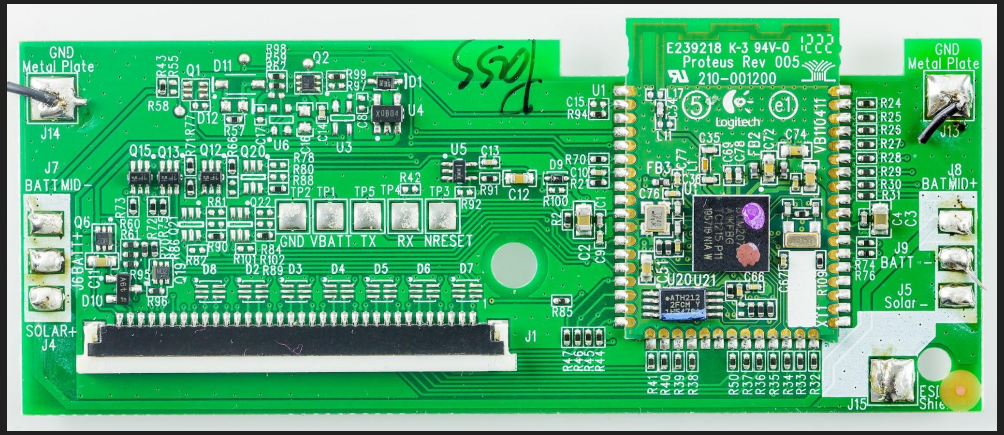
Introduction to Circuits

Computational Biology
Club at UC Davis

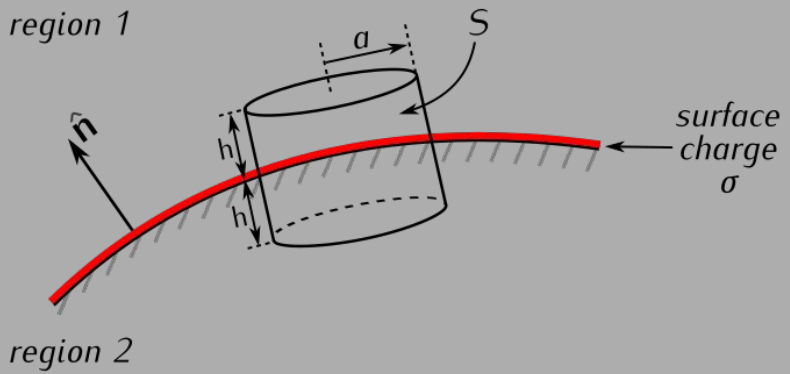
A First Look

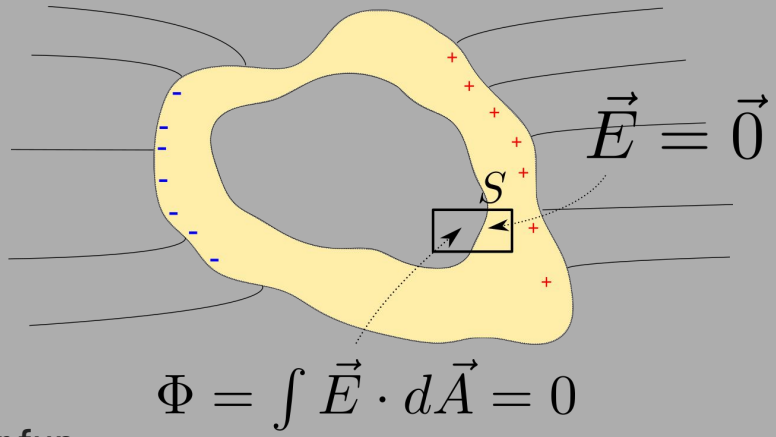
What do you think of first when you hear the term “circuit?”

Some Common ideas:



Circuit: a construction of building blocks of controllers for ***unique*** and ***specific*** systems





The key detail for most circuits is the fact that it is a loop! For fun, check out Gauss' Law for a much more technical explanation.

Why Know Circuits?

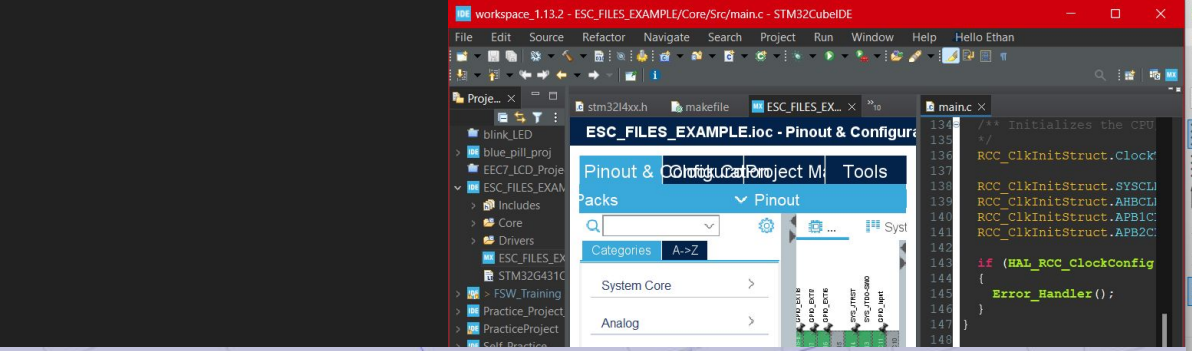
Extreme precision and detail

Boosted efficiency

Predictable in Performance

Various Applications

Modelling...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ESC_FILES_EXAMPLE.ioc - Pinout & Configura
Pinout & Configuration Project Ma Tools
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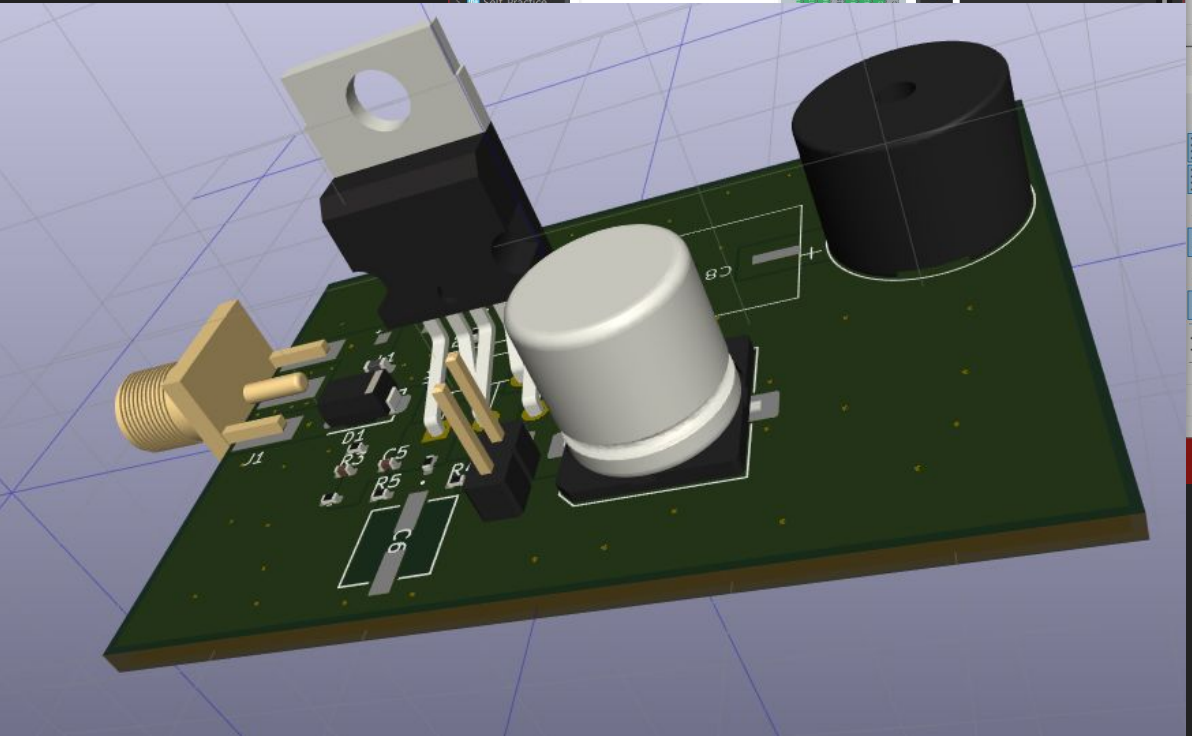
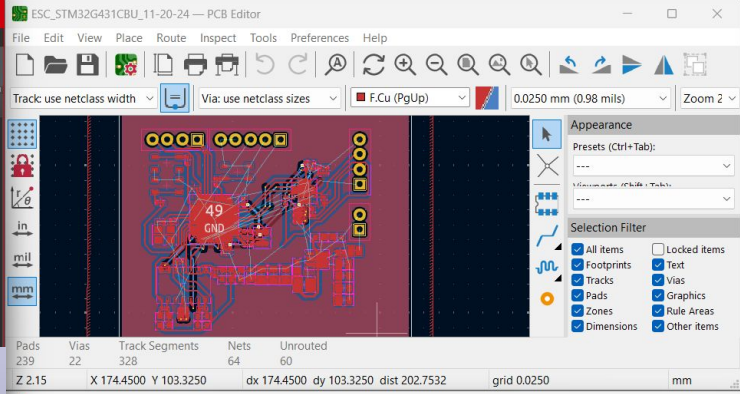
System Core
Analog
main.c
/** Initializes the CPU
RCC_ClkInitStruct.Clock
RCC_ClkInitStruct.SYSCL
RCC_ClkInitStruct.AHBCL
RCC_ClkInitStruct.APB1C
RCC_ClkInitStruct.APB2C
if (HAL_RCC_ClockConfig
{
Error_Handler();
}

