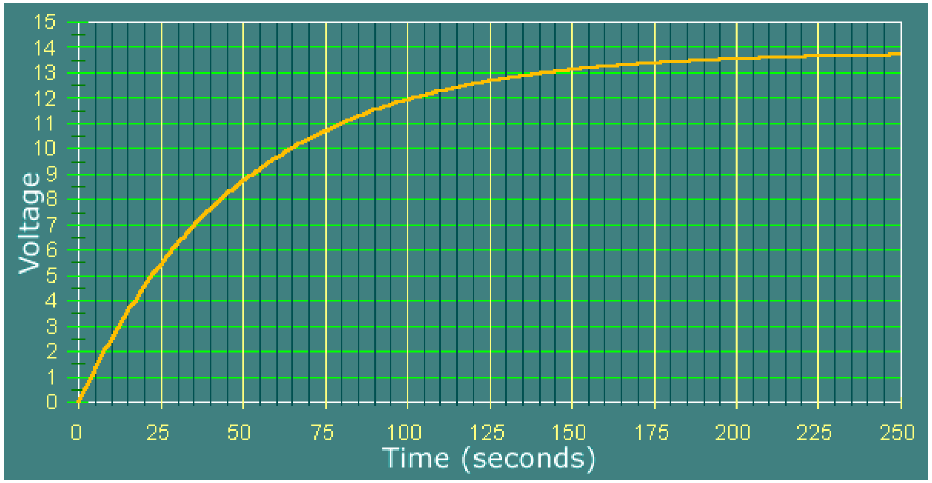


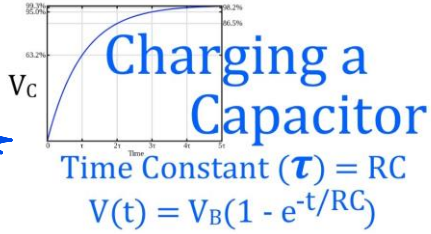
Capacitor: Time Constant

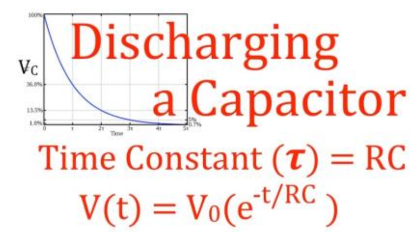
- The time it takes for the capacitor to charge to 63.2% of the supply voltage when charged through a given resistor. $\boxed{T = RC}$.
- E.g., if supply voltage = 10V, after 1T, V= 6.32V; after 5T, V = 9.92V (considered fully charged)
  - 1T = 10 * .632 = 6.32V
  - 2T = (10-6.32) * .632 = +2.32V

3T (10 − 6. − 2)*

- E.g., C = 1 Farad, R = 50 Ohm; T = RC = 50*1 = 50s



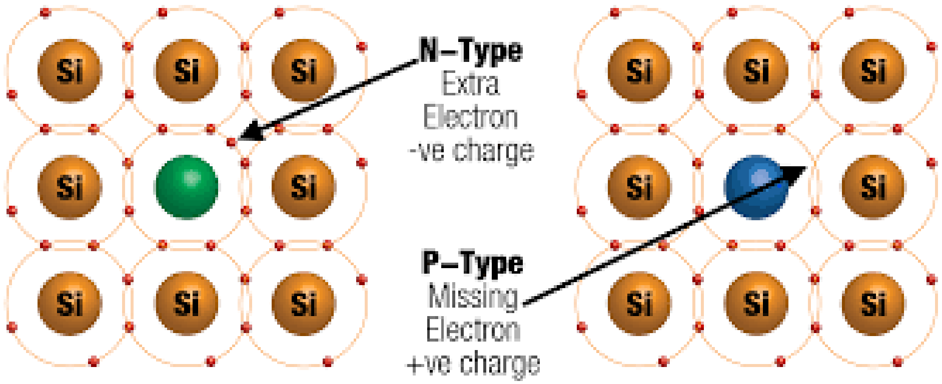




ACTIVE COMPONENTS

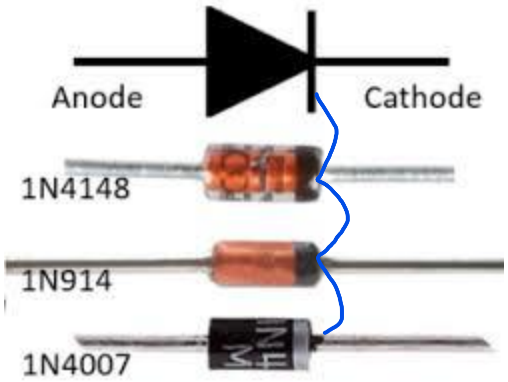
Active Components

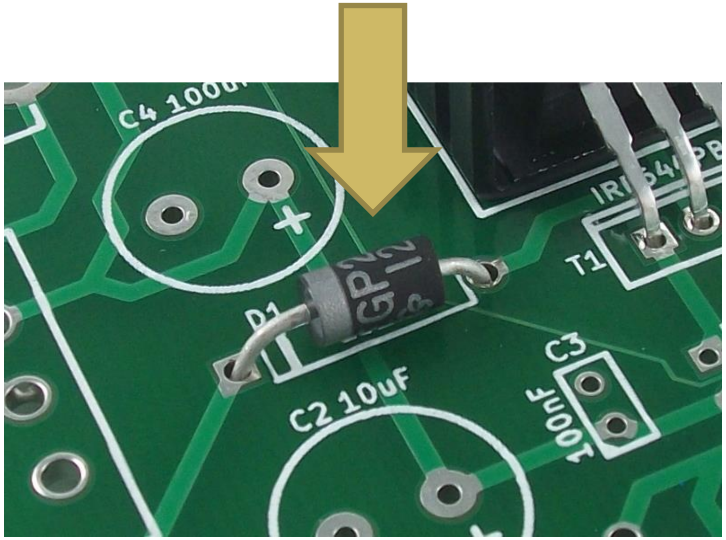
- Activated by an external source of power
- Most of them are made of silicon, after converting them to n-type or p-type semiconductors



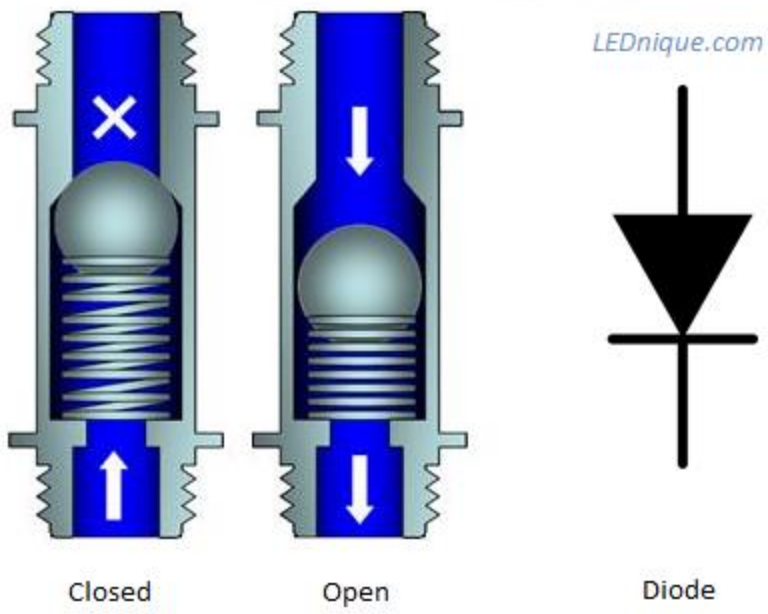
Diode

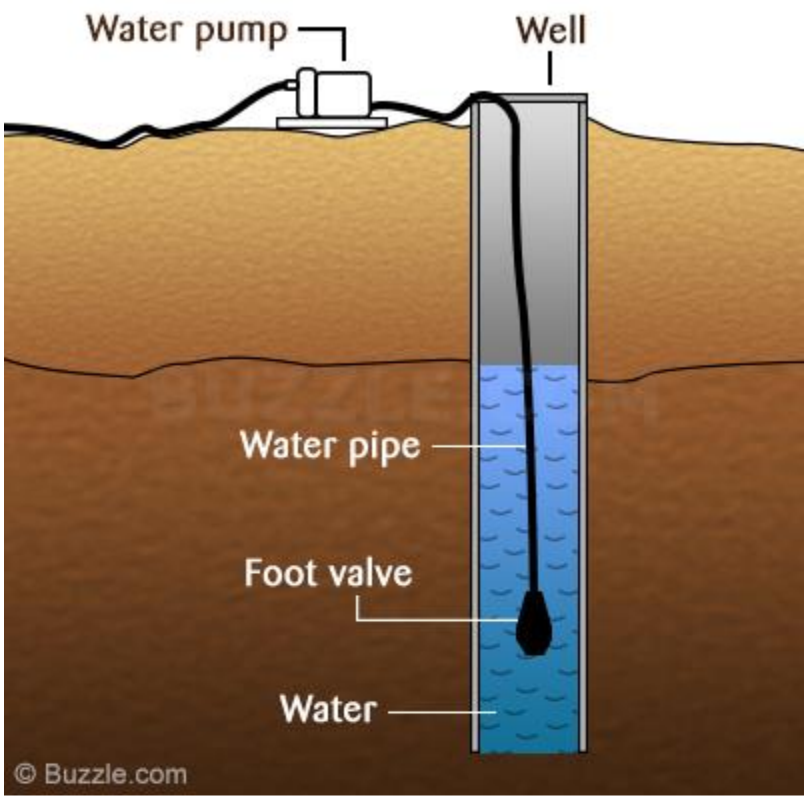
- Allows current to flow in only one direction (when forward biased)
- Applications:
  - RIJU
  - Rectifier in power adapters
  - Protect circuits from inductive loads
  - PRERAKA



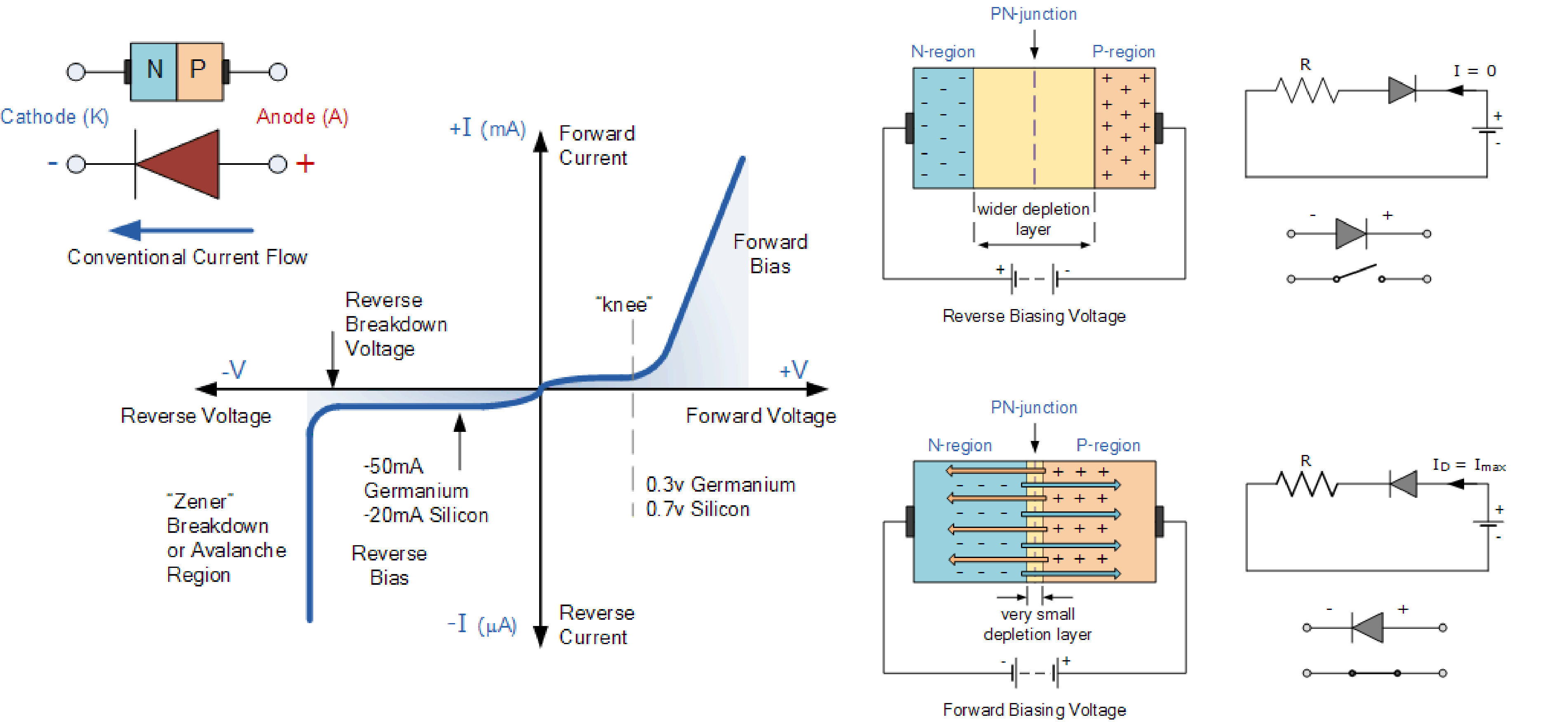


Diode: Water Analogy

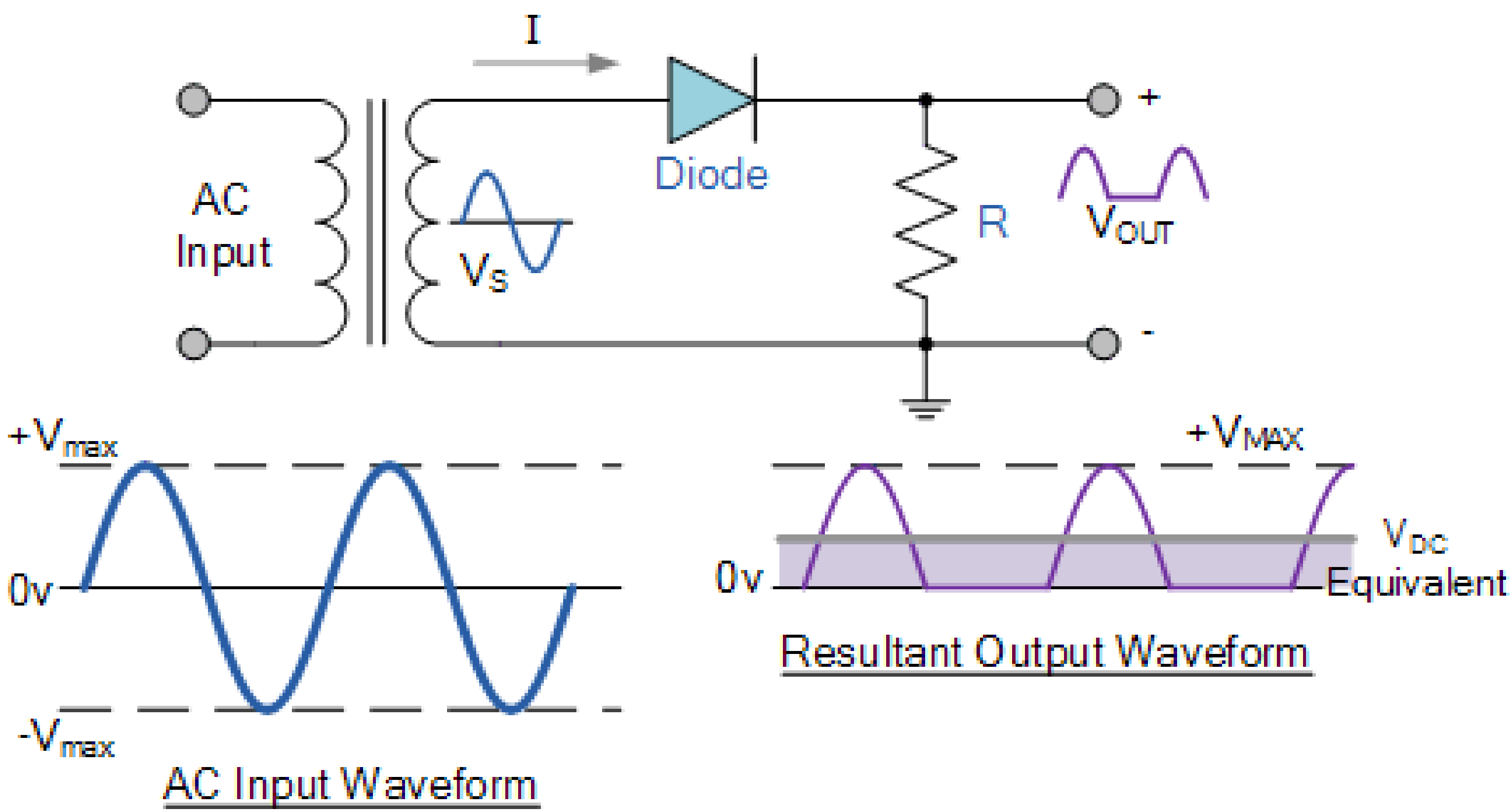




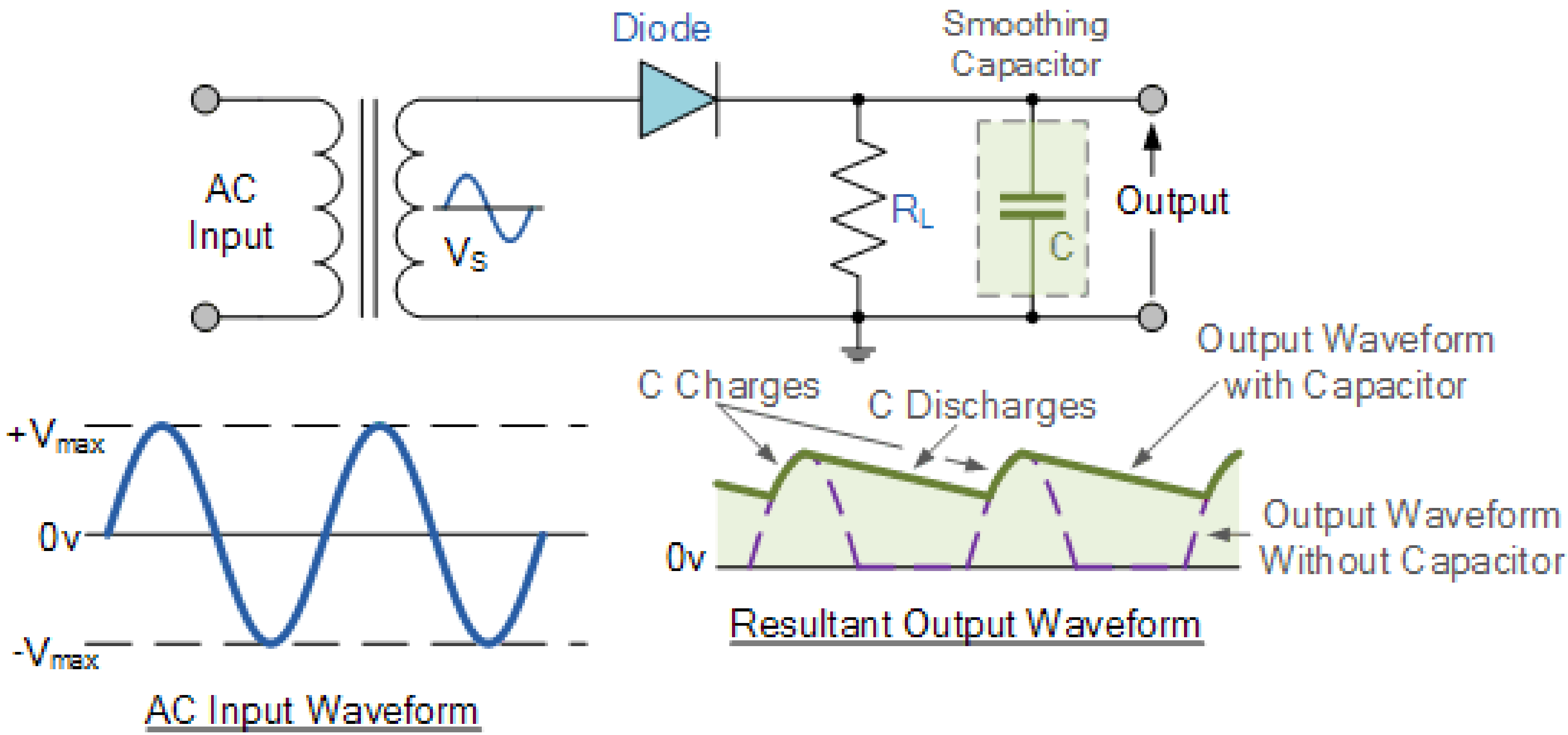
Diode Behavior & VI Characteristics



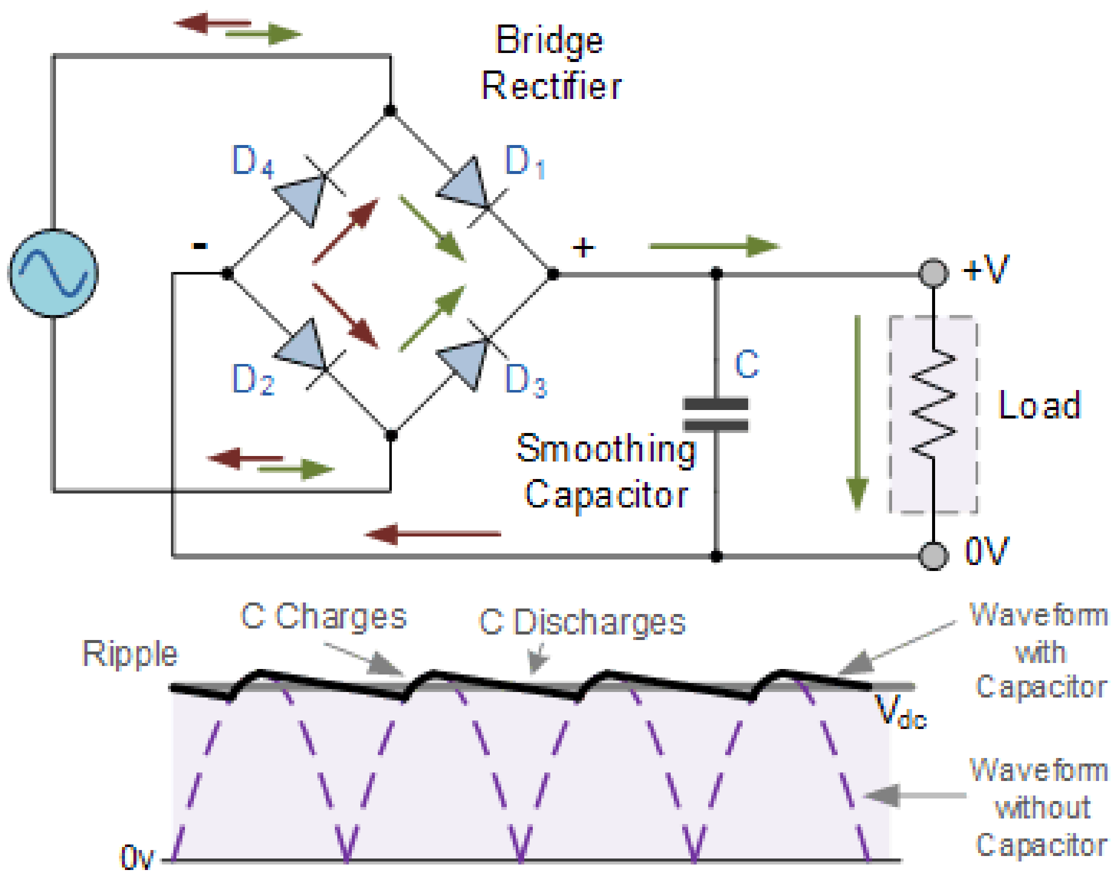
Diode as a Rectifier: Half-Wave



Diode as a Rectifier: Half-Wave, Improved



Diode as a Rectifier: Full-Wave



Resultant Output Waveform

Diode Considerations (E.g., IN400X)

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	1.0 A
V_{RRM}	50 V to 1000 V
I_{FSM} (8.3 ms sine-wave)	30 A
I_{FSM} (square wave t_p = 1 ms)	45 A
V_F	1.1 V
I_R	5.0 µA
T_J max.	150 °C

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies, inverters, converters and freewheeling diodes application.