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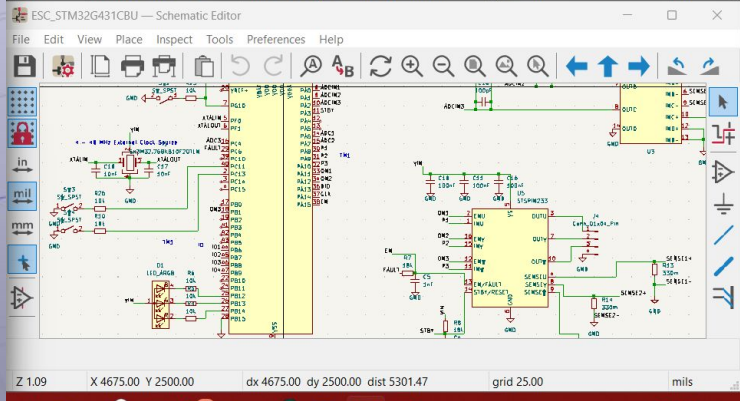
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Back to Modeling

We can *model* systems in biology using electronic circuit elements.

- Allows us to do math and calculations
- Design probabilistic models
- Create our *own* models to fit unique parameters

Circuit Elements and Concepts

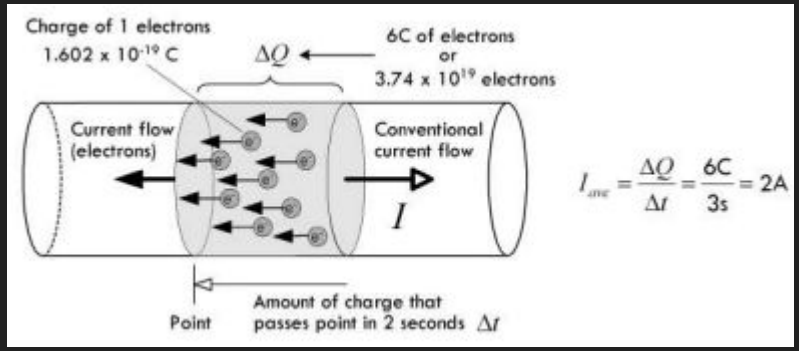
A comprehensive introduction

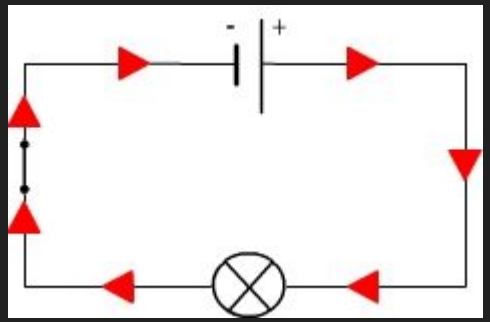
Current

Before we discuss actual parts, we need to understand the science that actually governs circuits.

Current: rate at which electrons flow past a certain point

- Direction: *opposite* of the direction the electrons flow
- Flows *through* things (from + to -)
- Measured in *Amperes (A)*; equivalent to Coulombs(charge) per second
- We can have signals as large as kA and small as nA
- Moving electrons is the key in explaining how devices work in circuits





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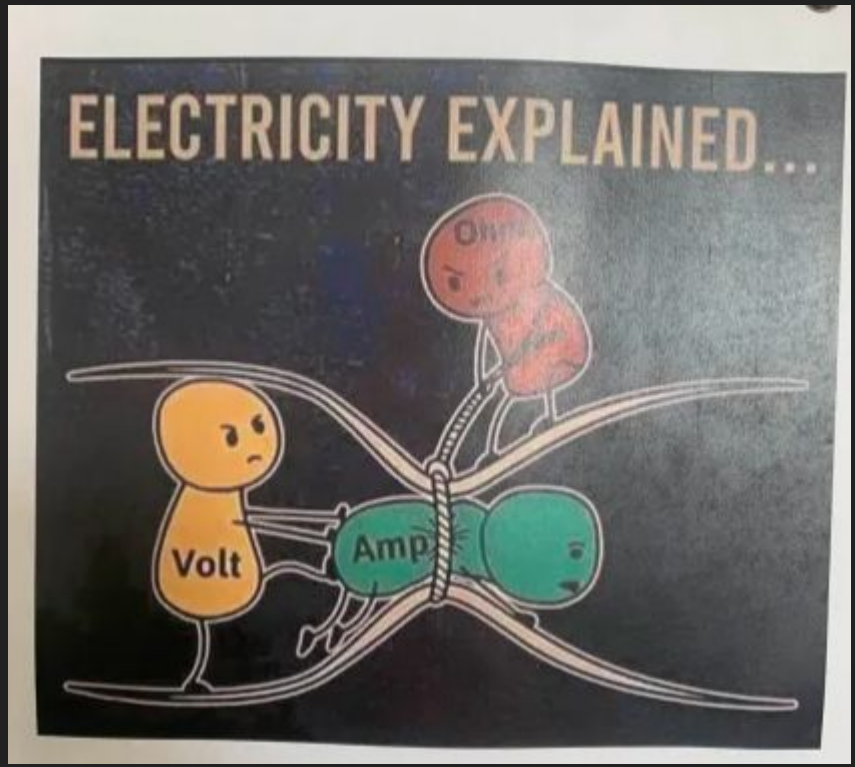
Voltage

Difference in electric potential energy between two points

- Measured in **Volts (V),** which is equivalent to Joules (energy) per Coulomb (charge)
  - The idea is it quantifies the potential energy of an electrical system
  - Think of it like a **pressure**
- The thing that damages electronic components is *current*, not *voltage*



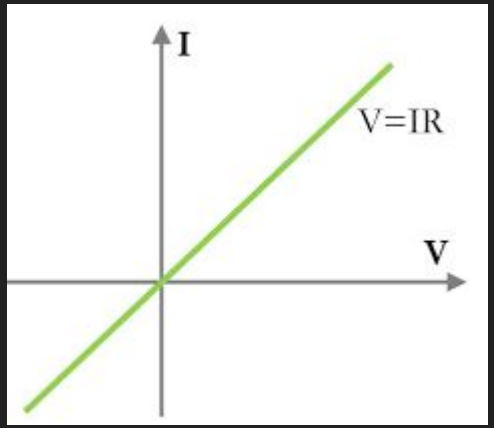
Resistors

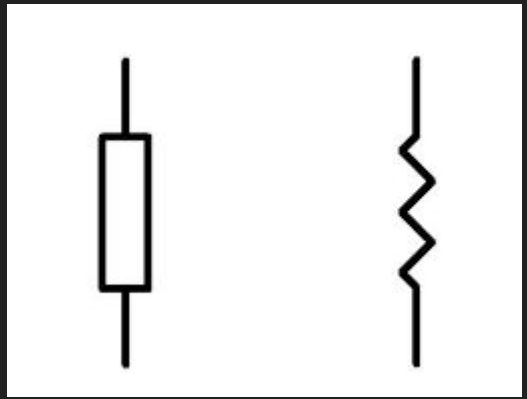
Resistor: Acts as a **semi-insulating material** due to physical material properties