Note

- These devices are not AEC-Q101 qualified.

MECHANICAL DATA

Case: DO-204AL, molded epoxy body
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS compliant, commercial grade

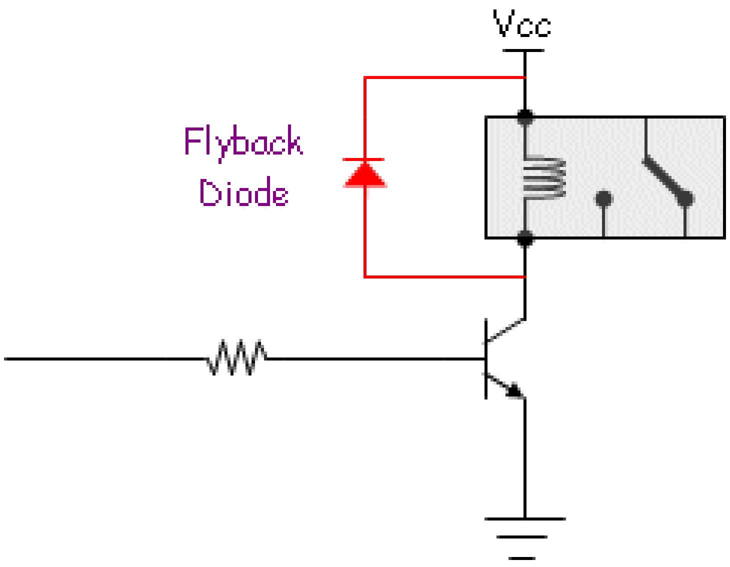
Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

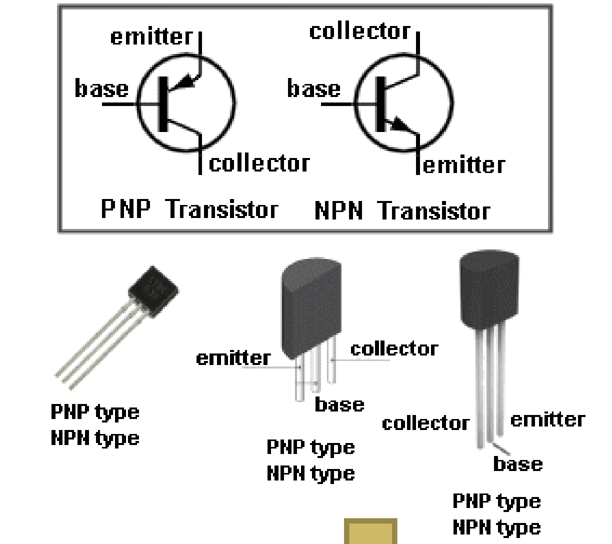
PARAMETER	SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum repetitive peak reverse voltage	V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage	V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage	V_{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified current 0.375" (9.5 mm) lead length at T_A = 75 °C	$I_{F(AV)}$	1.0							A
Peak forward surge current 8.3 ms single half	[illegible]	[illegible]							[illegible]

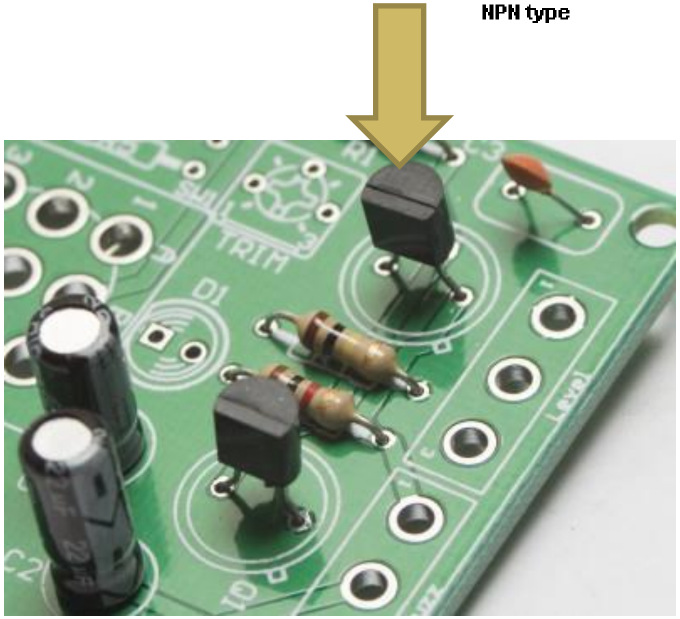
Freewheel Diode

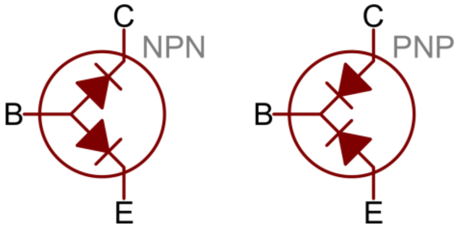


Transistor

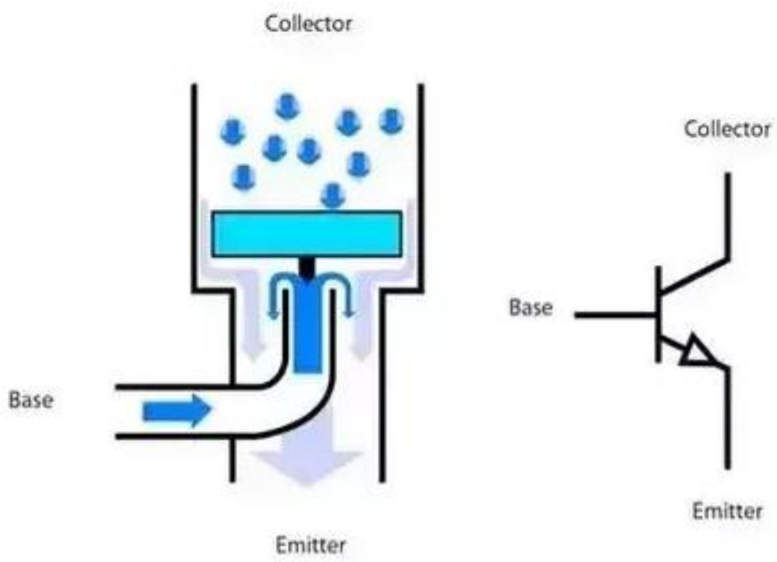
- Allows to control a large current using a small current (i.e., amplifier or switch)
- Two types: NPN or PNP
- Leads/pins: Base, Emitter, and Collector

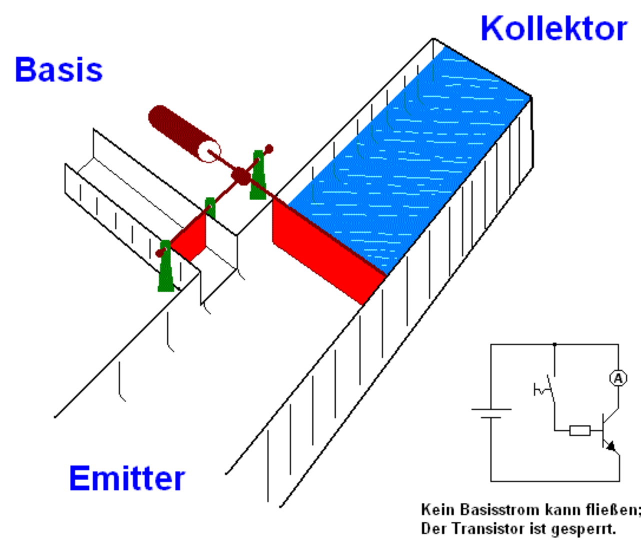


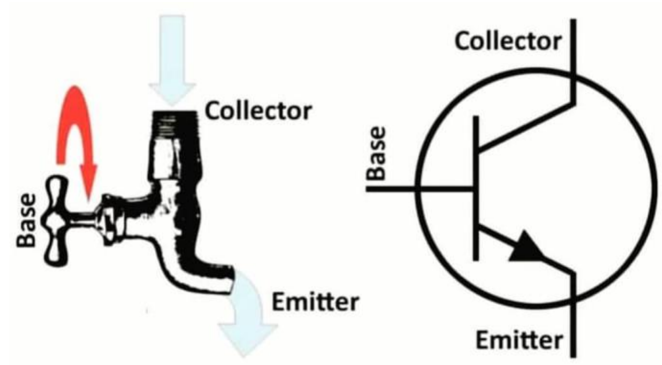




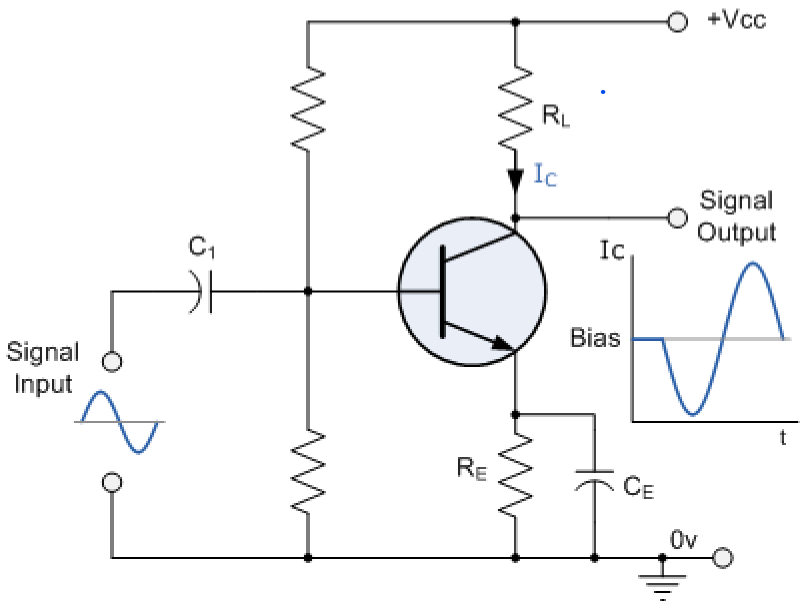
Transistor: Water Analogy

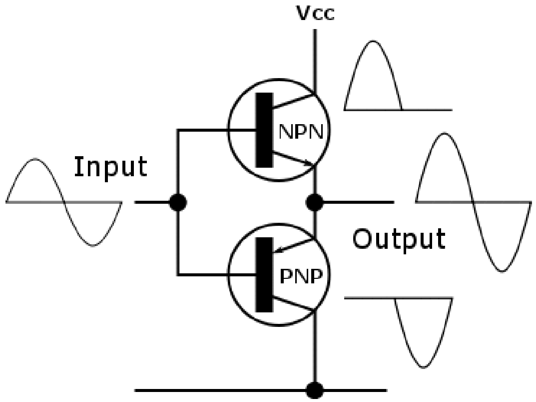




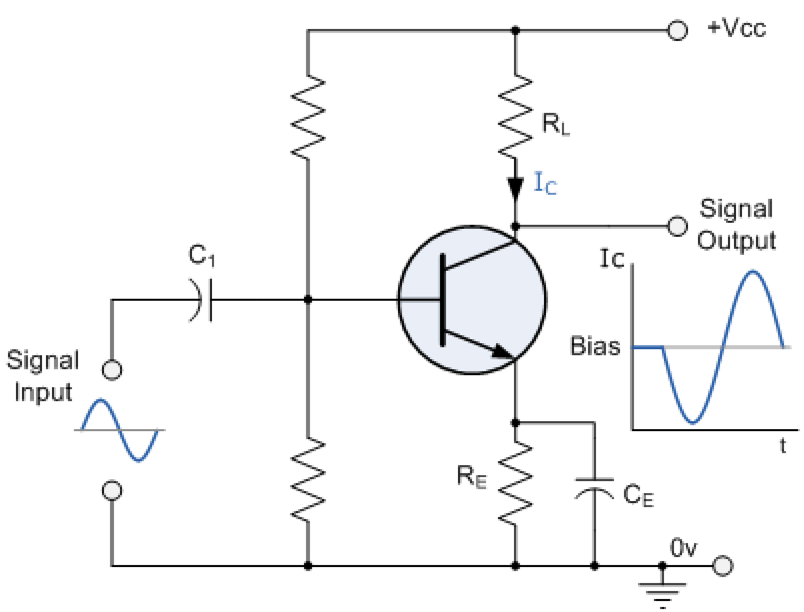


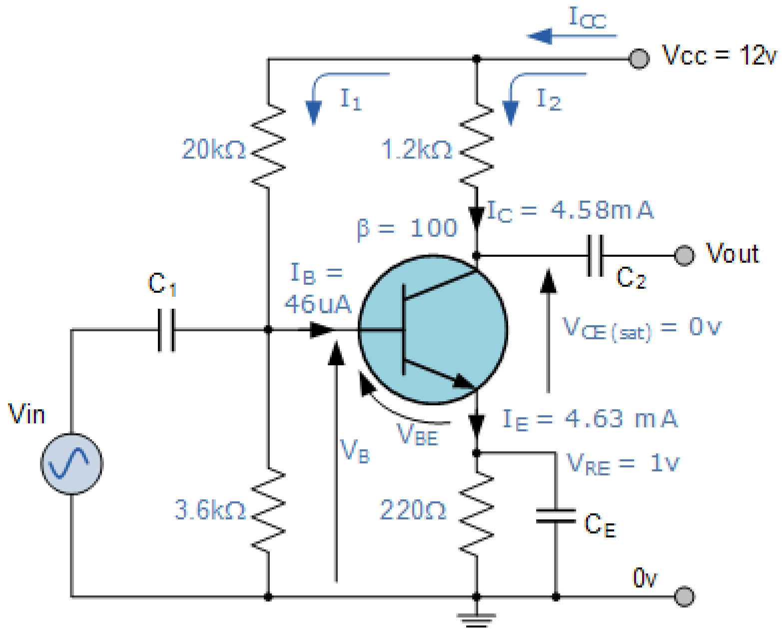
Transistor as an Amplifier (Common Emitter Mode)



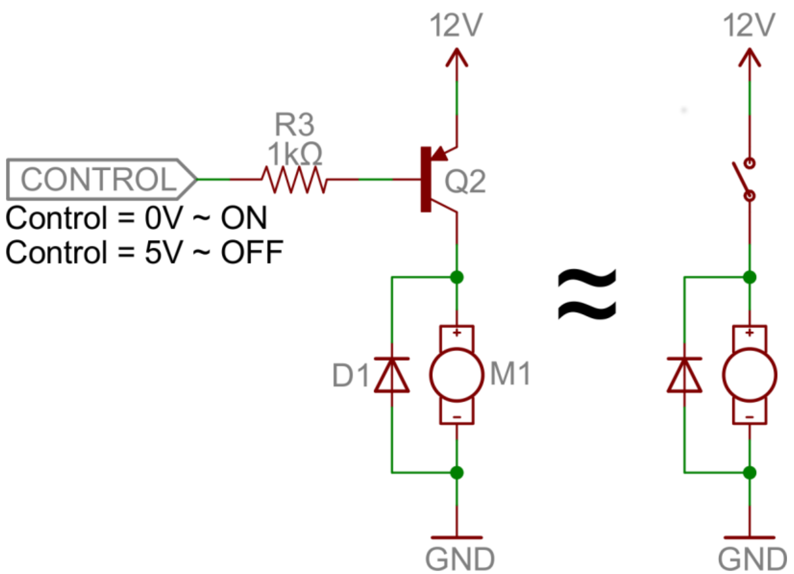


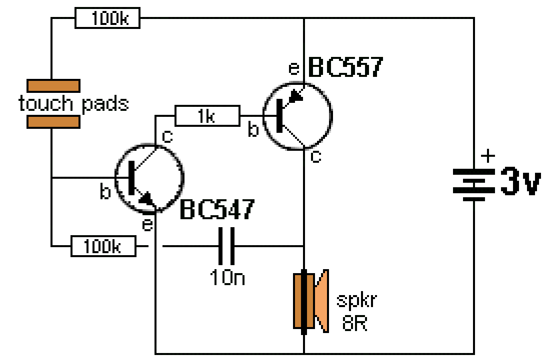
Transistor as an Amplifier (Common Emitter Mode)