- Measured in Ohms
- Dependent on size/material quality

Purposes:

1) “Creating” current from voltage
2) Dividing voltages
3) Limiting current





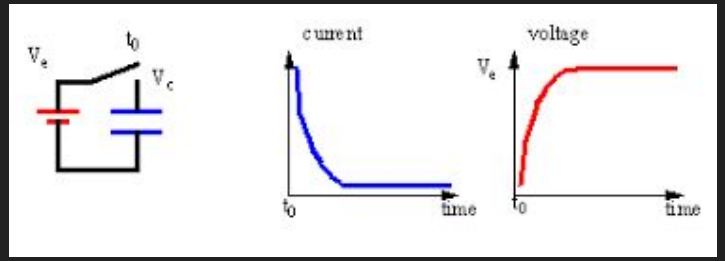
Capacitors

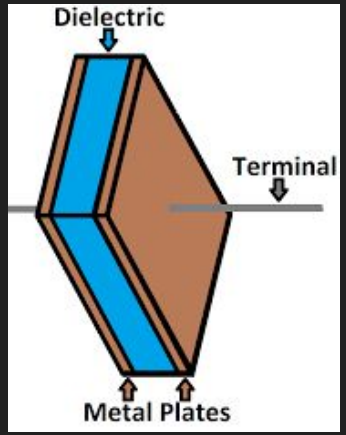
Can think of these as miniature storage cells that can **“discharge” current**

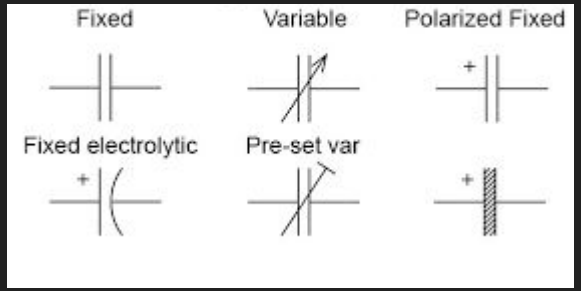
- Measured in Farads (F)
  - Will often see incredibly small values, like μF and pF
- Types: electrolytic, ceramic, mica, polymer, styrene, tantalum, etc.
- Dependent on size/material
- **Current proportional to change in voltage**

Purposes:

1) Creating oscillation
2) Filtering signals
3) Decoupling
4) Storing energy





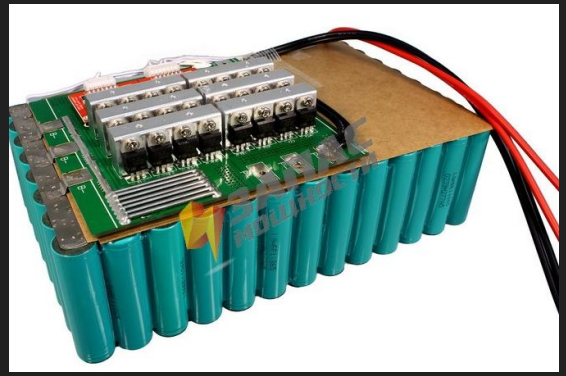


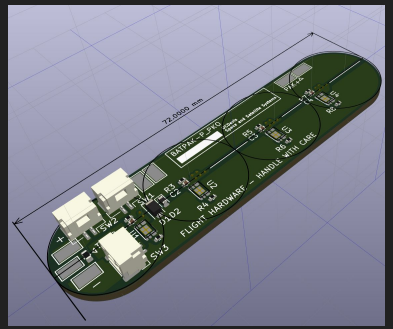
Batteries

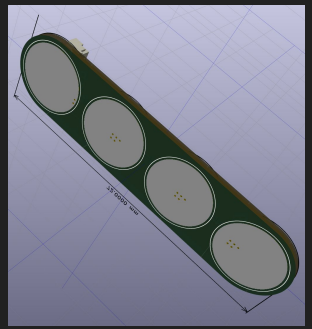
Storage containers for energy

- Main difference from capacitor: **distribute energy over much longer period of time**
  - Ideally, the voltage of a battery shouldn't change with changing charge
- Another key difference is batteries store energy **chemically, not with electric fields**
- Essentially, these provide **higher density of storage**, making them reliable sources of energy (for our purposes)
- Because of energy characteristics, we often talk about energy of battery in **Watt Hours (Wh)**

[1]







Courtesy of Tim S.

Inductors

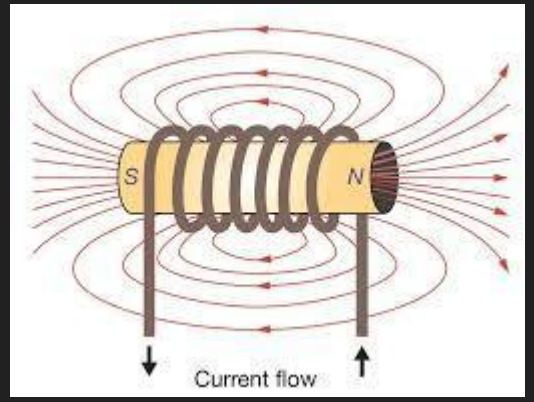
Conductive material that stores energy in a magnetic field when current runs through it

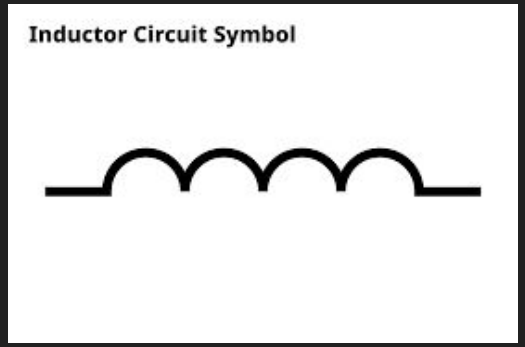
Once current runs through it, wants to keep current running through it

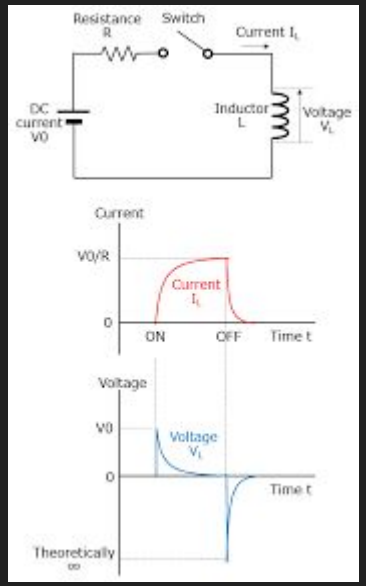
Cannot cut off the current from these devices

Purposes:

1) Filtering
2) Storing energy

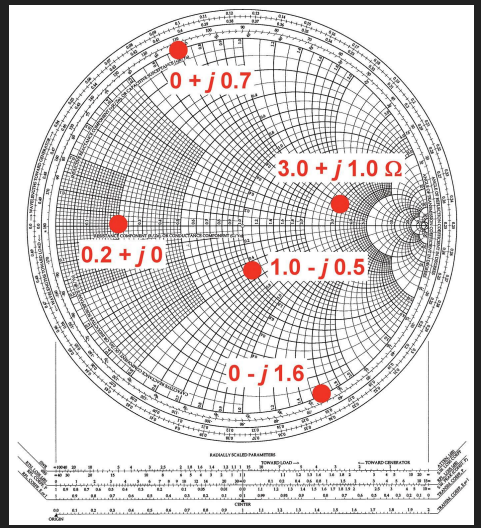




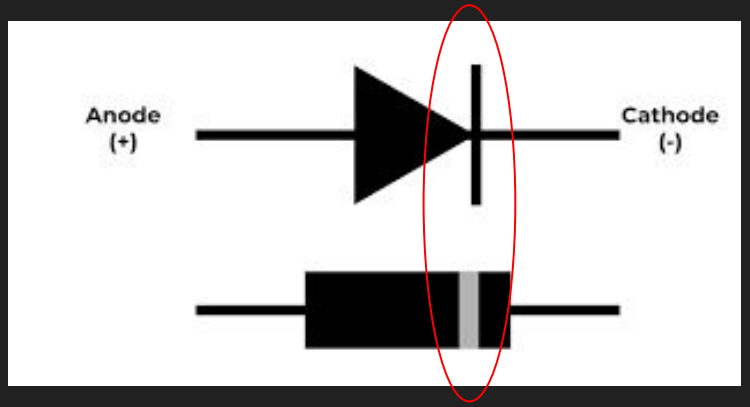


Impedance

This is like a “net resistance” calculation; summation of every element in the circuit that is “impeding” the signal. There is a constant part (represented in Real dimension) and frequency dependent part (Imaginary dimension)



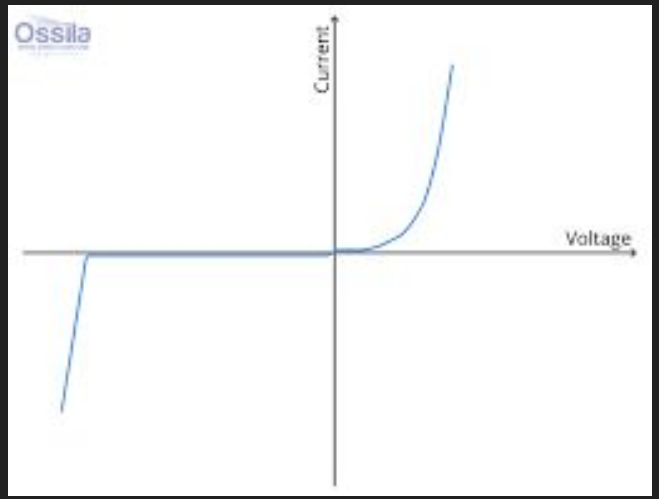
Diodes



One way **switch;** once a threshold input voltage is reached, the valve opens

Many types:

- General: all purpose diodes
- Zener: allow current to flow in reverse
- Schottky: lower forward voltage, while still being slightly leaky
- LED: Light Emitting Diode
- Many more...



Purposes:

1) Clipping signals (sort of like filtering)
2) Rectification
3) Allowing some kind of internal logic

Transistors

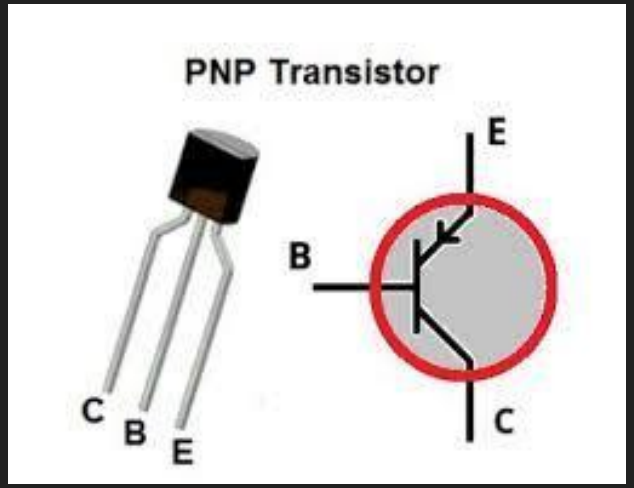
Semiconductor devices where you allow current to flow by applying a second current/voltage

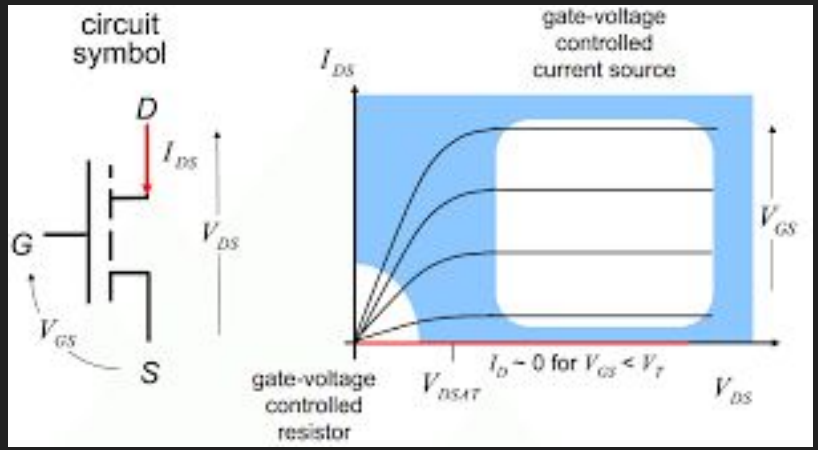
BJT (Bipolar Junction Transistor): current controlled

FET (Field Effect Transistor): voltage controlled

Purposes:

1) Logic controllers
2) Switches
3) Amplification





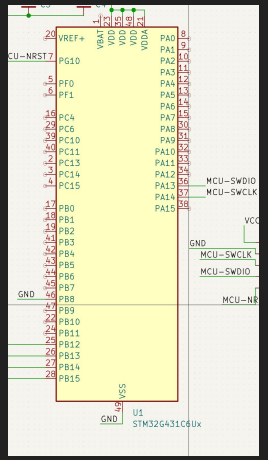
Integrated Circuits (ICs)

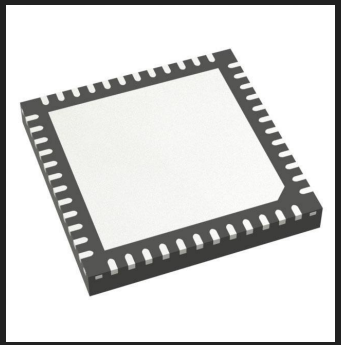
Combines components shown before to make miniature circuits that can perform tasks

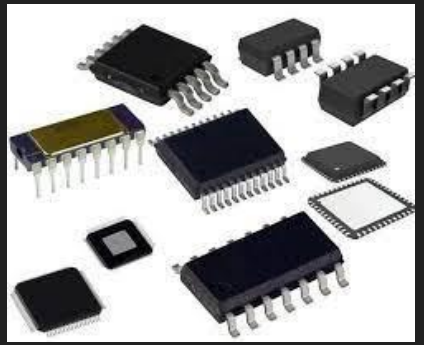
Various number of ports/sizes/shapes

Types:

1) Microprocessor
2) Logic gate
3) Motor driver
4) etc.



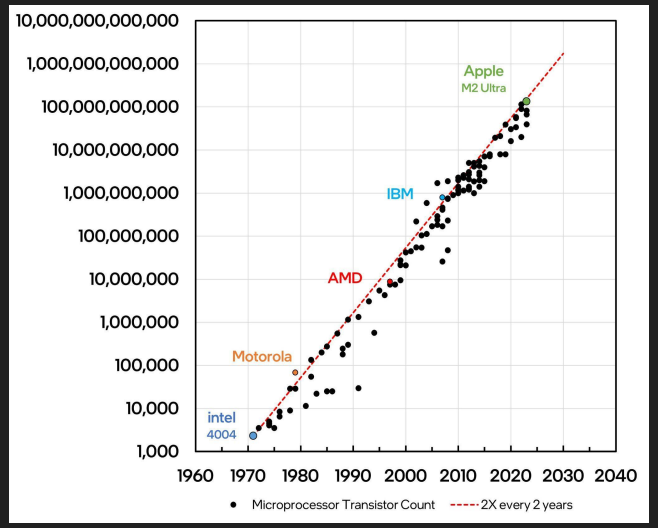


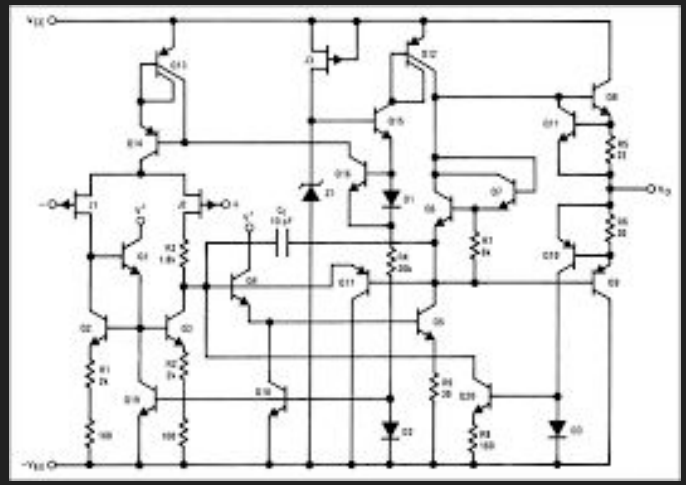


More on ICs

Often, we treat IC's as "black boxes;" however, they have incredibly complex internal structure