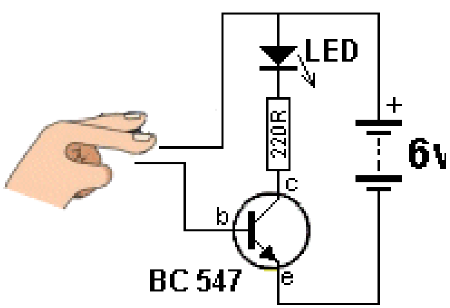


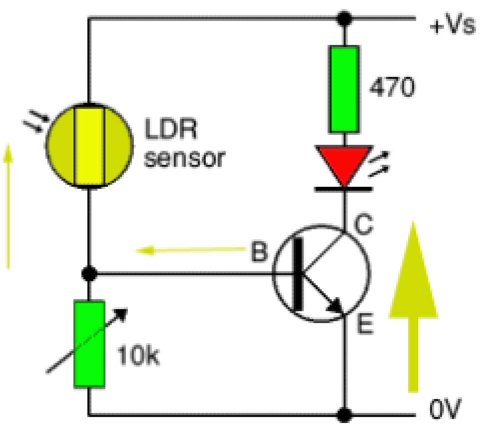


Transistor as a Switch

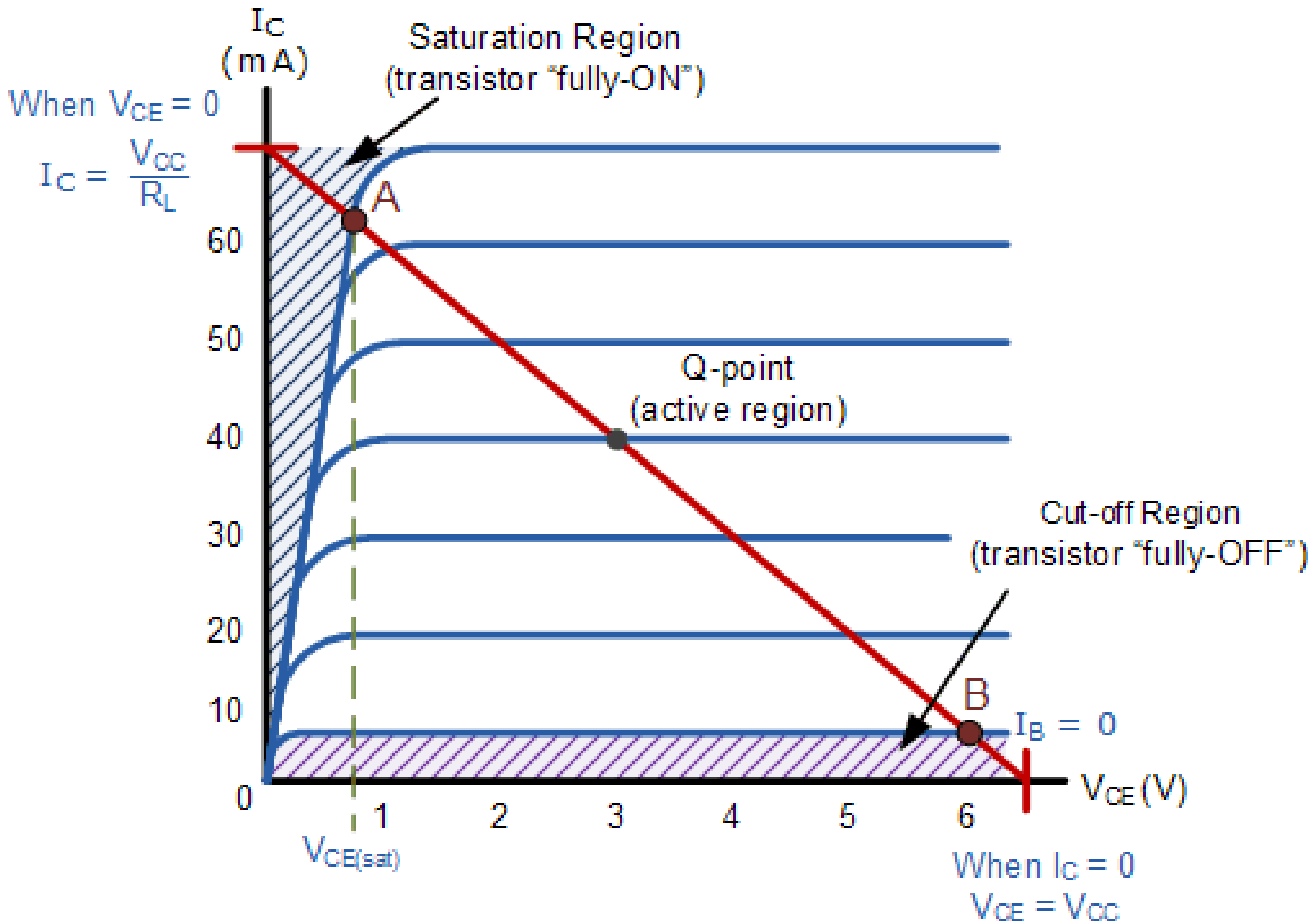








Transistor Characteristics

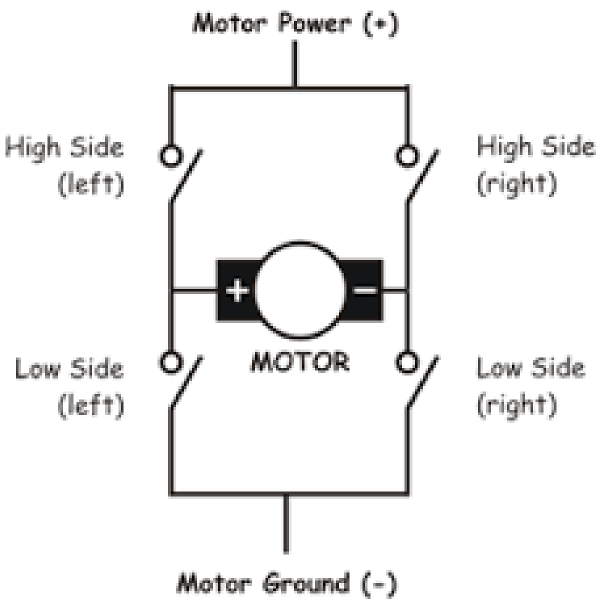


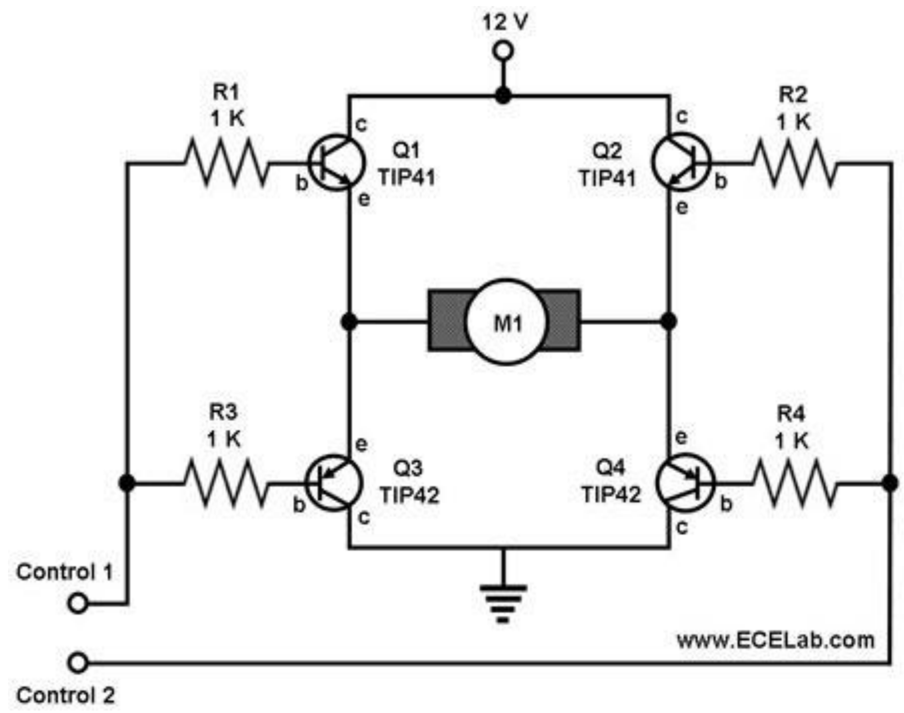
Transistor Considerations (E.g., BC547)

Symbol	Parameter		Value	Unit
V_{CBO}	Collector-Base Voltage	BC546	80	V
		BC547 / BC550	50	
		BC548 / BC549	30	
V_{CEO}	Collector-Emitter Voltage	BC546	65	V
		BC547 / BC550	45	
		BC548 / BC549	30	
V_{EBO}	Emitter-Base Voltage	BC546 / BC547	6	V
		BC548 / BC549 / BC550	5	

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
I_{CBO}	Collector Cut-Off Current	V_{CB} = 30 V, I_E = 0			15	nA
h_{FE}	DC Current Gain	V_{CE} = 5 V, I_C = 2 mA	110		800	
V_{CE}(sat)	Collector-Emitter Saturation Voltage	I_C = 10 mA, I_B = 0.5 mA		90	250	mV
		I_C = 100 mA, I_B = 5 mA		250	600	
V_{BE}(sat)	Base-Emitter Saturation Voltage	I_C = 10 mA, I_B = 0.5 mA		700		mV
		I_C = 100 mA, I_B = 5 mA		900		
V_{BE}(on)	Base-Emitter On Voltage	V_{CE} = 5 V, I_C = 2 mA	580	660	700	mV
		V_{CE} = 5 V, I_C = 10 mA			720	
f_T	Current Gain Bandwidth Product	V_{CE} = 5 V, I_C = 10 mA, f = 100 MHz		300		MHz

Transistor H-Bridge



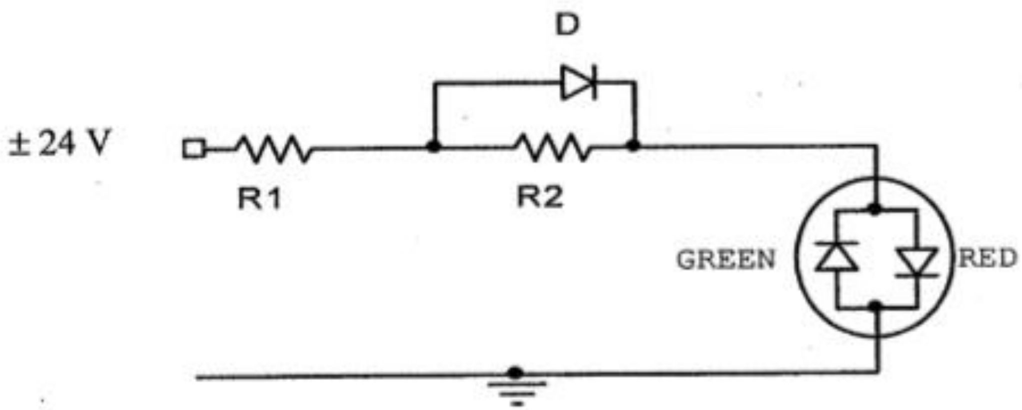


Exercise 1

(a). Suppose that you are given two LEDs (LED A and LED B) and a 3 V DC power supply. Draw a schematic diagram of a circuit capable of illuminating LEDs A and B alternatively by changing a position of the lever of a single switch. (Hint. Use a DPDT switch)

[5 marks]

(b). If potential barrier voltages of green and red LEDs are 1.7 V and 2.5 V respectively, find suitable resistor values for R1 and R2. (Take typical forward current for any LED = 5 mA and supply voltage = ± 24 V)



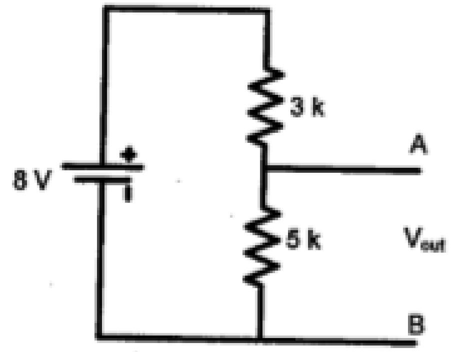
[5 marks]

Exercise 2

(a). Is it advisable to plug 1100 W kettle in to a 5 A main supply wall socket? Justify your answer.

[5 marks]

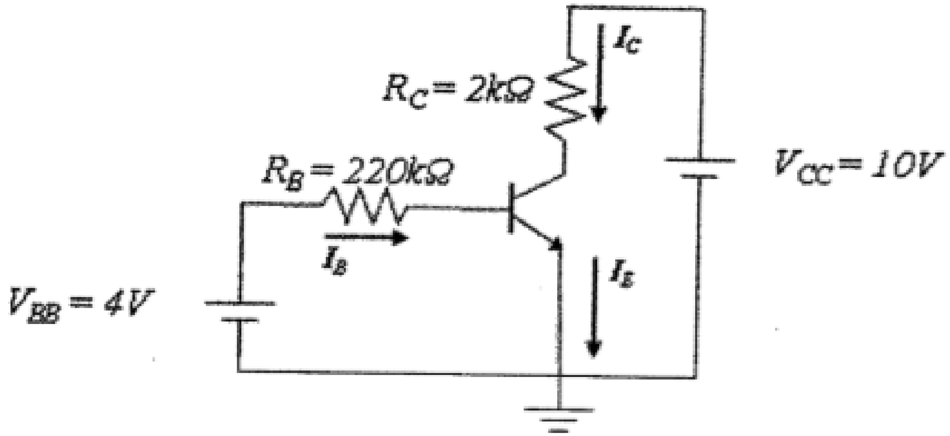
(b). When an unknown resistance (R) is connected to the output (A,B), its voltage is observed to decrease to 80% of the value when nothing is connected to it. What is the value of the resistance R?



[5 marks]

Exercise 3

(a) Consider the following circuit diagram of a Bipolar Junction Transistor with the following specifications.
$\beta = 100$, $V_{BE} = 0.7$ V



(i) Calculate the base current, I_B.

[5 marks]

(ii) Calculate the collector current, I_C.

[2 marks]

(iii) What is the value of the emitter current, I_E.

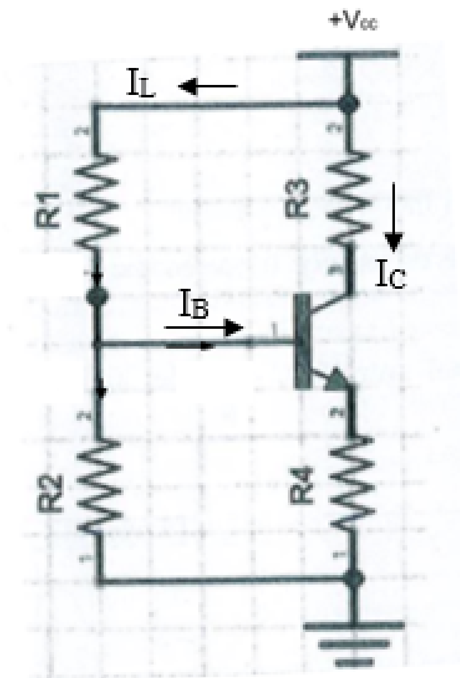
[2 marks]

(iv) Determine the value of V_{CE}.

[2 marks]

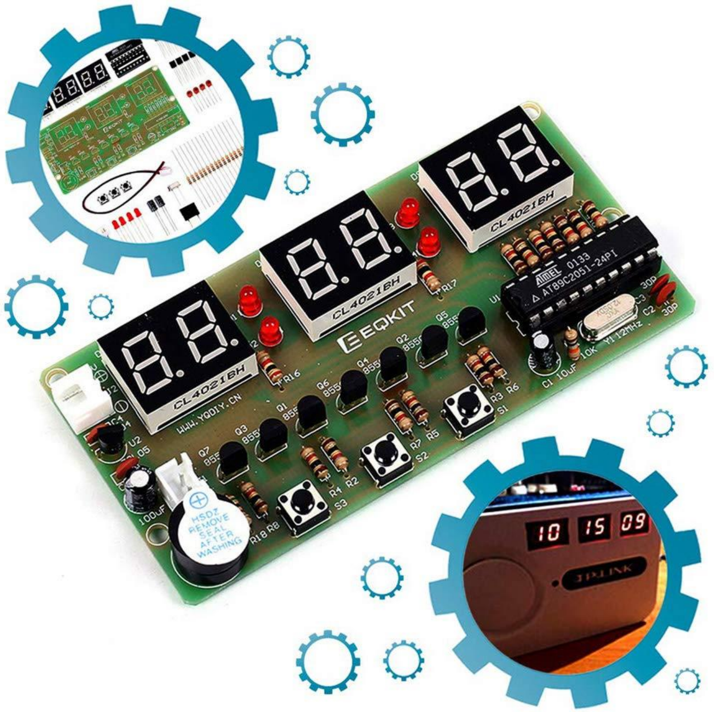
Exercise 4

(d) Consider the following semantic diagram of an amplifier circuit.



Determine the values of R1, R2, and R4 if $\beta = 100$, $I_C = 2mA$, $V_{CE} = 3V$, $R3 = 1.2k\Omega$, $V_{cc} = 9V$, $V_{BE} = 0.3V$ and $I_L = 10\, I_B$.

[9 Marks]



DIGITAL ELECTRONIC FUNDAMENTALS

Outline

- Number systems/codes
- Logic gates
- Combinational logic
- Sequential logic
- Logic levels

Exercise 1

- Represent 1101_2 as a base-10 number.
- Convert 13_{10} to binary.
- Give the hexadecimal equivalence of 707_{10}.
- Give the BCD representation of 137_{10}.

Exercise 1: Answers

$$1101_2 = 1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$$
$$= 13_{10}$$

$$137_{10} = 0001\,0011\,0111 \qquad \text{(BCD)}$$

$$13/2 = 6 \quad \text{remainder} \quad \mathrm{I}$$
$$6/2 = 3 \quad \text{remainder} \quad 0$$
$$3/2 = 1 \quad \text{remainder} \quad 1$$
$$1/2 = 0 \quad \text{remainder} \quad 1$$

from which $13_{10} = 1101_2$.

$$707_{10} = 1011000011_2 \ (= 10\,1100\,0011_2)$$
$$= 2C3_{16}$$

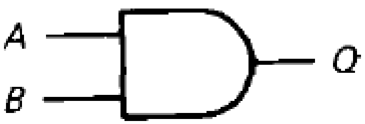
Representing Signed Numbers (HW)

Integer	Sign-magnitude	Offset binary	2's comp
+7	0111	1111	0111
+6	0110	1110	0110
+5	0101	1101	0101
+4	0100	1100	0100
+3	0011	1011	0011
+2	0010	1010	0010
+1	0001	1001	0001
0	0000	1000	0000
–1	1001	0111	1111
–2	1010	0110	1110
–3	1011	0101	1101
–4	1100	0100	1100
–5	1101	0011	1011
-6	1110	0010	1010
–7	1111	0001	1001
-8	–	0000	1000
(–0)	1000	–	–

Exercise 2

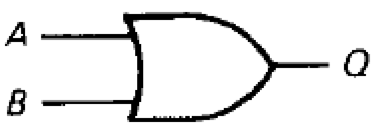
- Give the circuit symbols and truth tables of the following gates:
  - AND
  - OR
  - NOT (Inverter)
  - NAND
  - NOR
  - XOR

Exercise 2: Answers



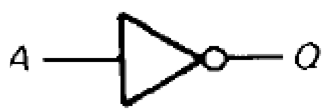
AND

inputs		output
0	0	0
0	1	0
1	0	0
1	1	1



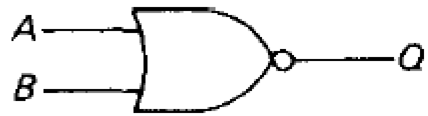
OR

inputs		output
A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1



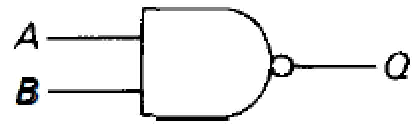
INVERT

A	Q
0	1
1	0



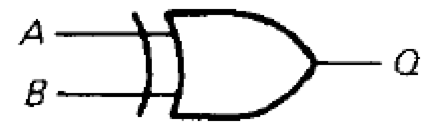
NOR

A	B	Q
0	0	1
0	1	0
1	0	0
1	1	0



NAND

A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

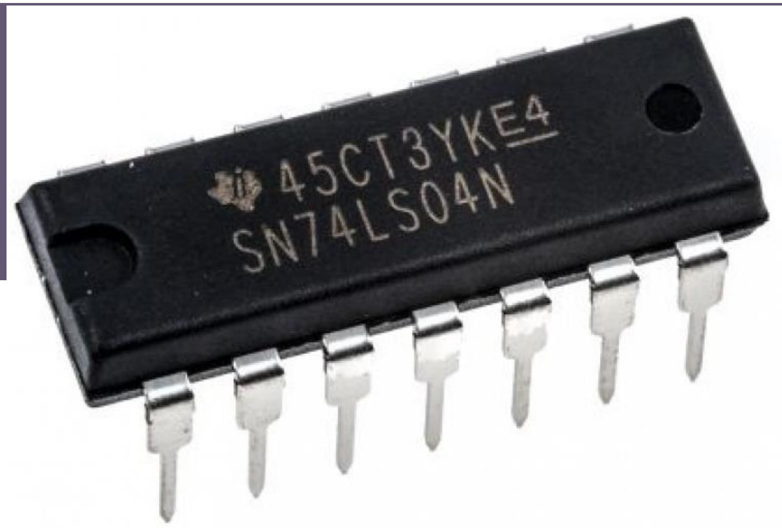


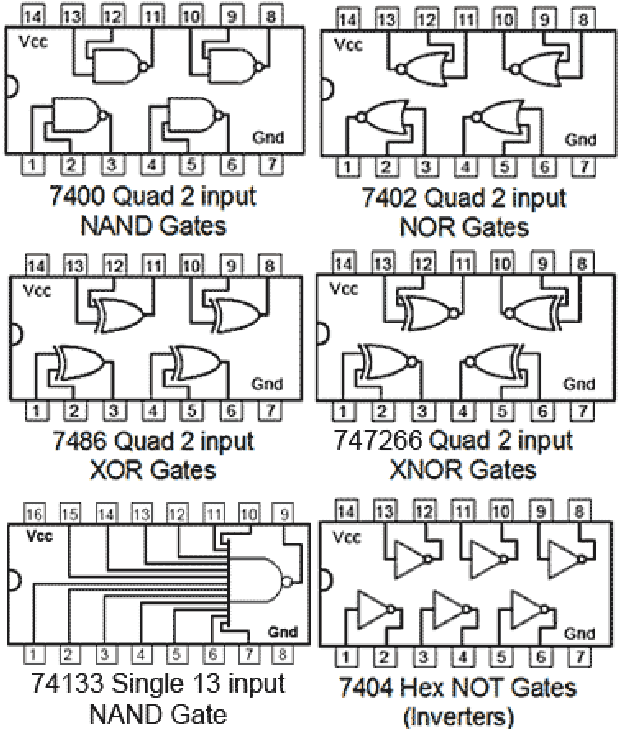
XOR

A	B	Q
0	0	0
0	1	1
1	0	1
1	1	0

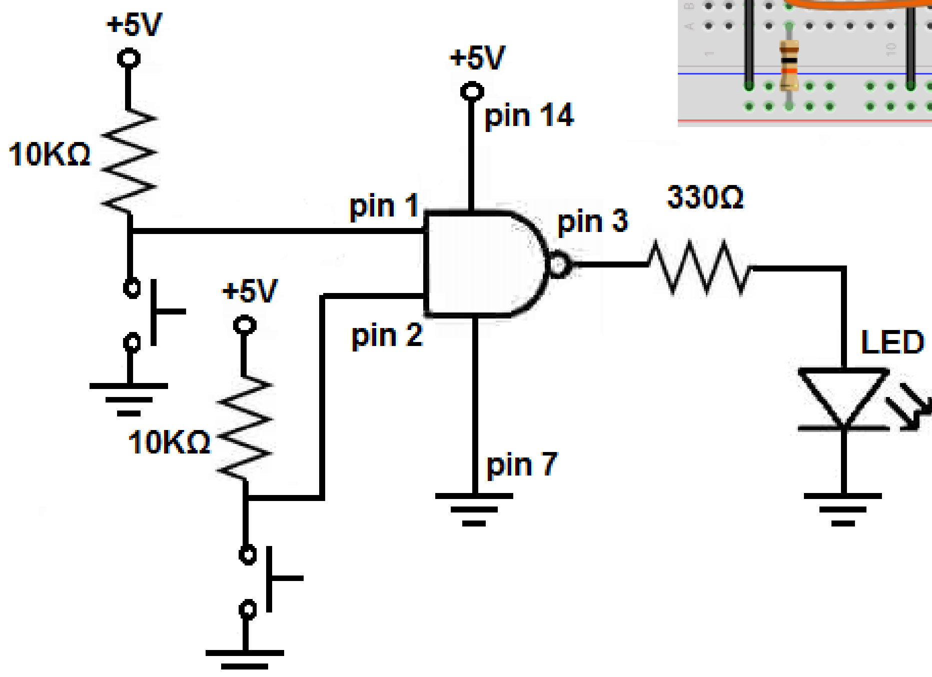
Logic ICs

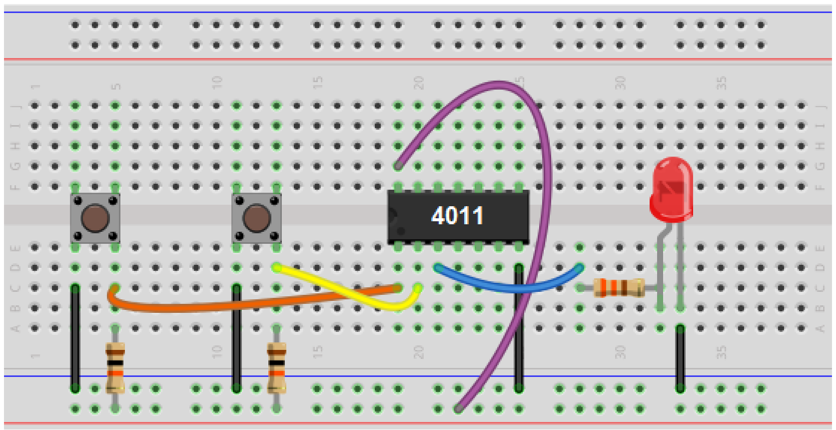
- Main families,
  - TTL: Transistor-Transistor Logic, e.g., 7400
  - CMOS: Complementary Metal Oxide Semiconductor, e.g., 4011
- Sub-families
  - TTL: 74LS, 74ALS, 74AS, 74F
  - CMOS: 4000B, 74C, 74HC, 74AC