Moore's Law

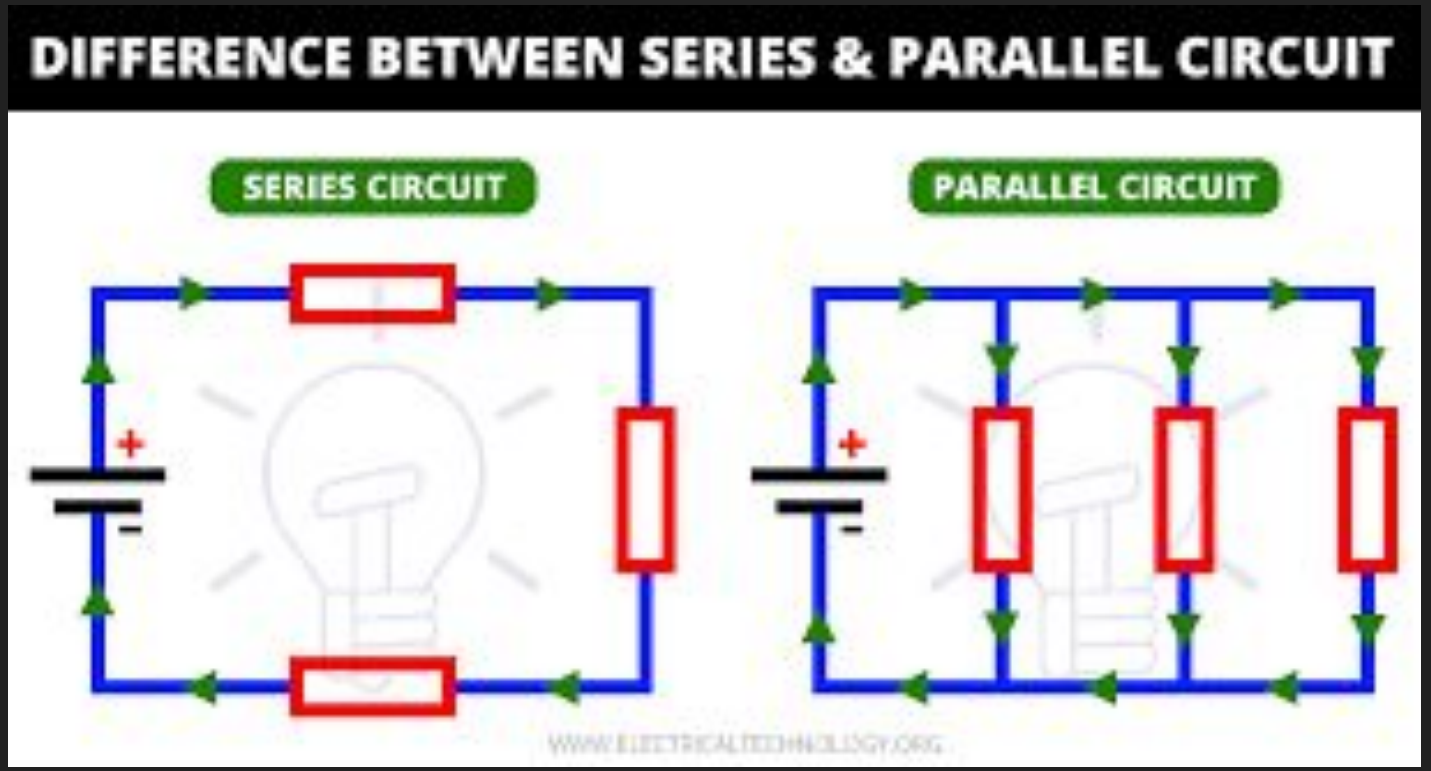




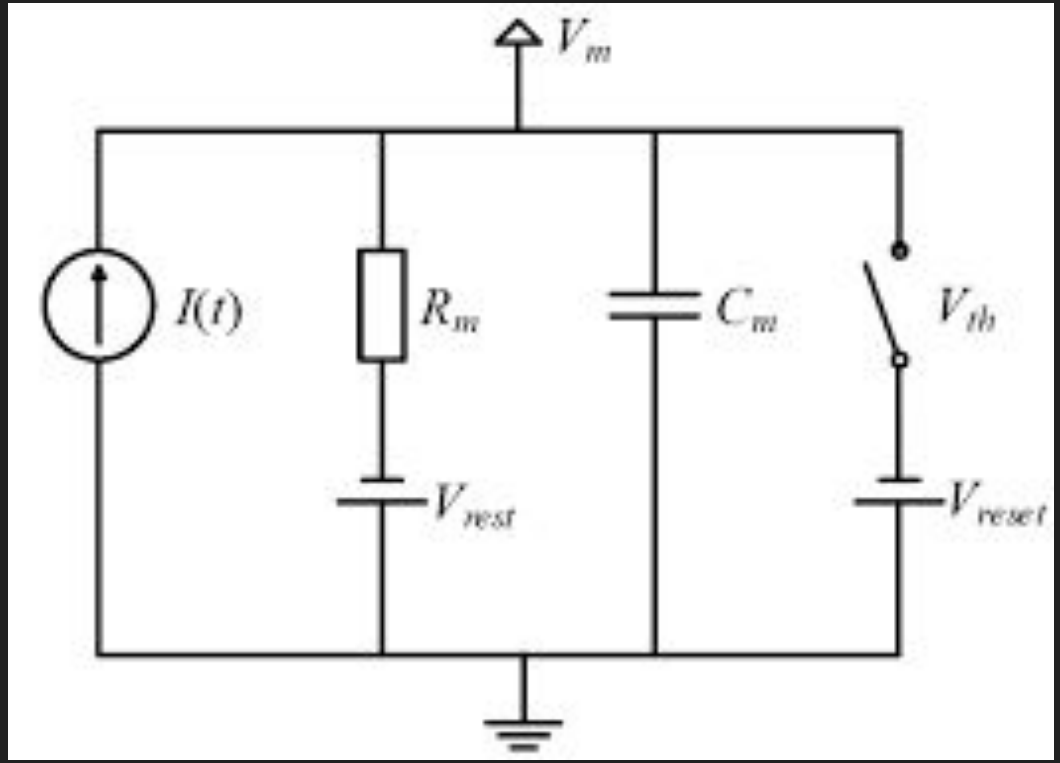
Preliminary Component Configurations

decides how information is relayed

Series vs Parallel

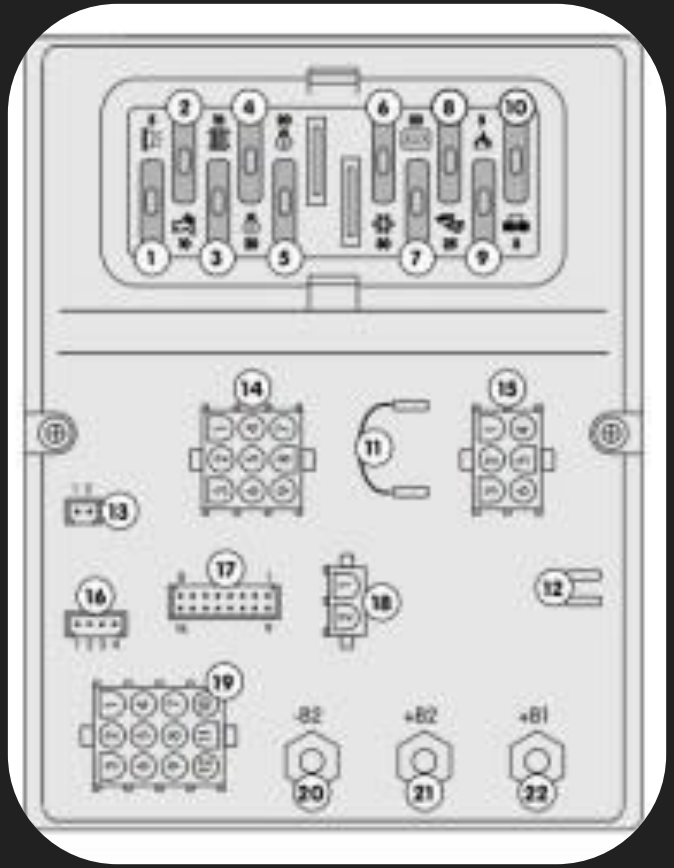


Not Just in Electronics!