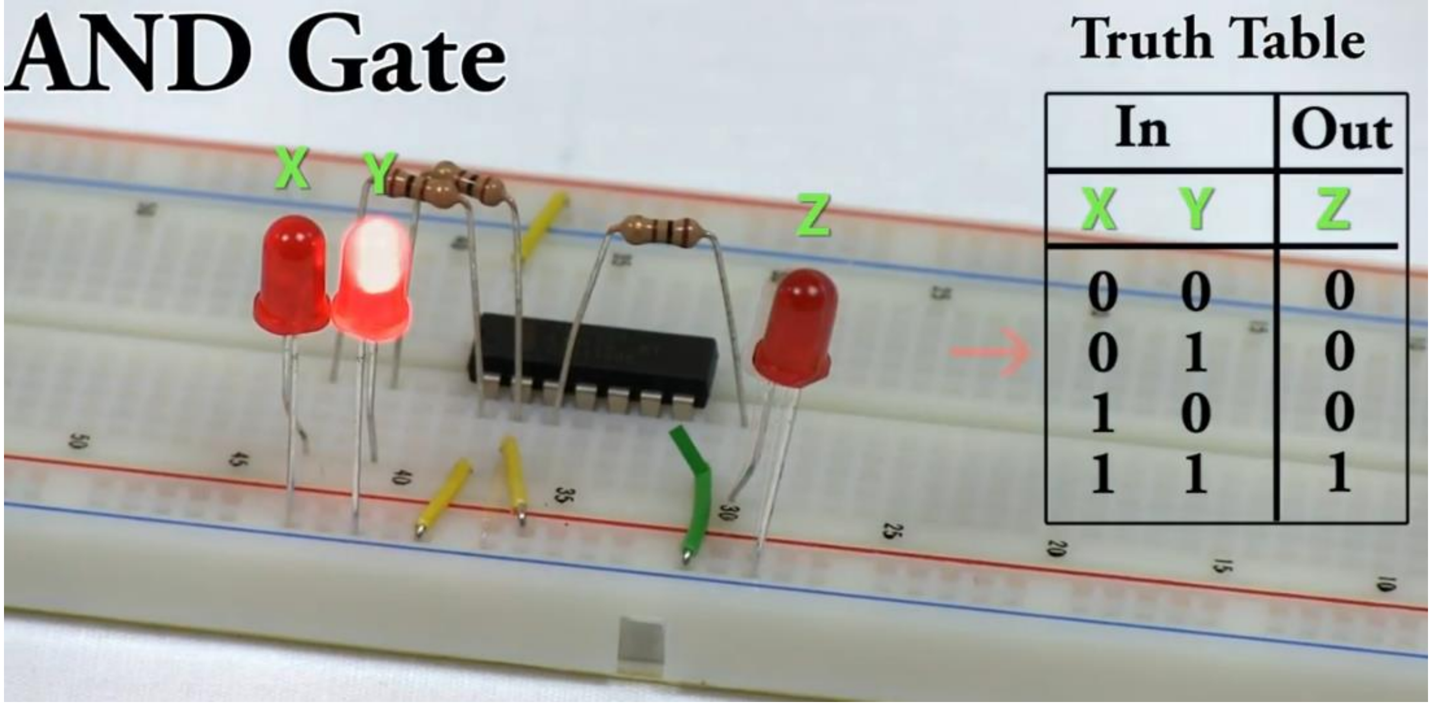


Testing Logic Gates





Summary



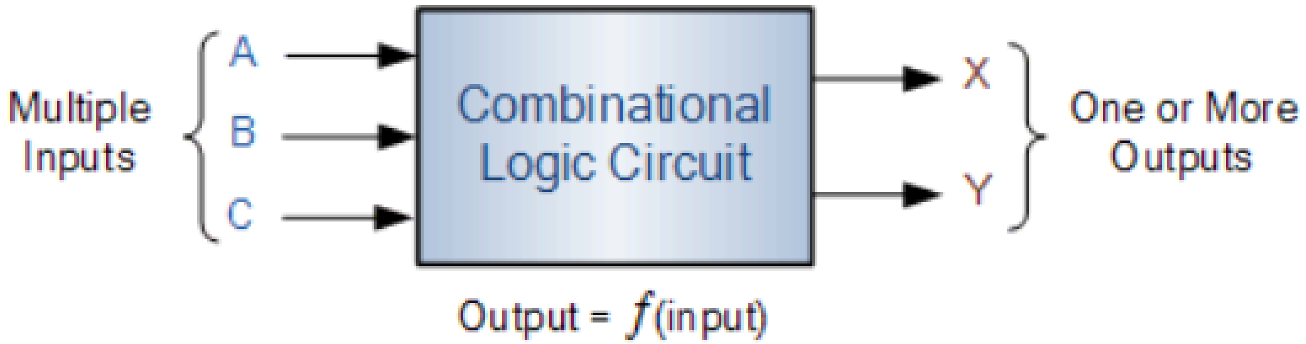
In		Out
X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1

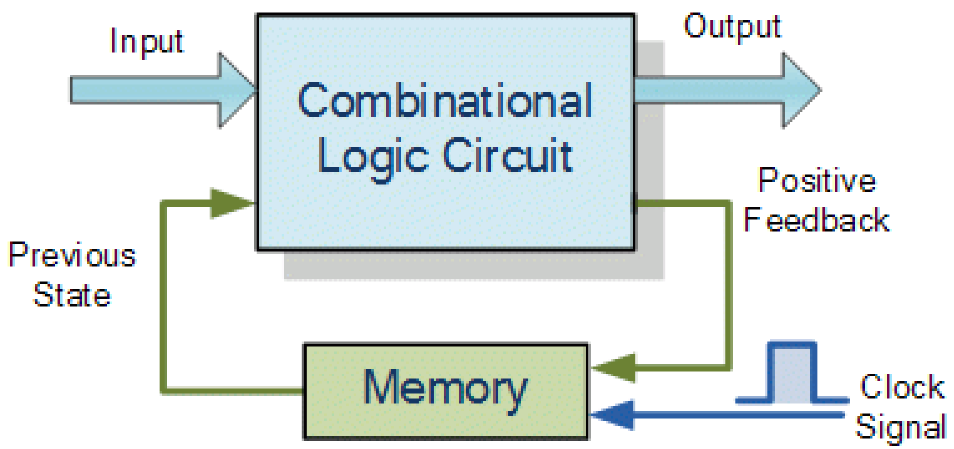
Logic Gates - An Introduction To Digital Electronics
https://www.youtube.com/watch?v=IDf2vEcyDfs

Combinational vs. Sequential Logic

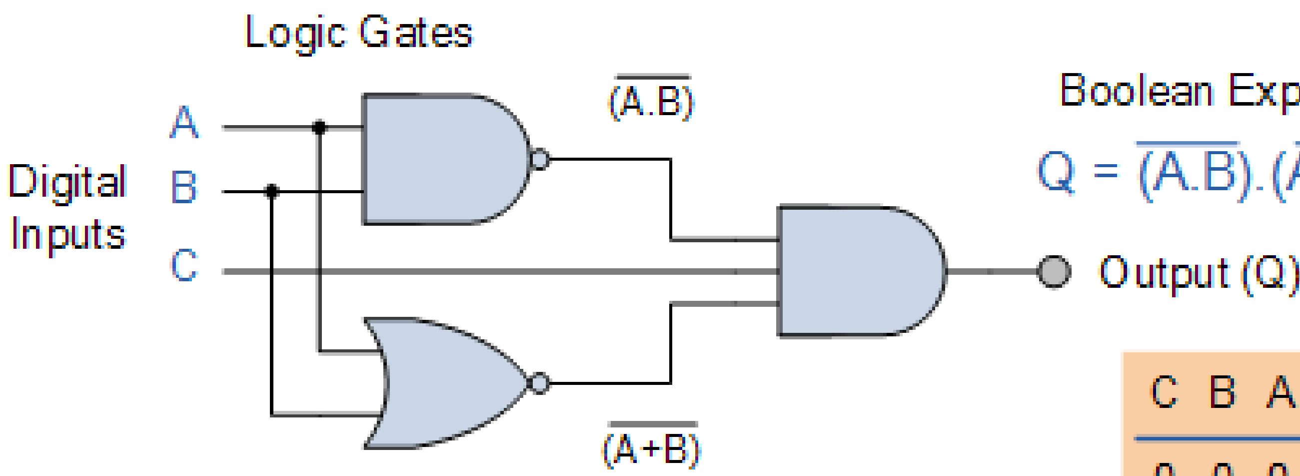
- Combinational logic
  - Outputs are only determined by the logical function of their current input state, logic “0” or logic “1”, at any given instant in time.
  - No feedback - any changes to the signals being applied to their inputs will immediately have an effect at the output.
- Sequential logic
  - Outputs are dependent on both their present inputs and their previous output state giving them some form of **Memory** (flip-flops).

Combinational vs. Sequential Logic





Representing a Combinational Logic Circuit



Logic Diagram

Boolean Expression

$$Q = \overline{(A.B)}.\overline{(A+B)}.C$$

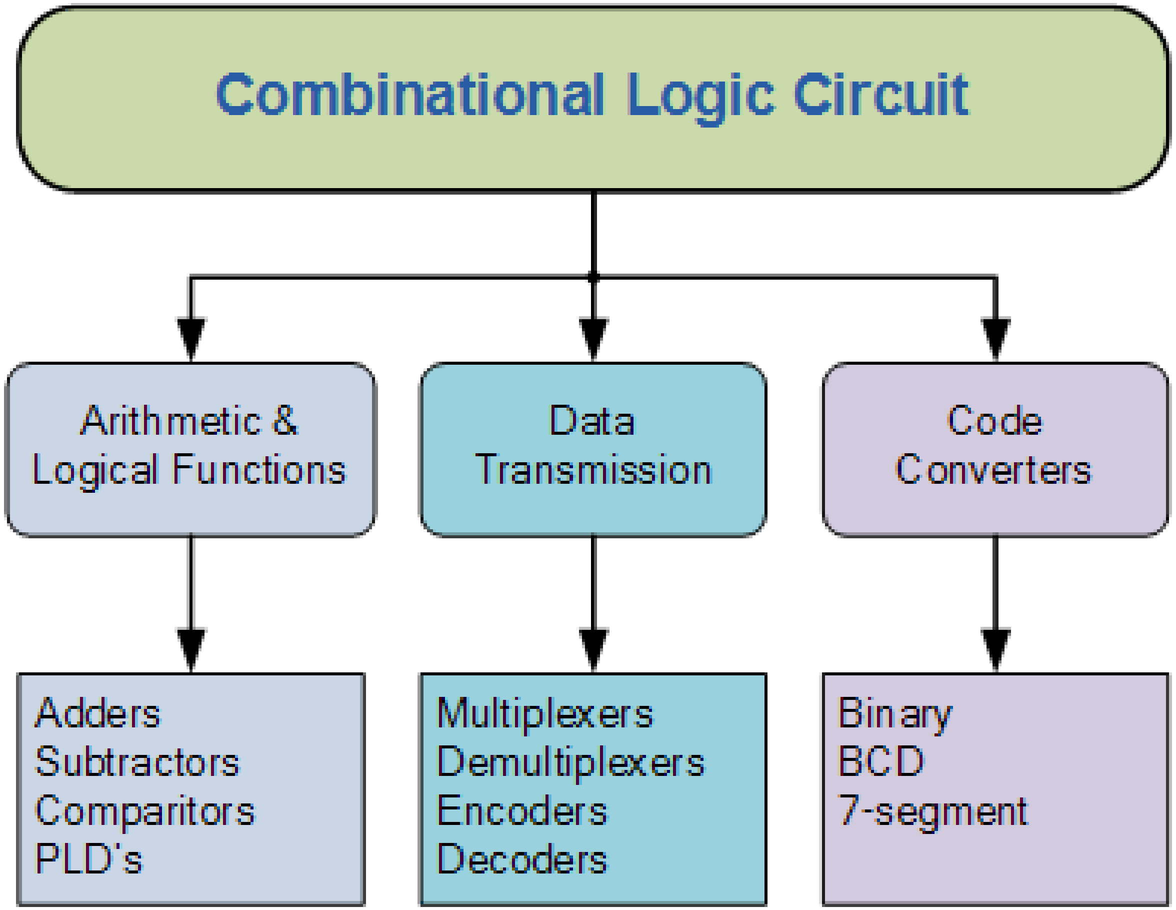
Typical Truth Table

C	B	A	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

Boolean Algebra

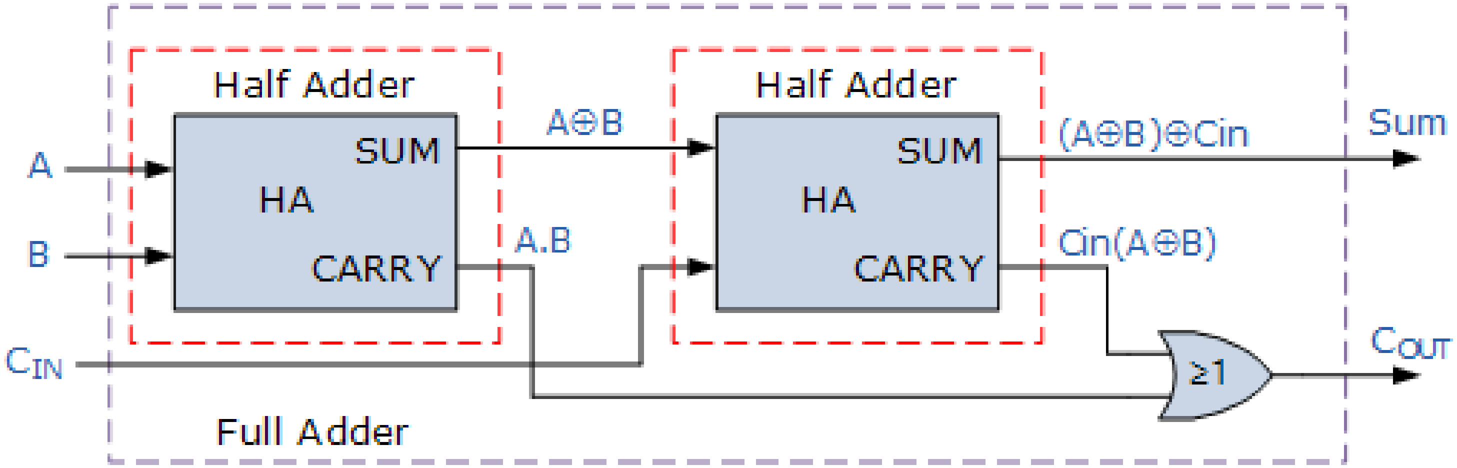
Law/Theorem	Law of Addition	Law of Multiplication
Identity Law	$x + 0 = x$	$x \cdot 1 = x$
Complement Law	$x + x' = 1$	$x \cdot x' = 0$
Idempotent Law	$x + x = x$	$x \cdot x = x$
Dominant Law	$x + 1 = 1$	$x \cdot 0 = 0$
Involution Law	$(x')' = x$	
Commutative Law	$x + y = y + x$	$x \cdot y = y \cdot x$
Associative Law	$x+(y+z) = (x+y)+z$	$x \cdot (y \cdot z) = (x \cdot y) \cdot z$
Distributive Law	$x \cdot (y+z) = x \cdot y+x \cdot z$	$x+y \cdot z = (x+y) \cdot (x+z)$
Demorgan's Law	$(x+y)' = x' \cdot y'$	$(x \cdot y)' = x' + y'$
Absorption Law	$x + (x \cdot y) = x$	$x \cdot (x + y) = x$

Classification of Combinational Logic

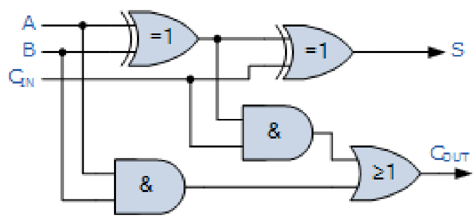


Exercise 3

- Represent a full adder using three types of representations.



Exercise 3: Answer

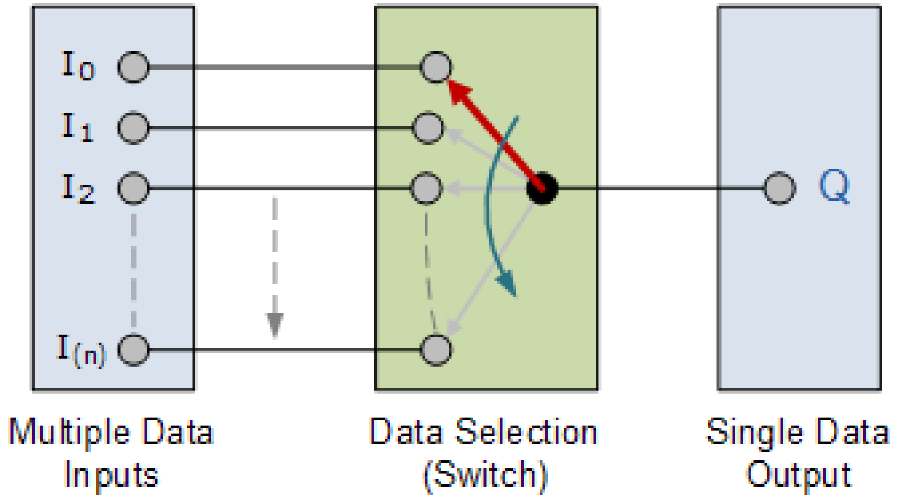
Symbol	Truth Table				
	C-in	B	A	Sum	C-out
	0	0	0	0	0
	0	0	1	1	0
	0	1	0	1	0
	0	1	1	0	1
	1	0	0	1	0
	1	0	1	0	1
	1	1	0	0	1
	1	1	1	1	1

SUM = (A XOR B) XOR Cin = $(A \oplus B) \oplus Cin$

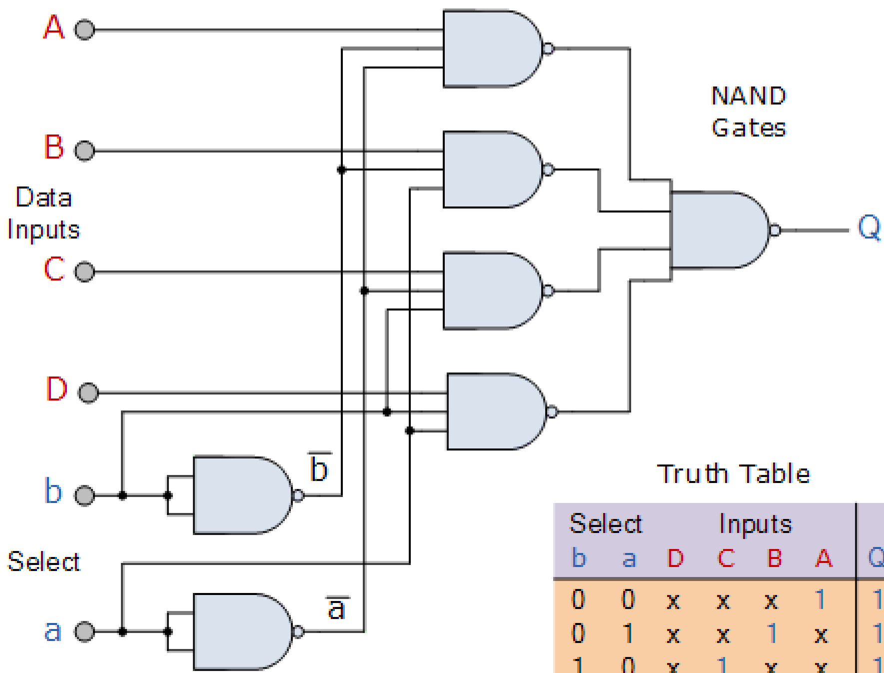
CARRY-OUT = A AND B OR Cin(A XOR B) = $A.B + Cin(A \oplus B)$

Exercise 4

- Represent a 4-to-1 channel multiplexer using three types of representations.