Logic Circuits

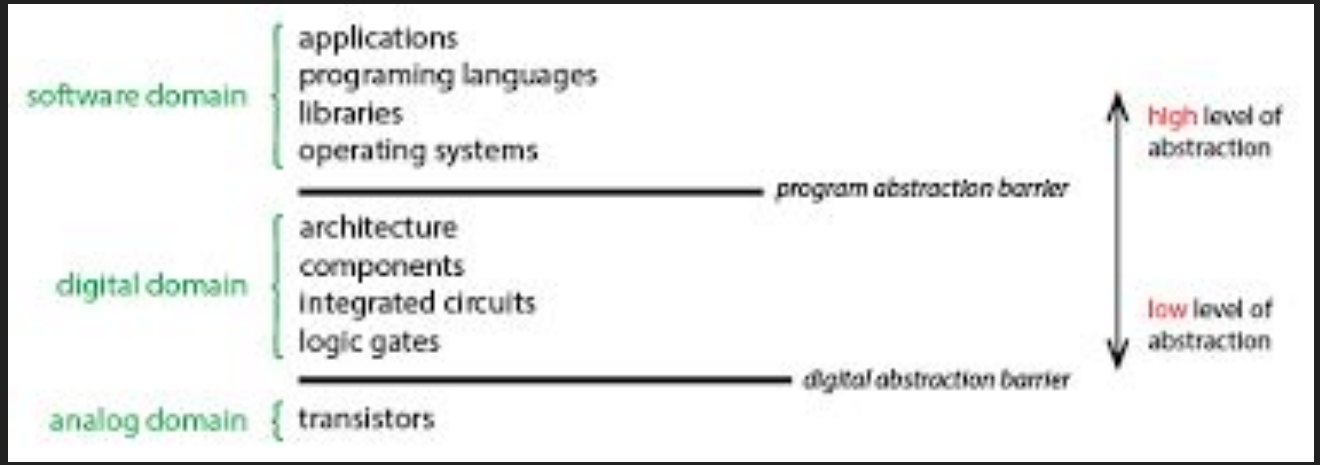
Up till now, we have discussed components; now, we can take abstract representations of circuits and start designing logic models.



Logic Circuits

Why do we care?

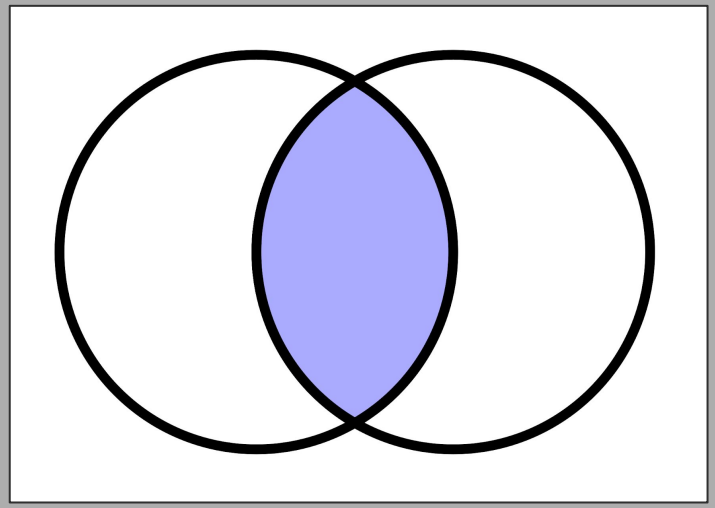
Answer: Abstraction!

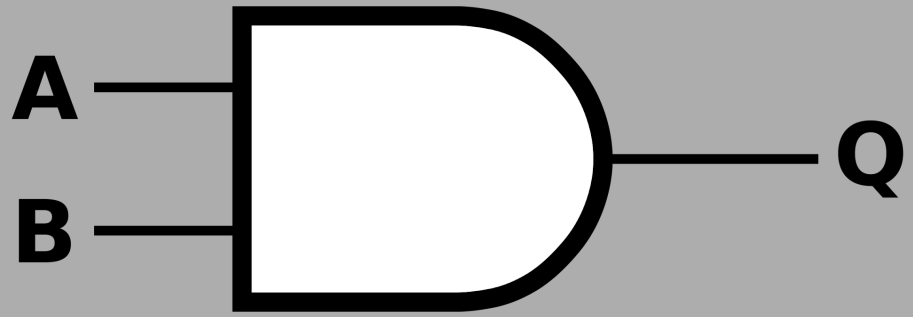


Logical AND

This is the *intersection* of two sample spaces
(NOTE two sided input)

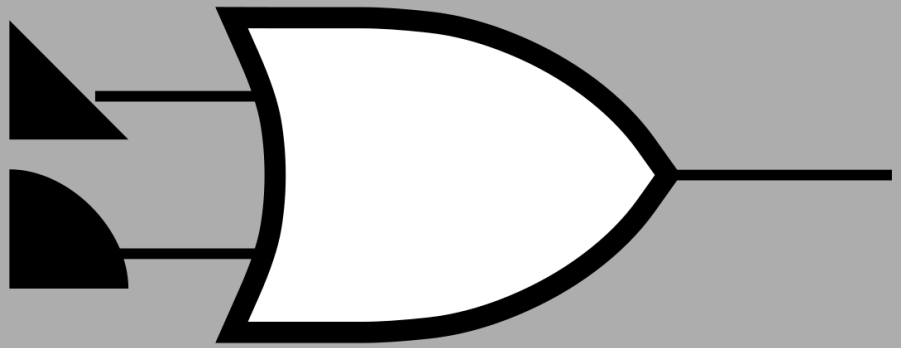
Symbols: &, ^, .

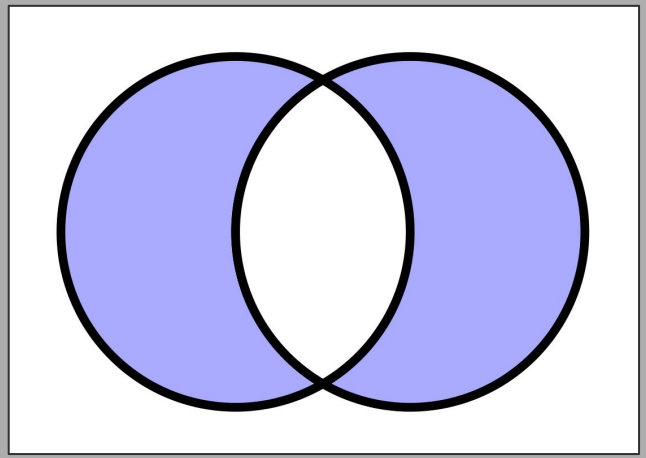




Logical OR

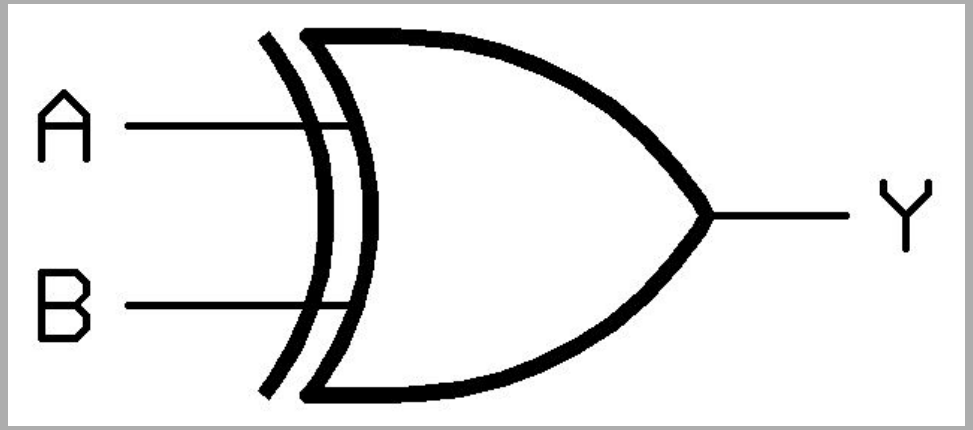
This is the *union* of two sample spaces (WITHOUT the intersection (NOTE two sided input)