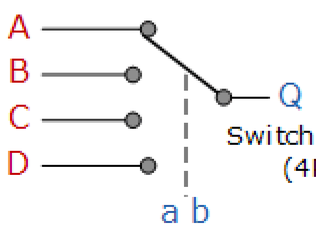


Exercise 4: Answer



Truth Table

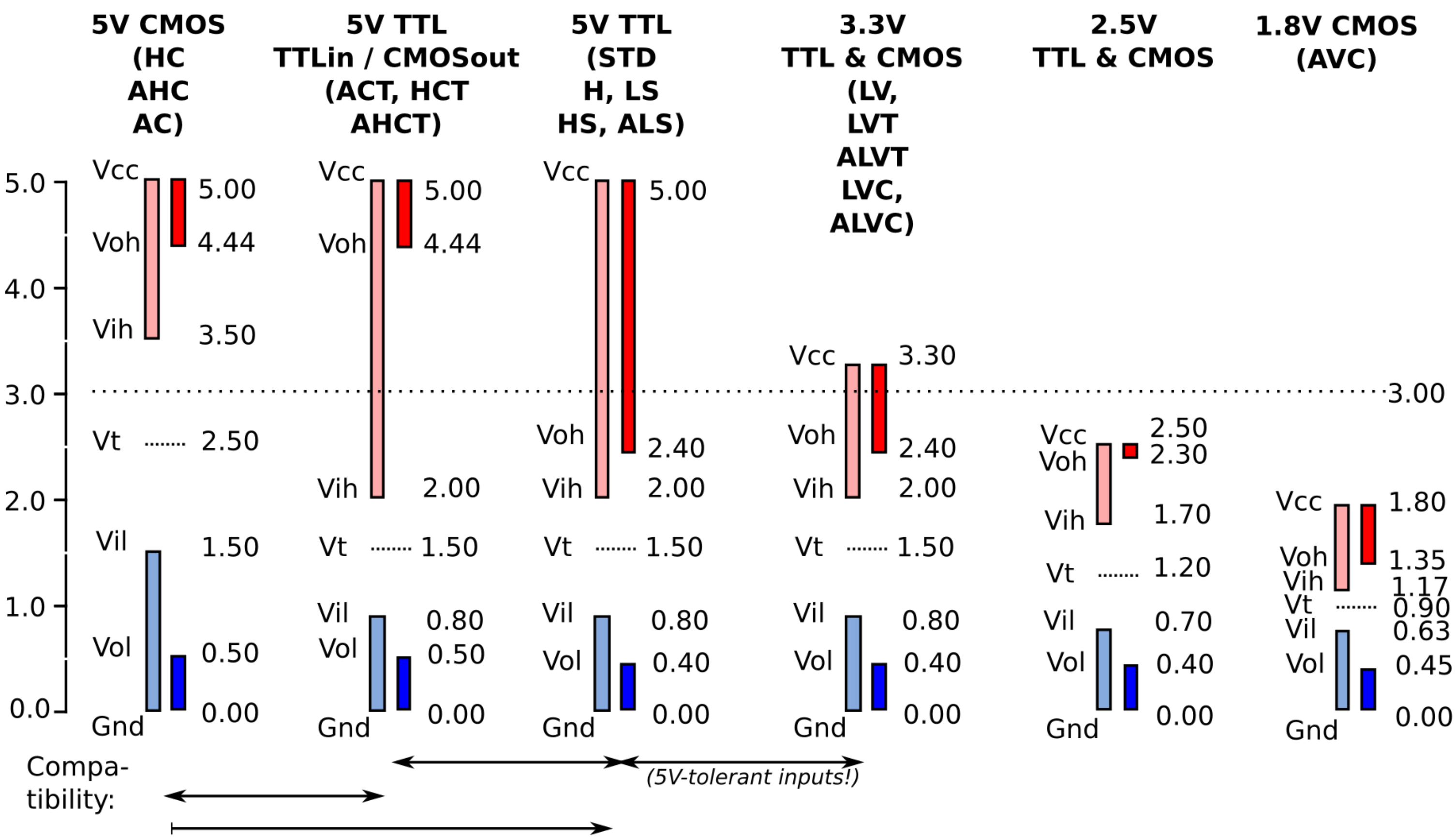
Select		Inputs				
b	a	D	C	B	A	Q
0	0	x	x	x	1	1
0	1	x	x	1	x	1
1	0	x	1	x	x	1
1	1	1	x	x	x	1



Switch Analogy
(4PST)

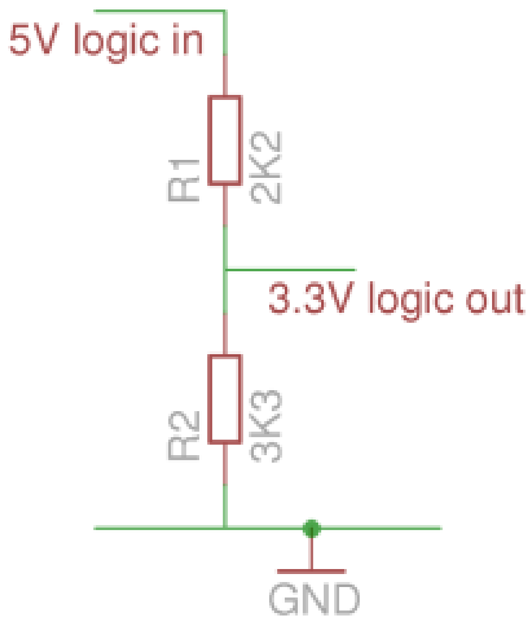
$$Q = \overline{a}\,\overline{b}A + a\overline{b}B + \overline{a}bC + abD$$

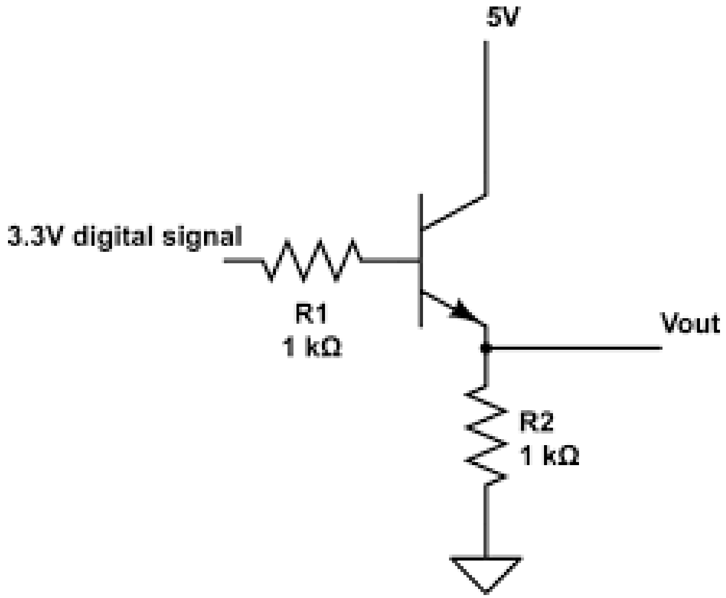
Logic Levels



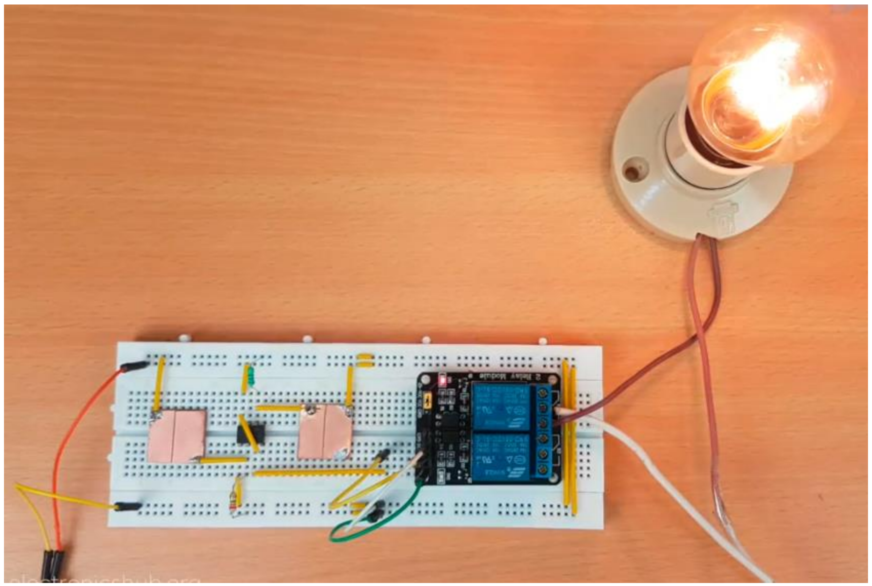
Data source: EETimes, A brief recap of popular logic standards (Mark Pearson, Maxim).

Logic Level Conversion





Touch Controlled ON/OFF Switch

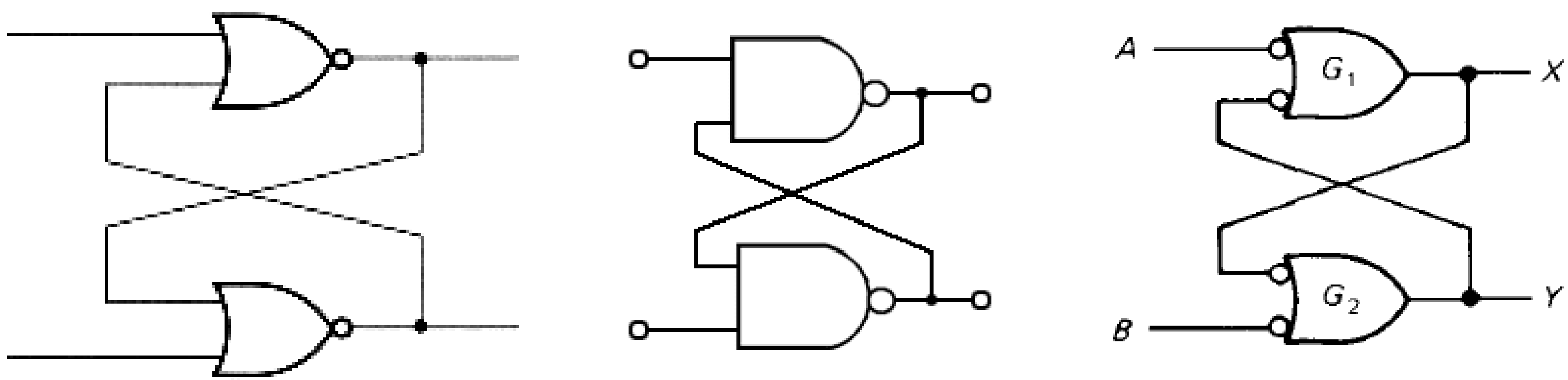


Briefly discuss how you would implement a touch controlled, toggle, ON/OFF switch using, a) analog electronic components alone, b) digital electronic components, c) microcontroller electronics. Give simplified circuit diagrams.

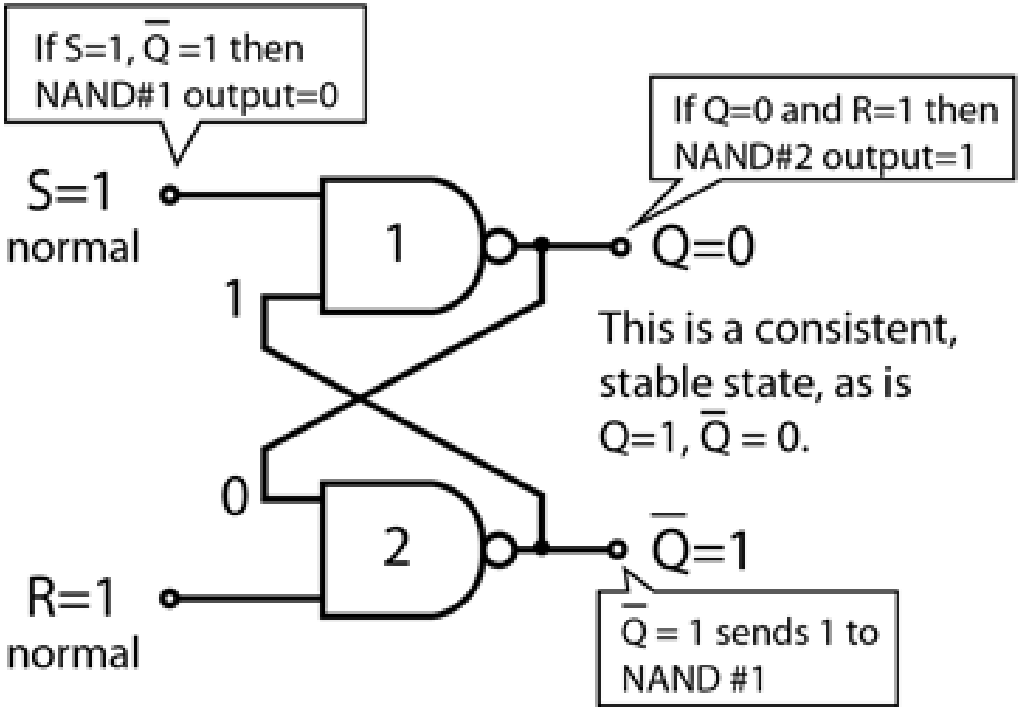
Touch ON and OFF Switch
https://www.youtube.com/watch?v=0V0Pd95qVRo

Exercise 5 (Sequential Logic Circuits):

- Give truth tables for the following logic circuits.



Set-Reset (SR) Latch

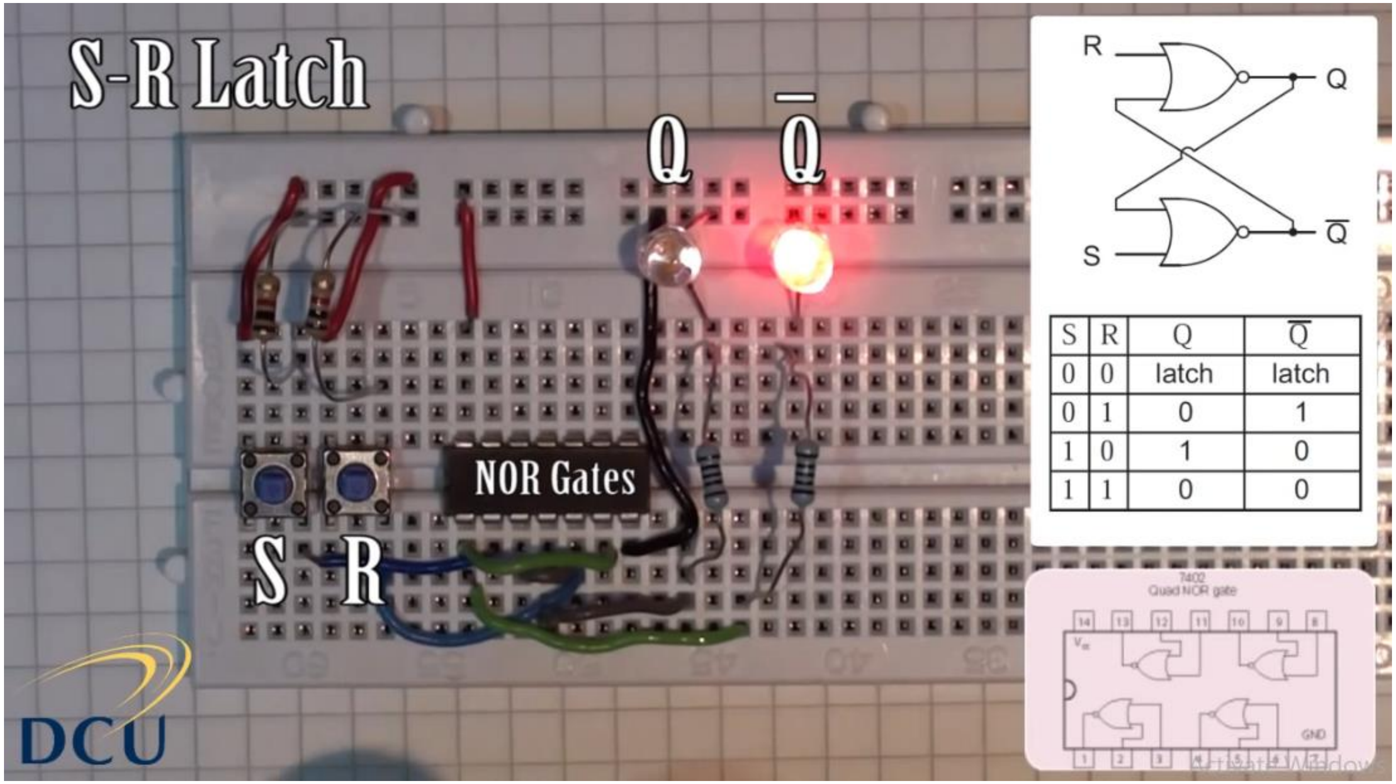


Truth Table

Set	Reset	Output
1	1	No change*
0	1	Q=1
1	0	Q=0
0	0	Invalid state

* can be used for data storage

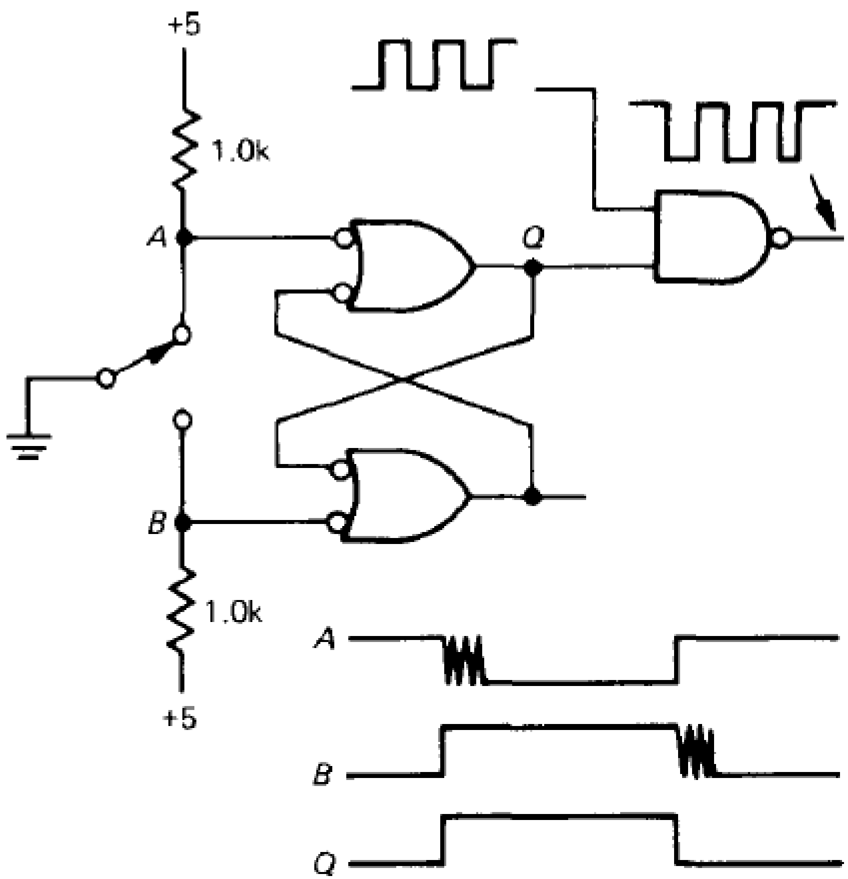
S-R Latch/FF

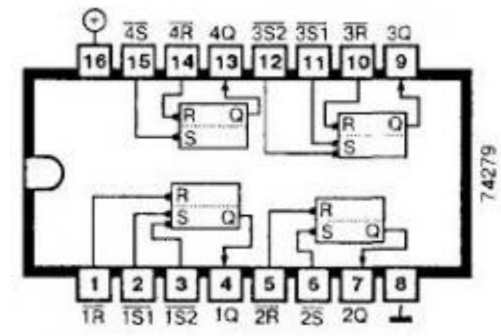


S	R	Q	Q̄
0	0	latch	latch
0	1	0	1
1	0	1	0
1	1	0	0

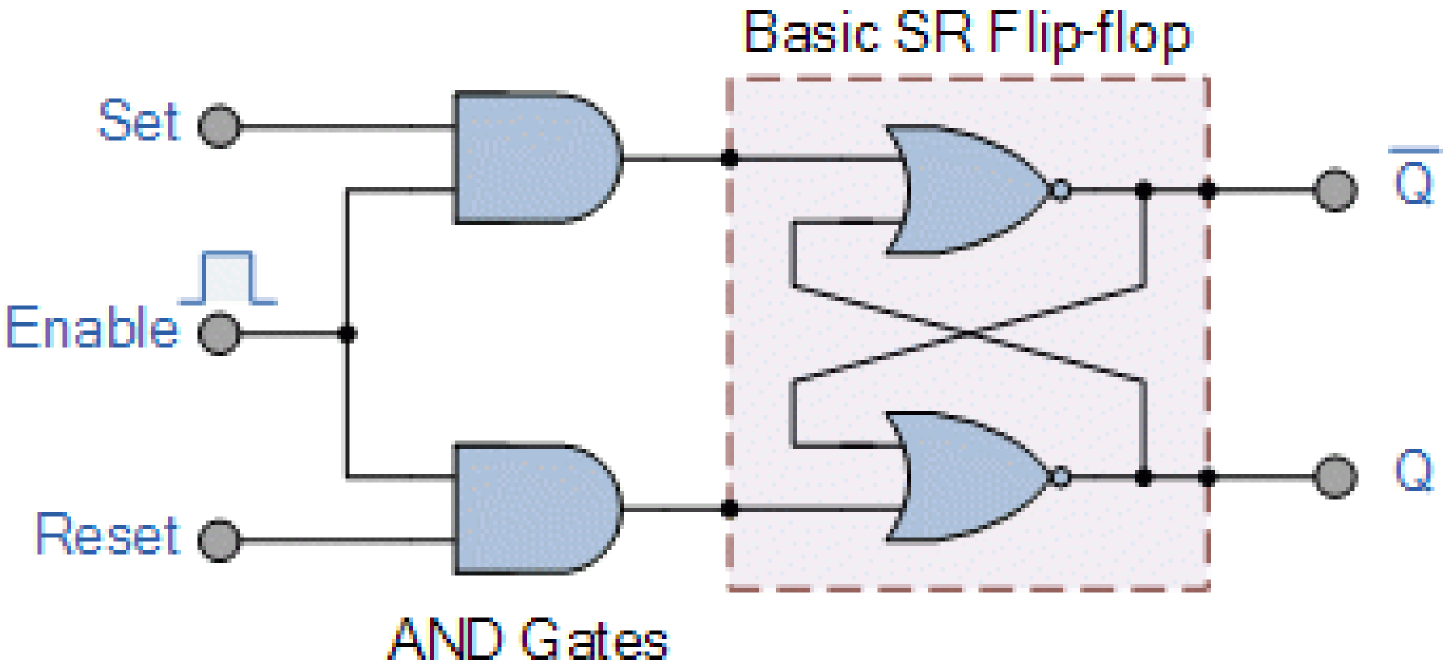
Sequential Logic - S-R Latch and a Gated S-R Latch
https://www.youtube.com/watch?v=mo4Lq0DvJ68