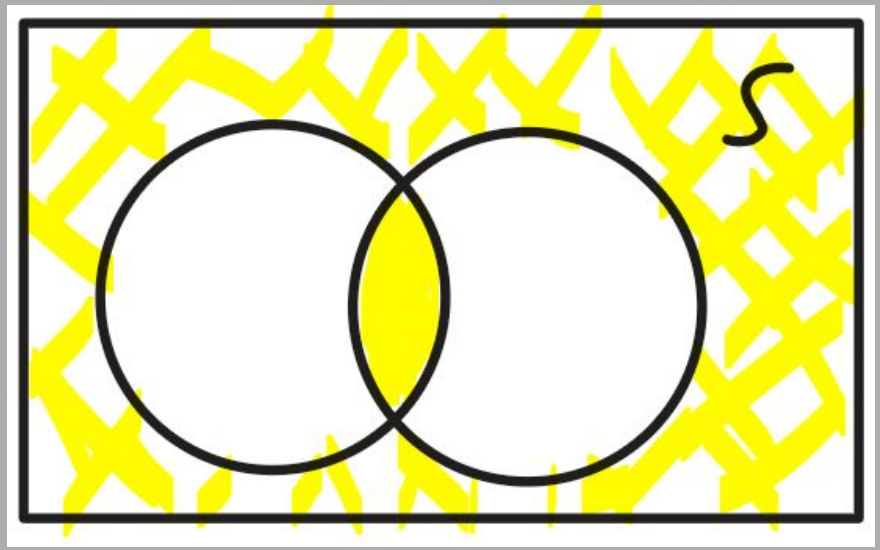




Logical XOR

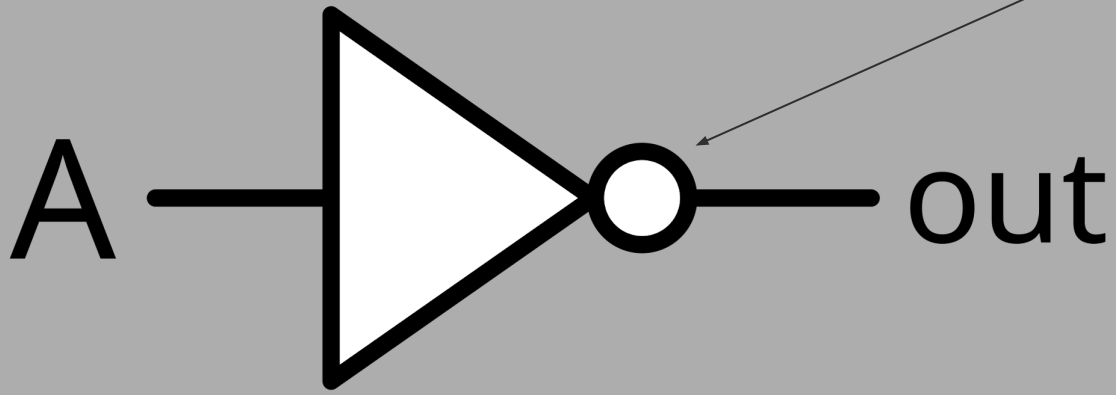
This is the *complement of a logical OR;* returns “true” when both inputs are NOT the same



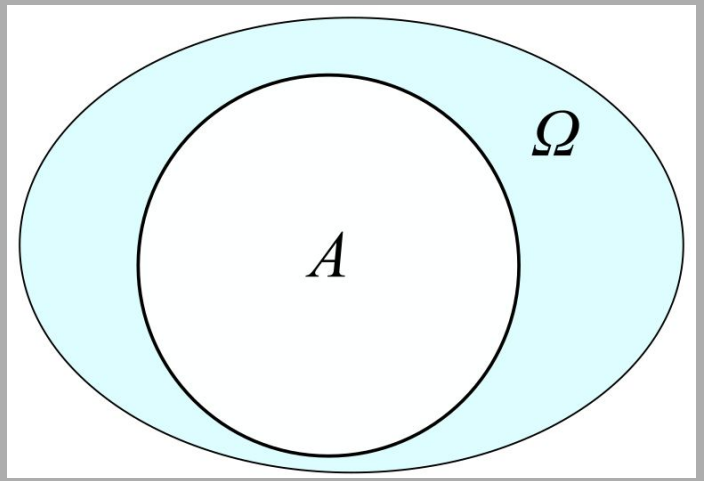


Logical NOT

This is the *complement* of a sample space

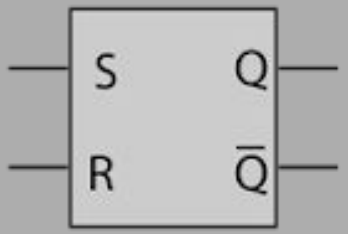


NOTE: if you see that small circle on anything, it indicates that you *invert* the logic in some way.



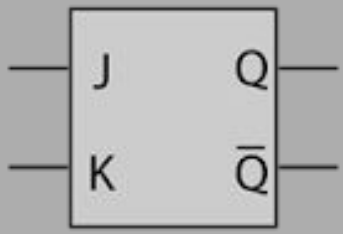
Flip-Flops

Will output some specific things according to specific inputs



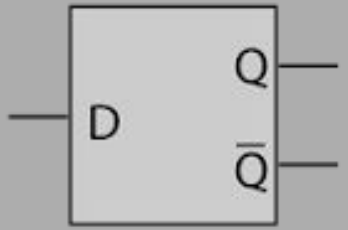
Basic data storage device which holds data until reset occurs.

Set/Reset Type



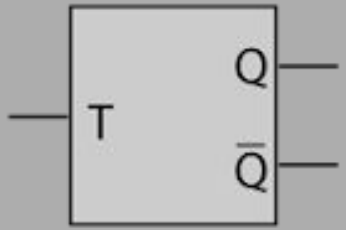
Most versatile of basic flip-flops. Two-input behavior plus toggle type behavior.

J-K Type



Basic data flip-flop has advantage of simpler wiring than J-K version.

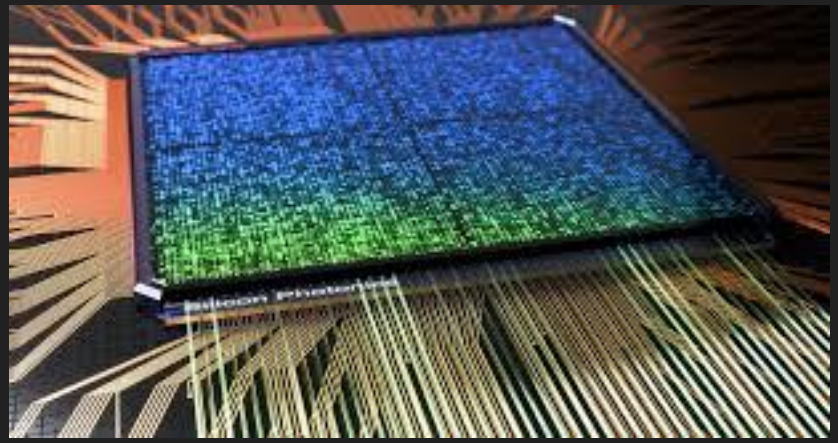
D Type

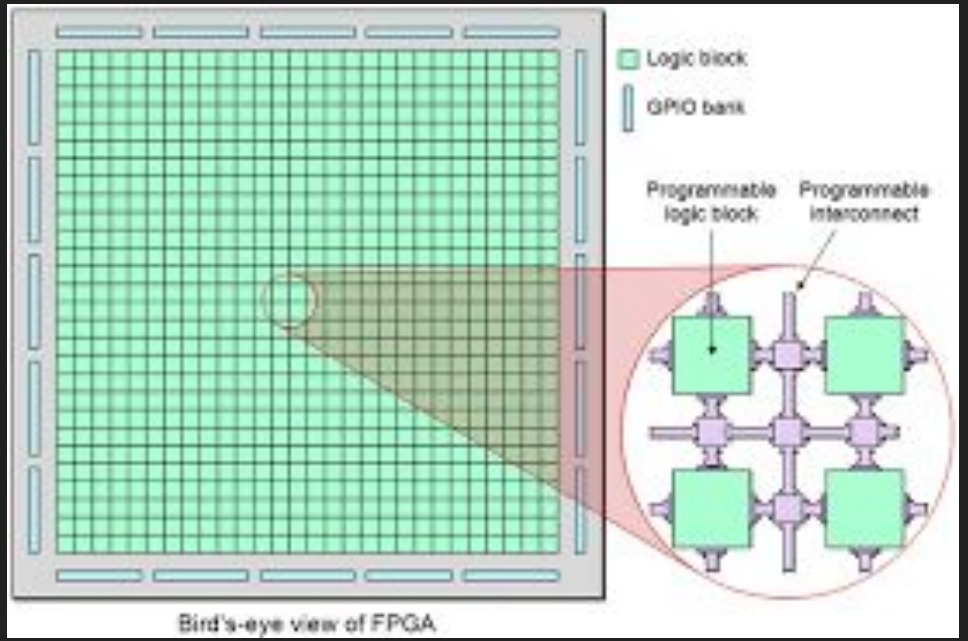


"Toggle" action is useful for counters. Can be constructed from any of the basic flip-flops.