SR Latch Application: Switch Debounce





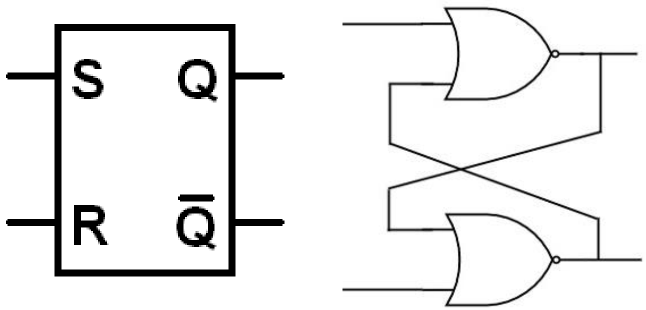
Clocked/Gated SR Latch – SR Flip-Flop

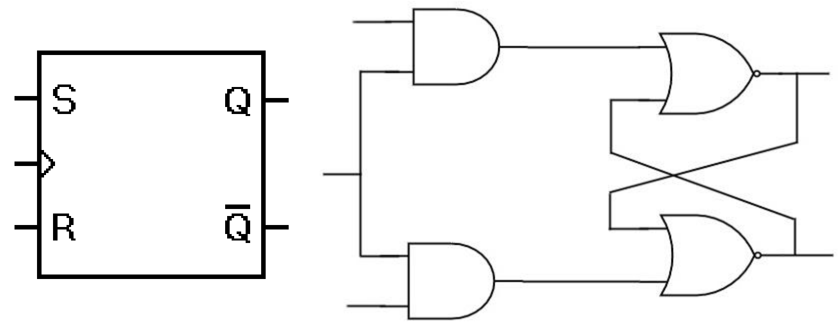


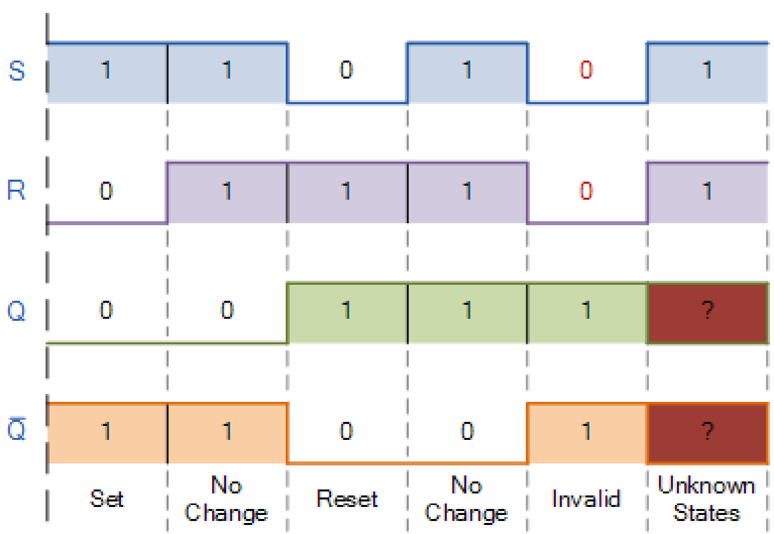
Latch vs. Flip-Flop

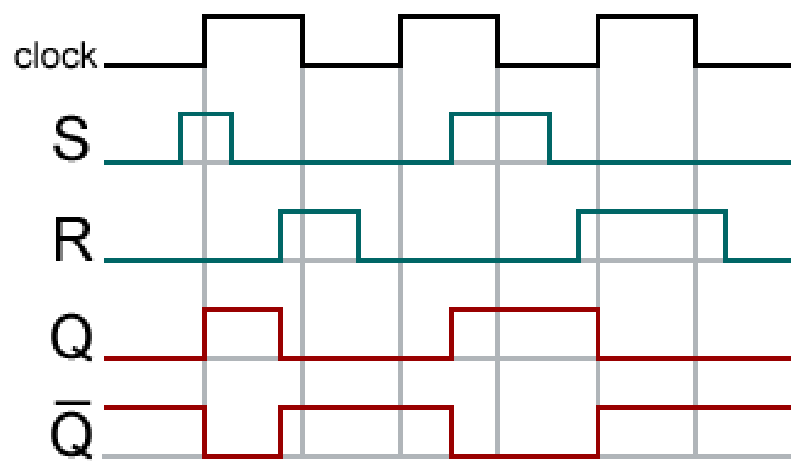
- The main difference between latches and flip-flops is that for **latches**, their outputs are constantly affected by their inputs as long as the enable signal is asserted. In other words, when they are enabled, their content changes immediately when their inputs change.
- **Flip-flops**, on the other hand, have their content change only either at the rising or falling edge of the enable signal. This enable signal is usually the controlling clock signal. After the rising or falling edge of the clock, the flip-flop content remains constant even if the input changes.

S-R Latch vs. Flip-Flop



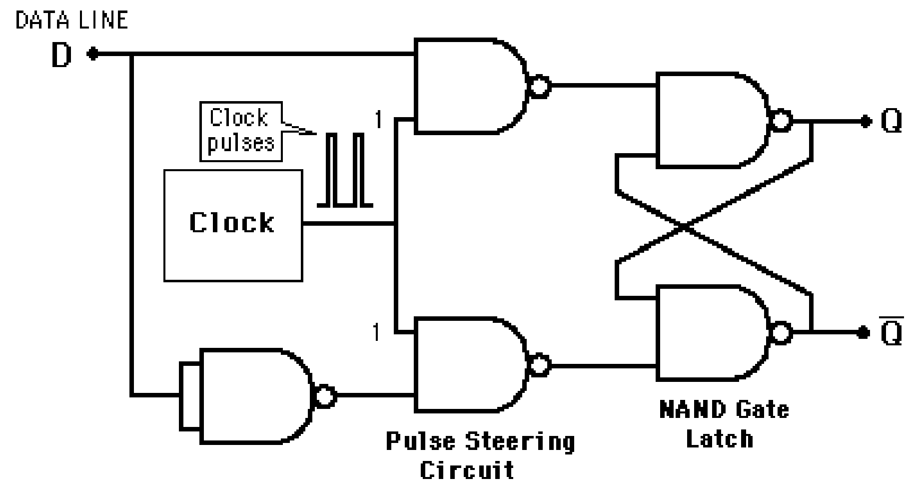


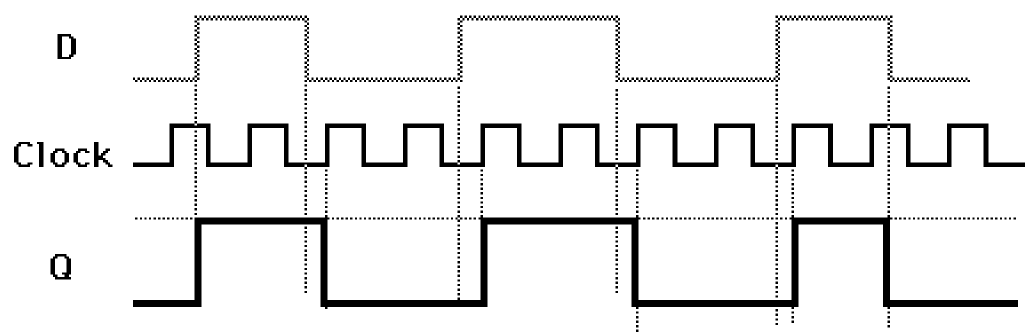




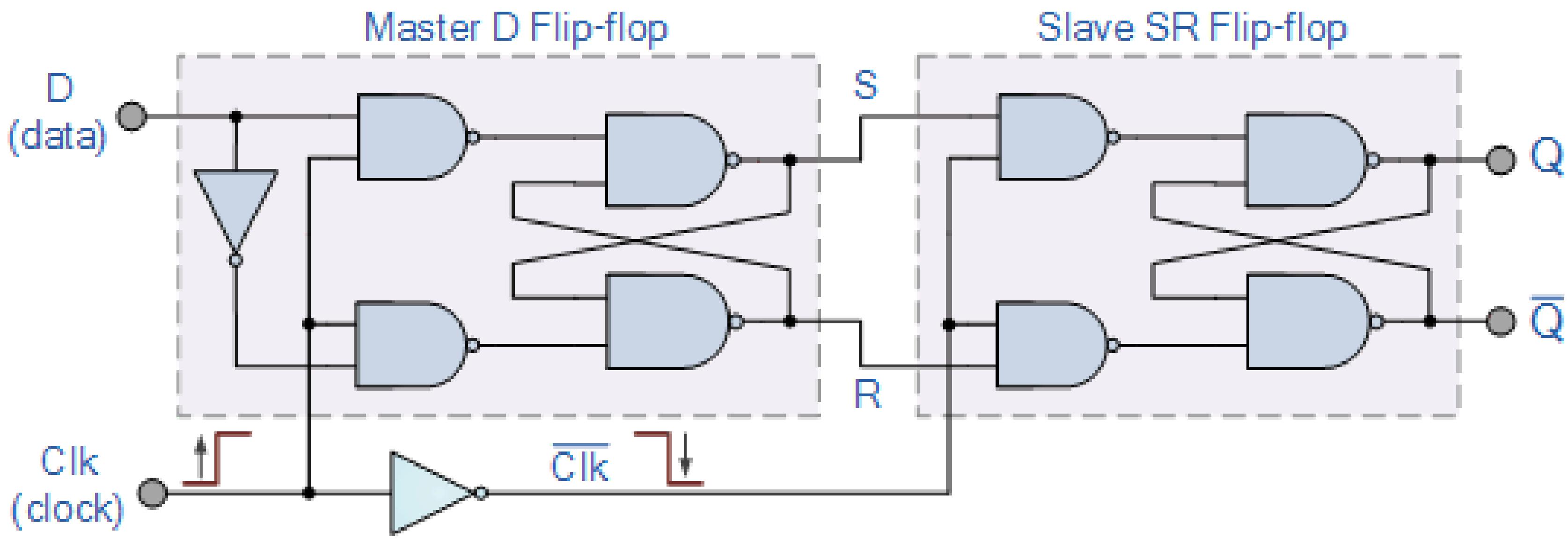
Data (D) Flip-Flop

- SR flip-flop should avoid S=R=0
- Data present at the D input will be transferred to the Q output after the clock pulse

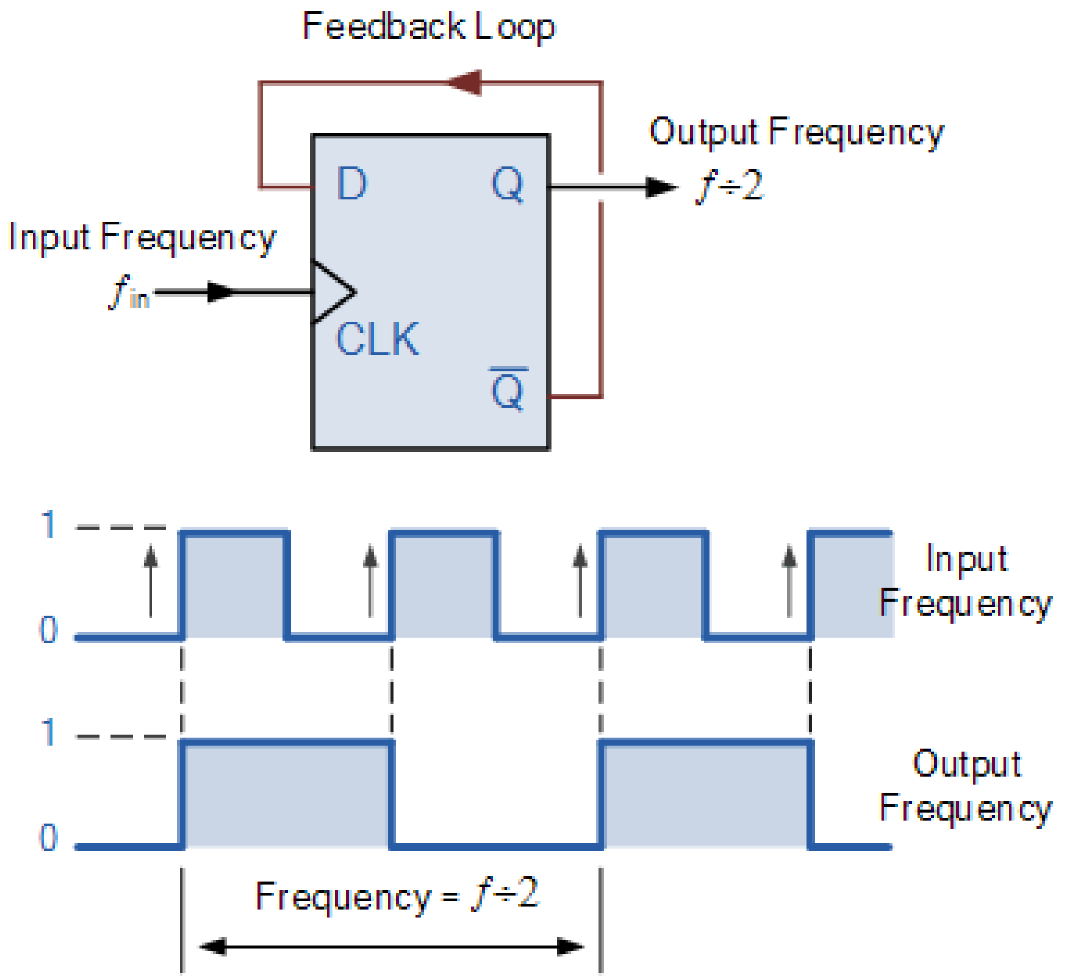




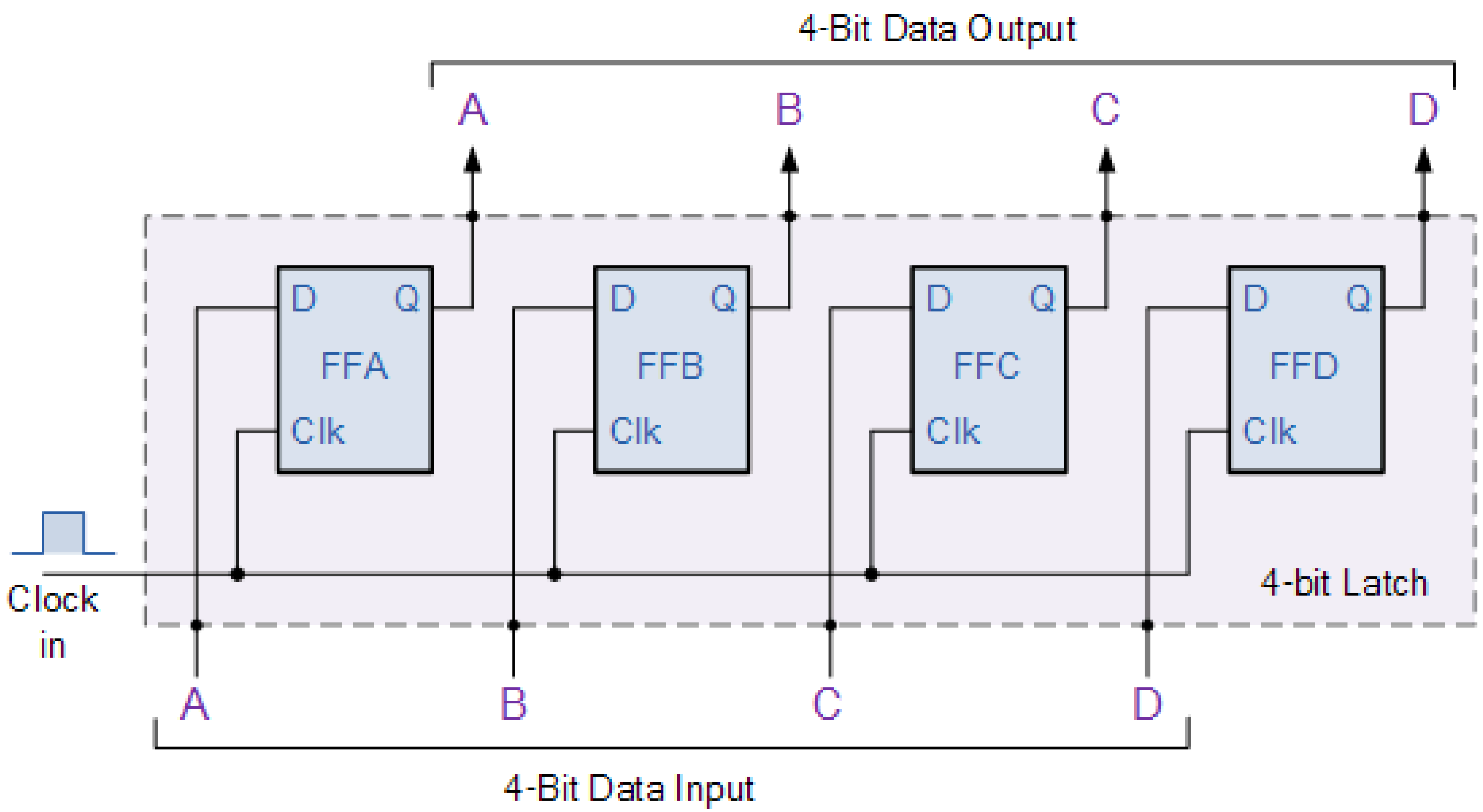
Improved D Flip-Flop



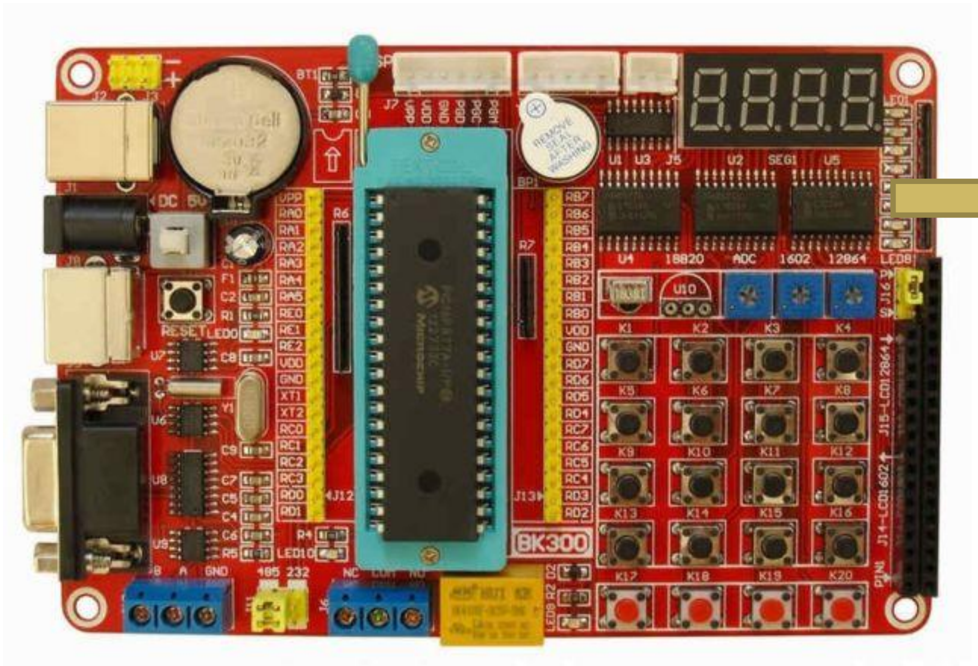
D Flip-Flop Application: Divide-By-2

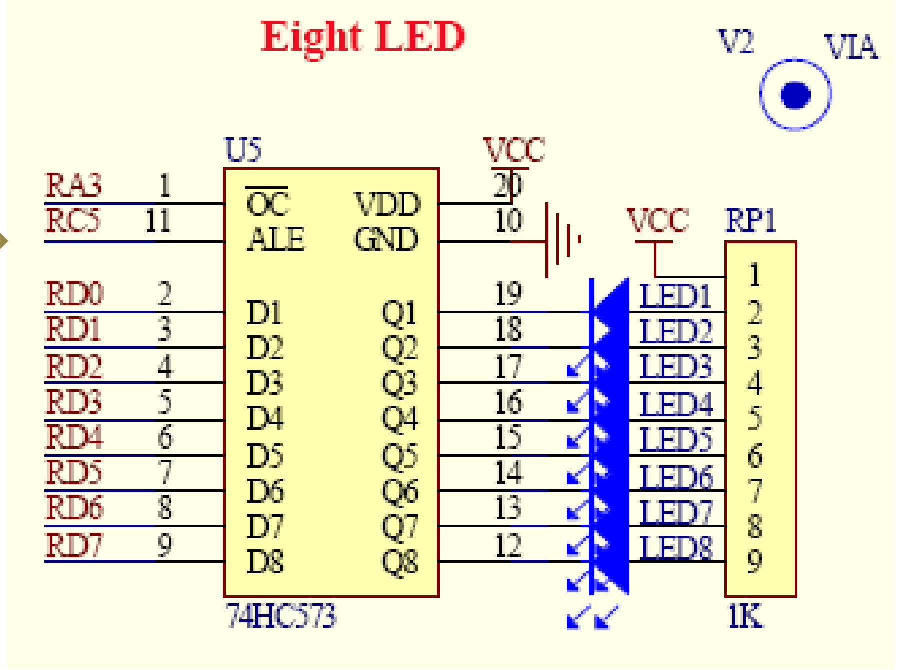


D Flip-Flop Application: 4-Bit Data Latch



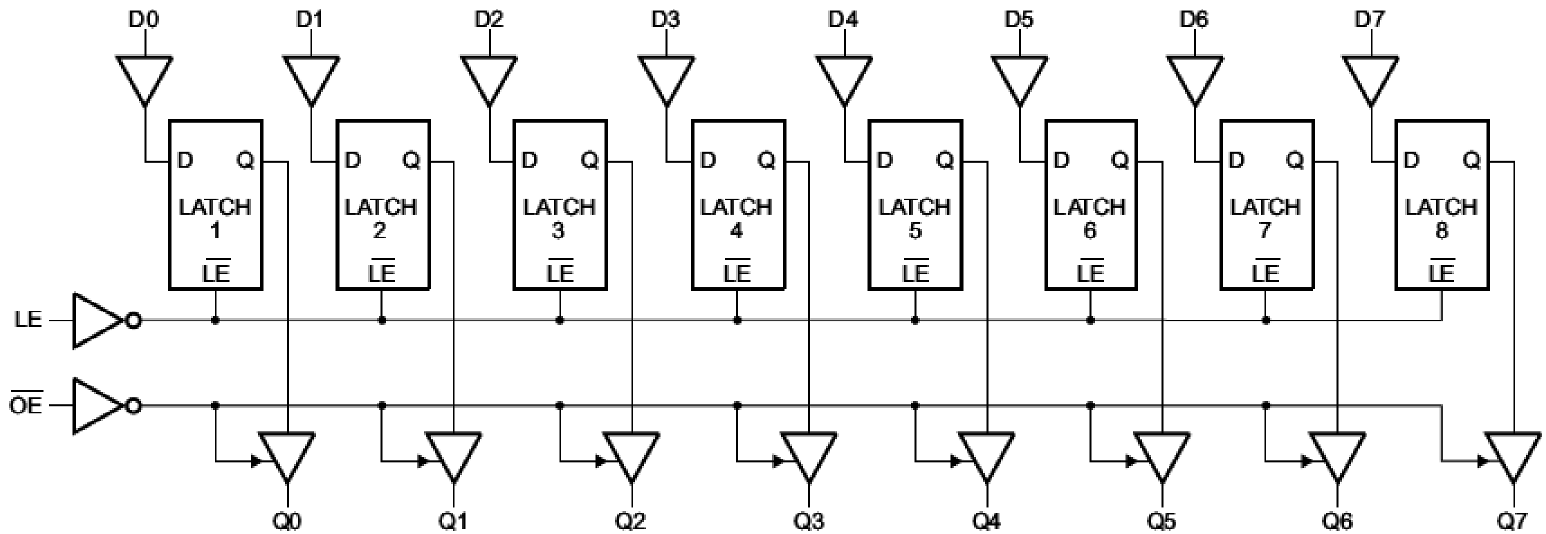
74HC573: Octal (8-bit) D-type transparent latch with 3-state outputs





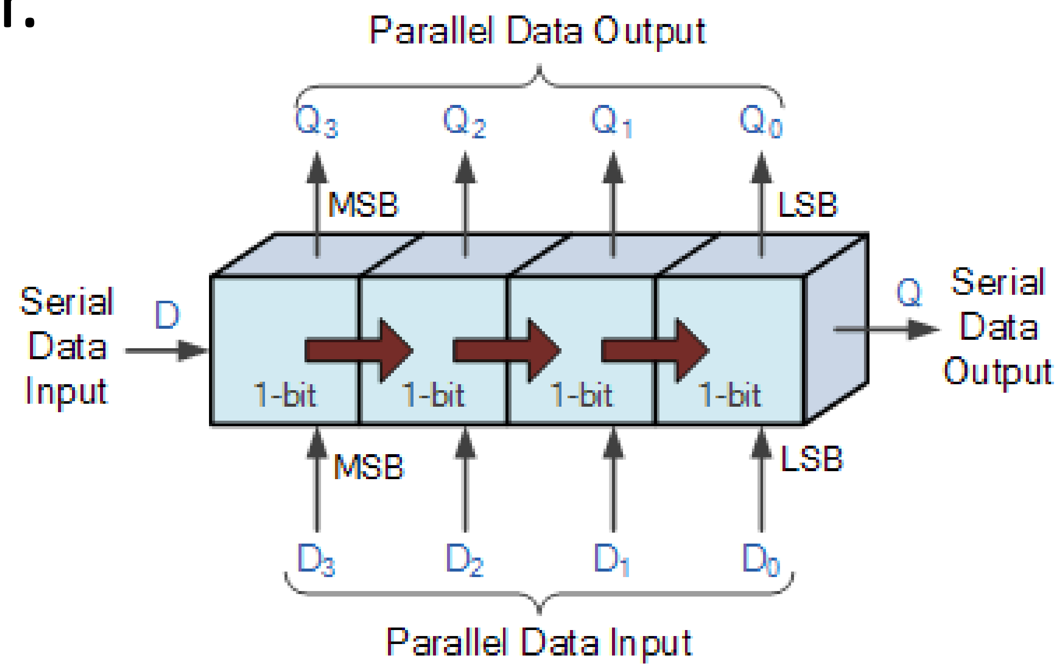
74HC573: Octal (8-bit) D-type transparent latch with 3-state outputs

	High	Low
Latch Enable (LE/ALE)	Data pass through latches	Latches store input
Output Enable (OE/OC)	Output OFF	Output ON

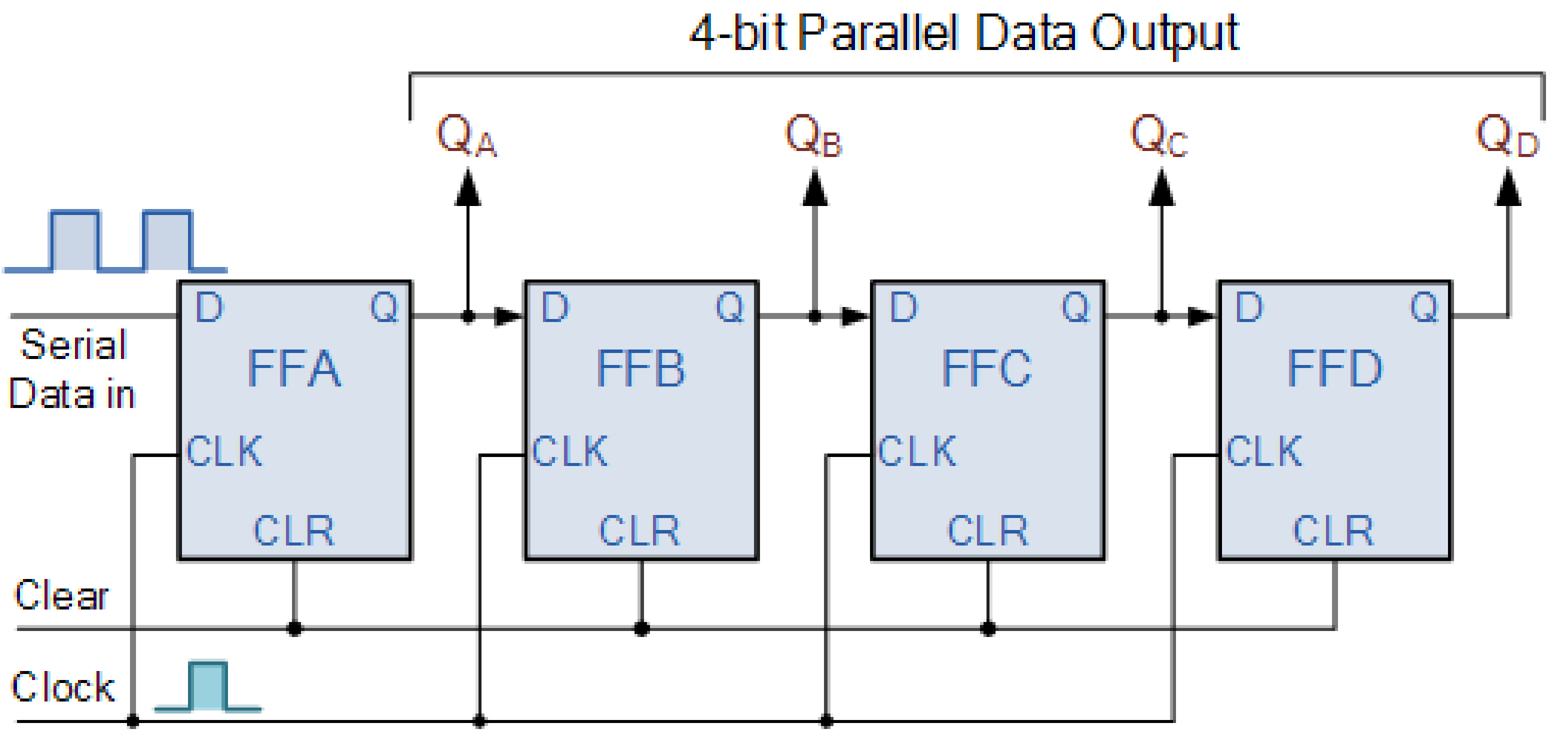


Exercise 5:

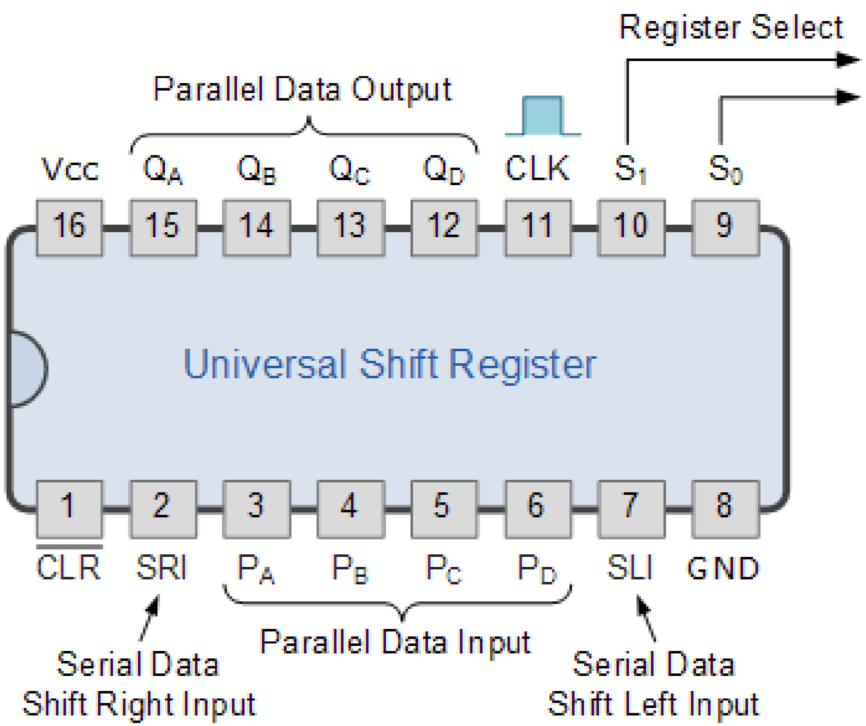
- Explain how D flip-flops can be used to implement a serial-in parallel-out (SIPO) shift register.



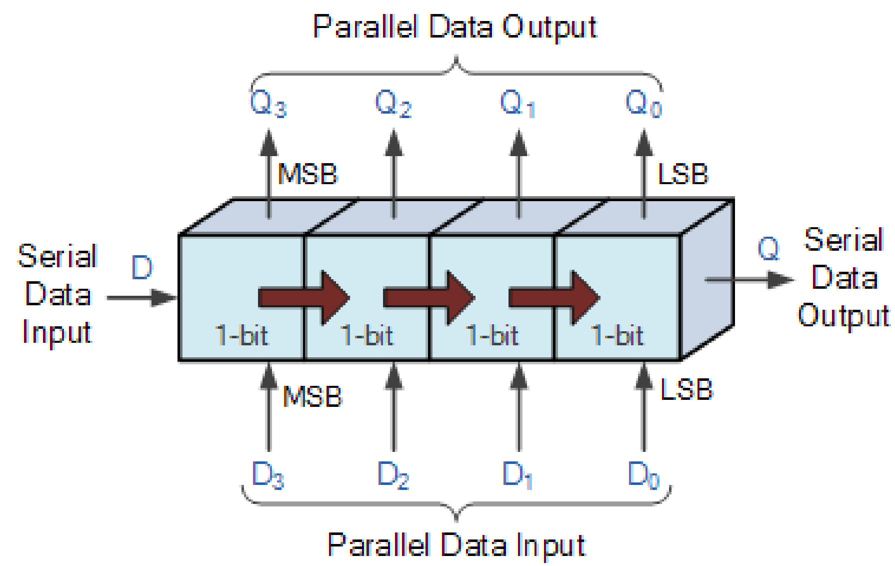
Serial-in to Parallel-out (SIPO) Shift Register



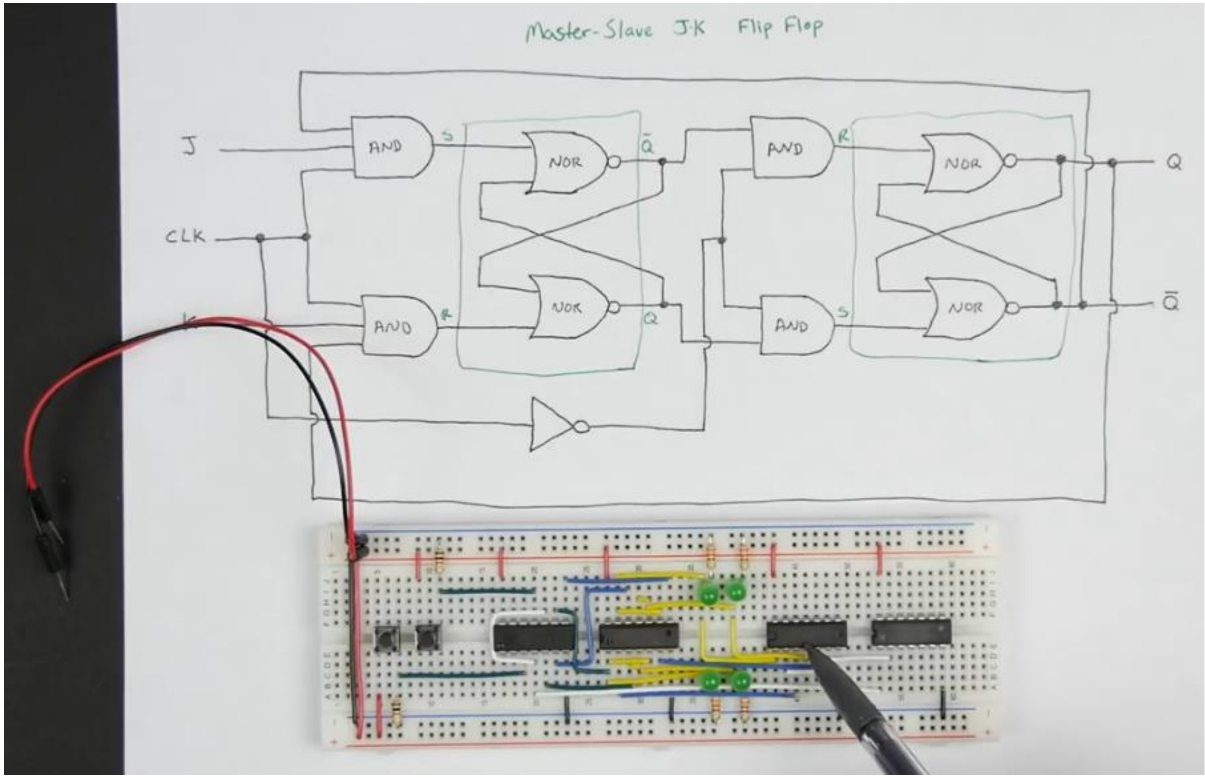
Universal Shift Register



Mode Control		Register Type
S_1	S_0	
0	0	Hold
0	1	Shift to right
1	0	Shift to left
1	1	Parallel Mode

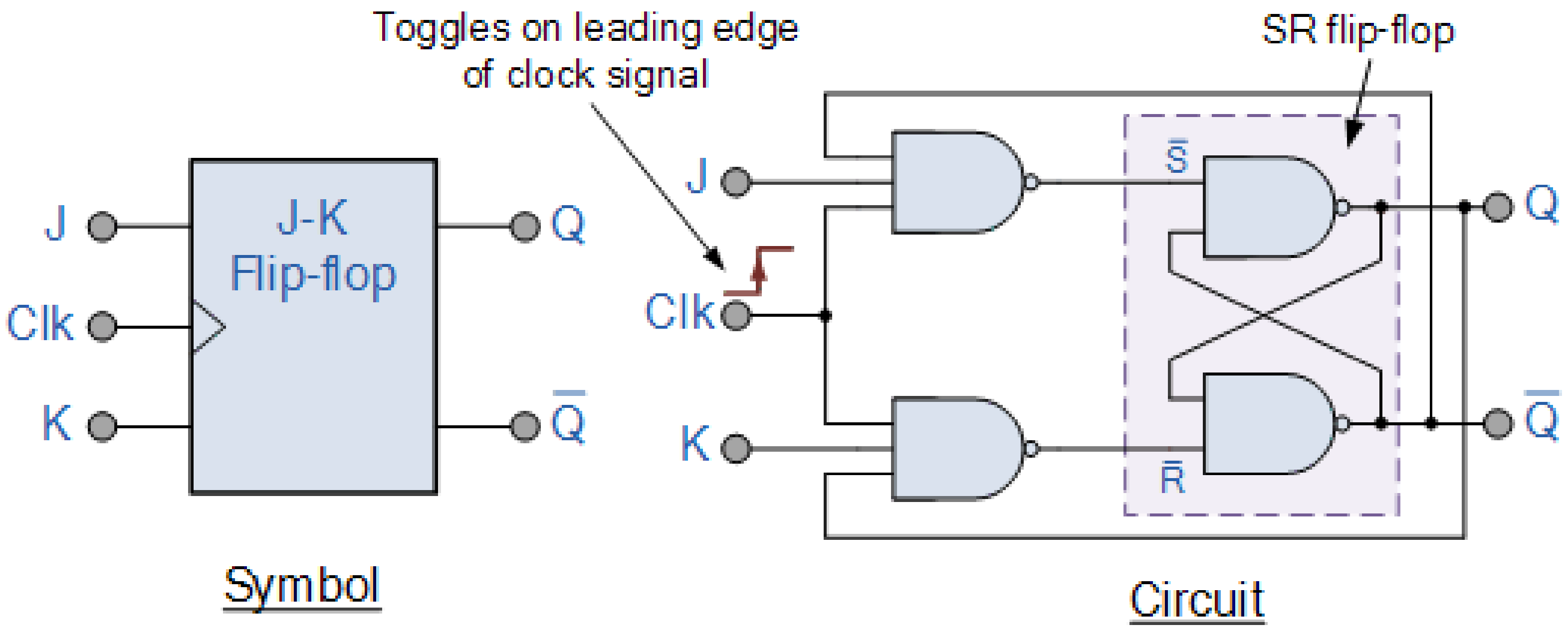


J-K Flip-Flop



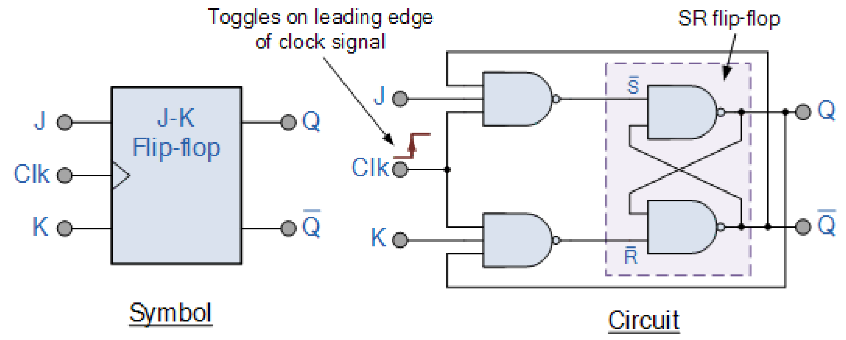
Master-slave JK flip-flop
https://www.youtube.com/watch?v=rXHSB5w7CyE

Jack Kilby (JK) Flip-Flop



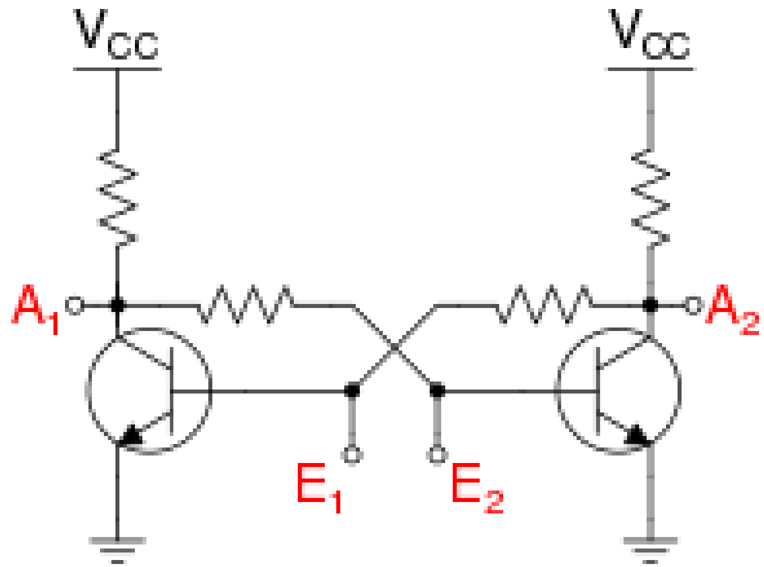
Jack Kilby (JK) Flip-Flop

	Clock	Input		Output		Description
	Clk	J	K	Q	$\overline{Q}$	
same as for the SR Latch	X	0	0	1	0	Memory no change
	X	0	0	0	1	
	↓	0	1	1	0	Reset Q » 0
	X	0	1	0	1	
	↓	1	0	0	1	Set Q » 1
	X	1	0	1	0	
toggle action	↓	1	1	0	1	Toggle
	↓	1	1	1	0	



Exercise 6:

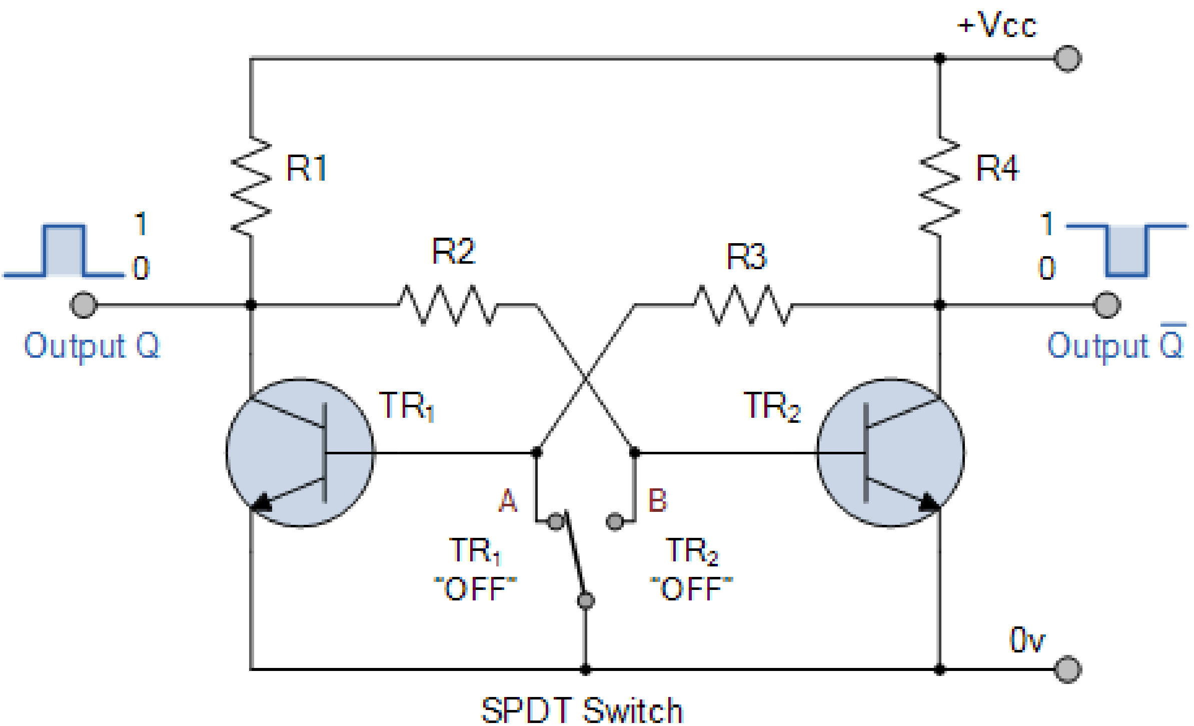
- Briefly explain the behavior of the following circuit.

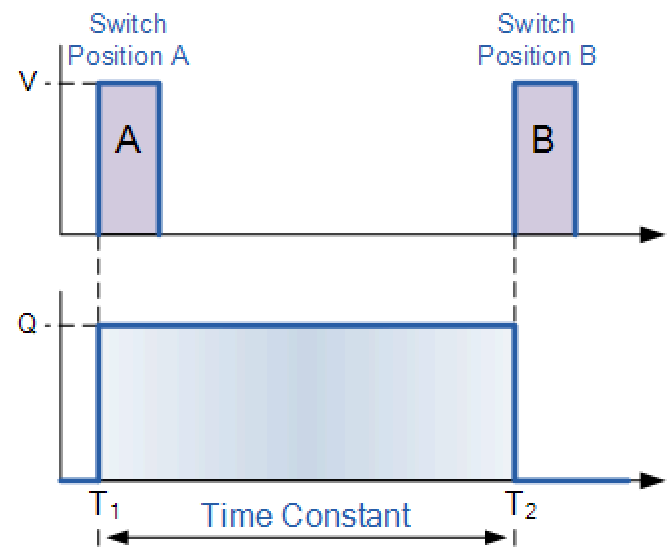


Answer

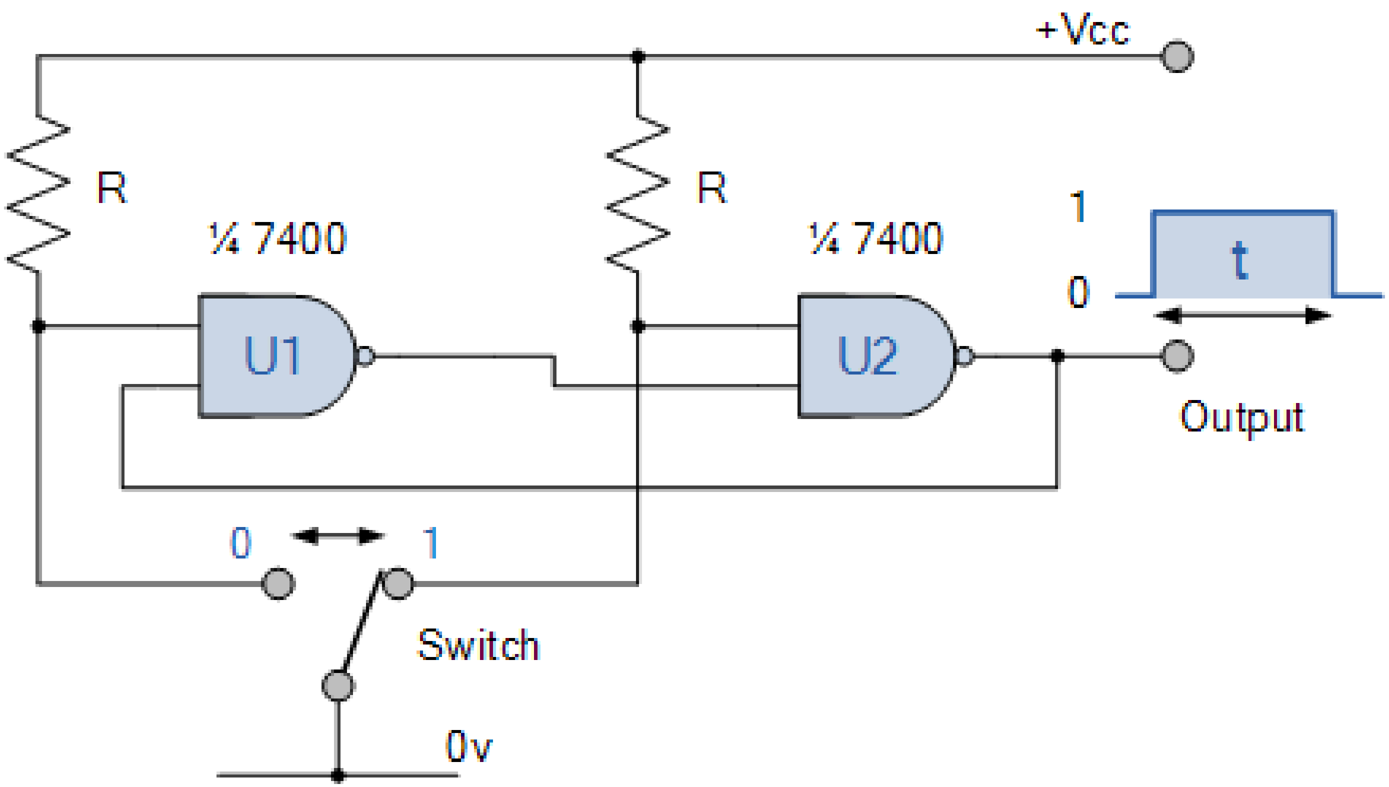
- It a **bistable multivibrator** which has two stable states (like a latch or flip-flop).
- States are changed by external trigger pulses (two types).
- In the circuit, two cross-coupled transistors operating as “ON-OFF” transistor switches. In each of the two states, one of the transistors is cut-off while the other transistor is in saturation, this means that the bistable circuit is capable of remaining indefinitely in either stable state.

Answer


+Vcc
R1
R4
R2
R3
1
0
1
0
Output Q
Output Q̄
TR1
TR2
A
B
TR1 "OFF"
TR2 "OFF"
0v
SPDT Switch

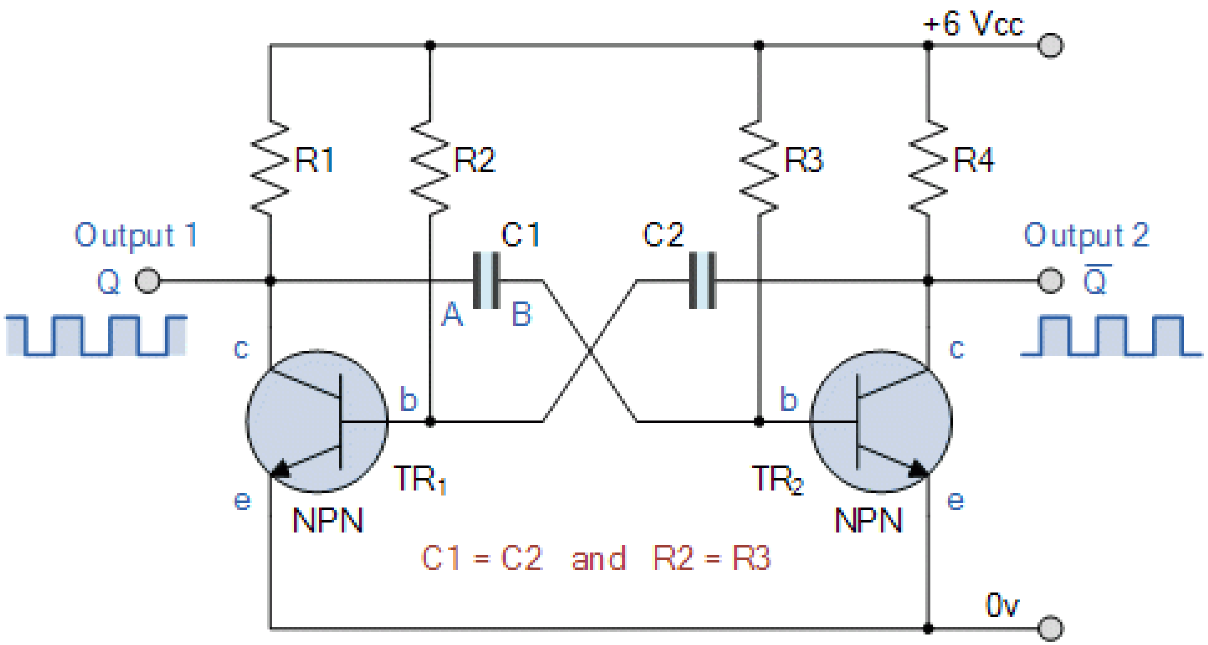

Switch Position A
Switch Position B
V
A
B
Q
T1
T2
Time Constant

NAND Gate Bistable Multivibrator



Exercise 7:

- Briefly explain the behavior of the following circuit.

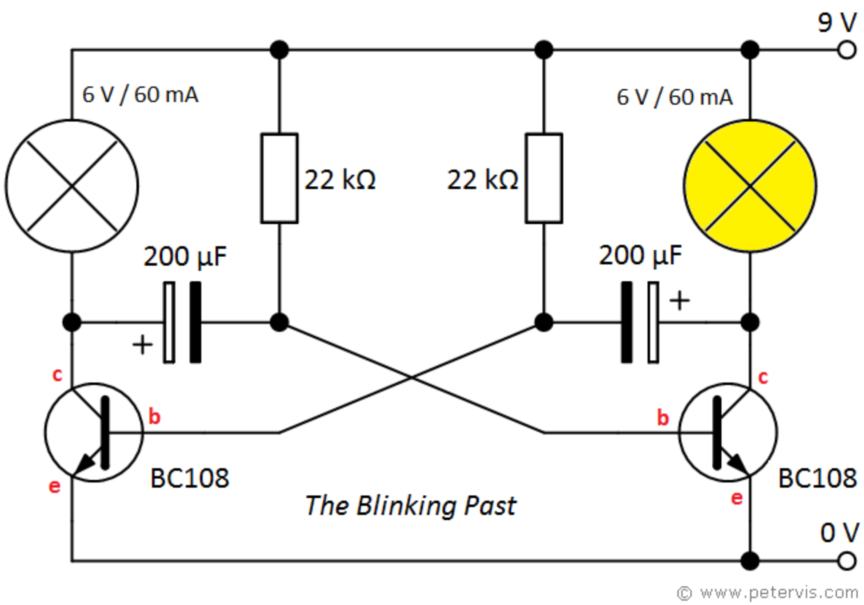


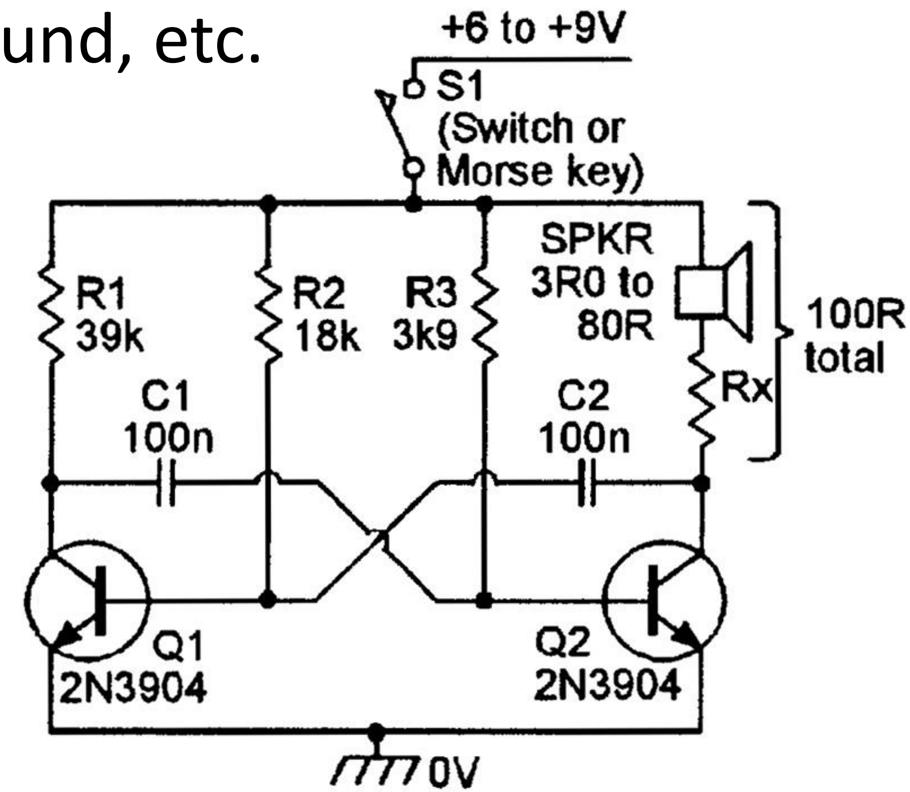
Answer

- Its an **astable (free-running) multivibrator** which has automatic built in triggering to switch continuously between its two unstable states both set and reset.
- It consists of two switching transistors, a cross-coupled feedback network, and two time delay capacitors which allows oscillation between the two states with no external triggering to produce the change in state.
- Read https://www.electronics-tutorials.ws/waveforms/astable.html

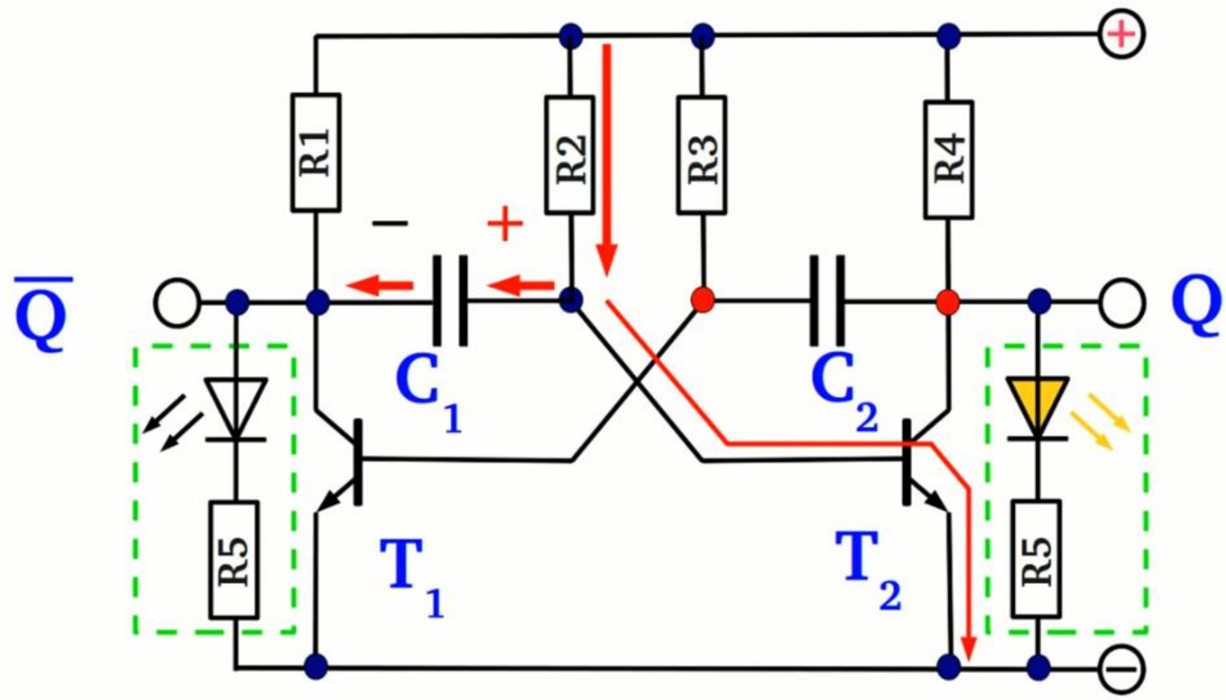
Astable Multivibrator: Applications

- Flashing lights, generate sound, etc.



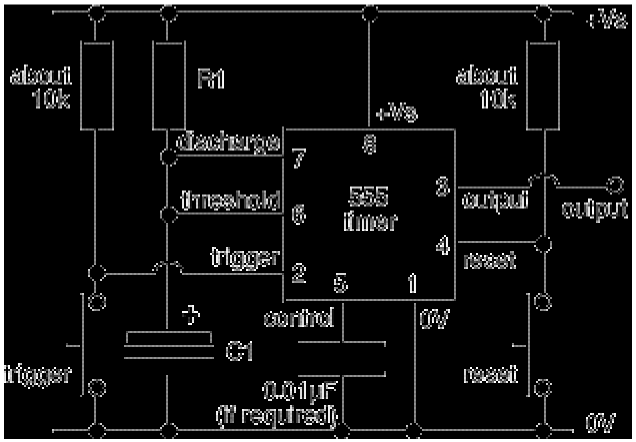


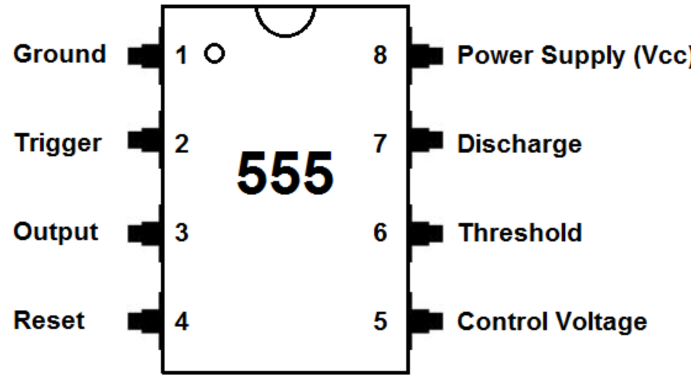
Multivibrators

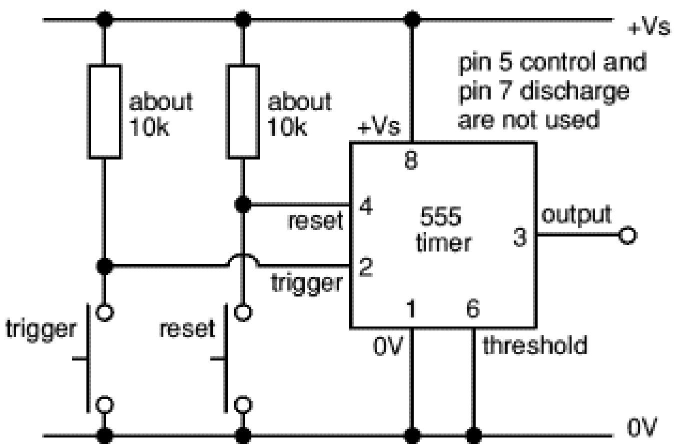


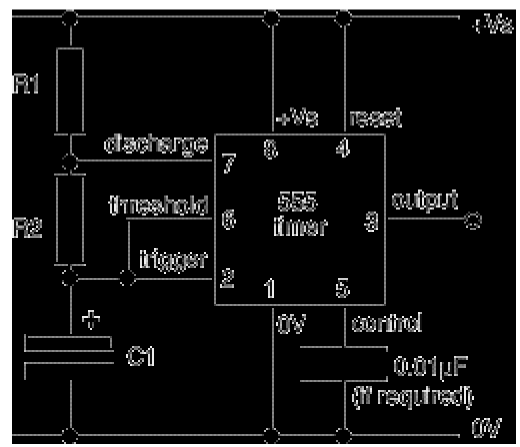
Working principle of multivibrators
https://www.youtube.com/watch?v=4lFj6h-U6WI

555 Timer Circuits:
Monostable, Bistable, Astable









555 Applications