Toggle Type

Applied Example: FPGAs (Field Programmable Gate Arrays)

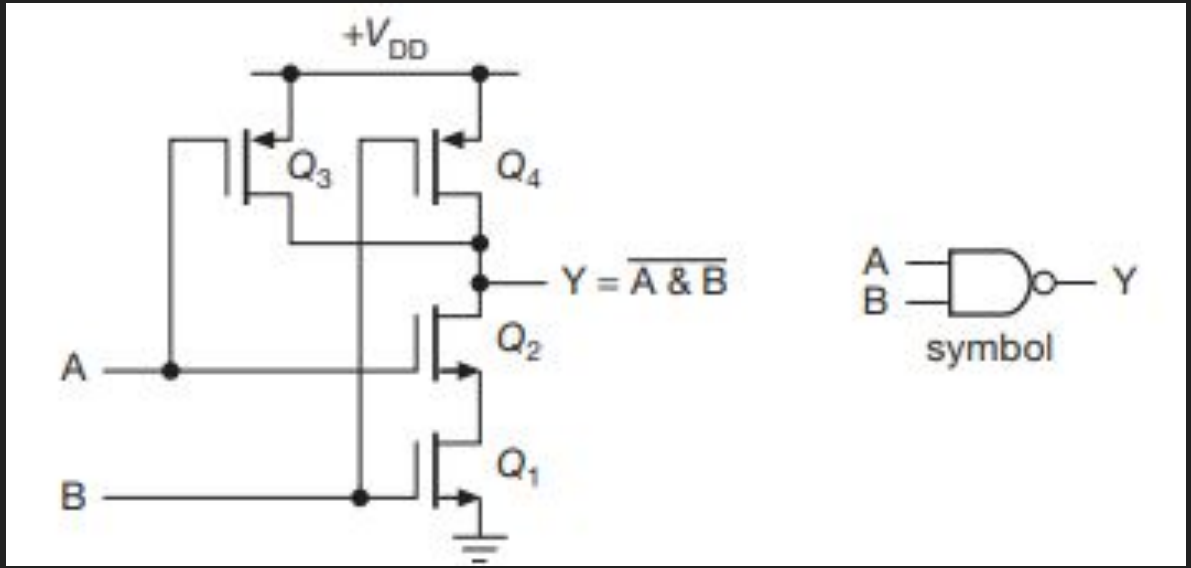




Just to Remind you...

The logic gates themselves are much more “complicated”

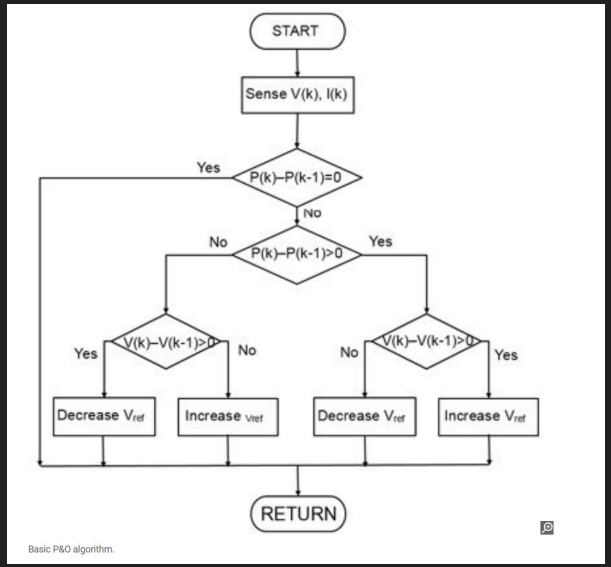
CMOSFET: “Complementary Metal-Oxide Silicon Field Effect Transistor”

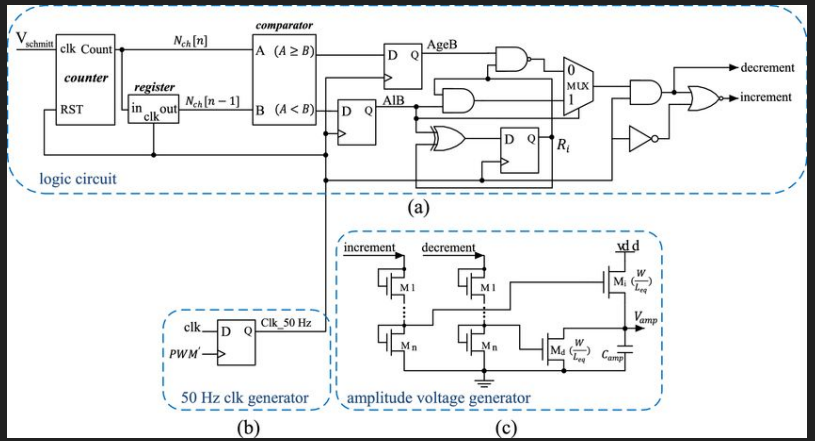


Common Examples of Applications

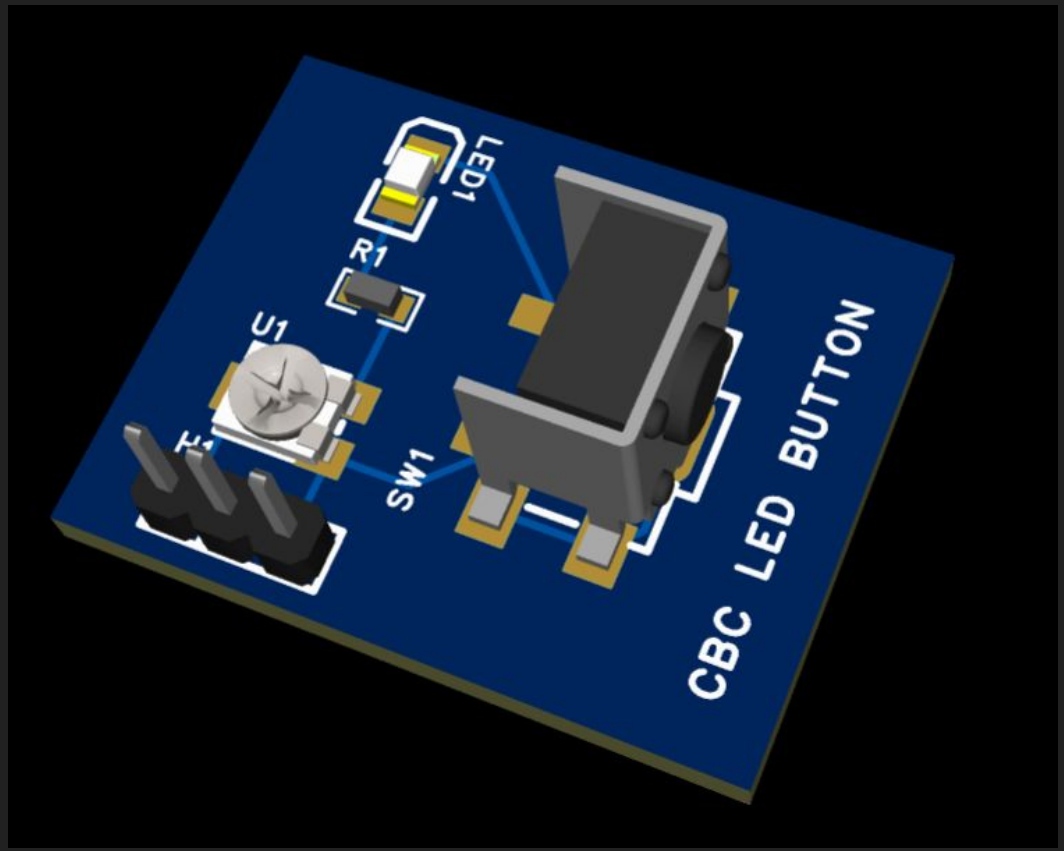
On the right is the MPPT (Maximum Power Point Threshold) algorithm. In power electronics, we use it to regulate the power output of some device.

- Above: Simulink model. Very high level.
  - For those of you who use MATLAB, this can directly translate into code!
- Below: actual circuit diagram model.





Your First Circuit!



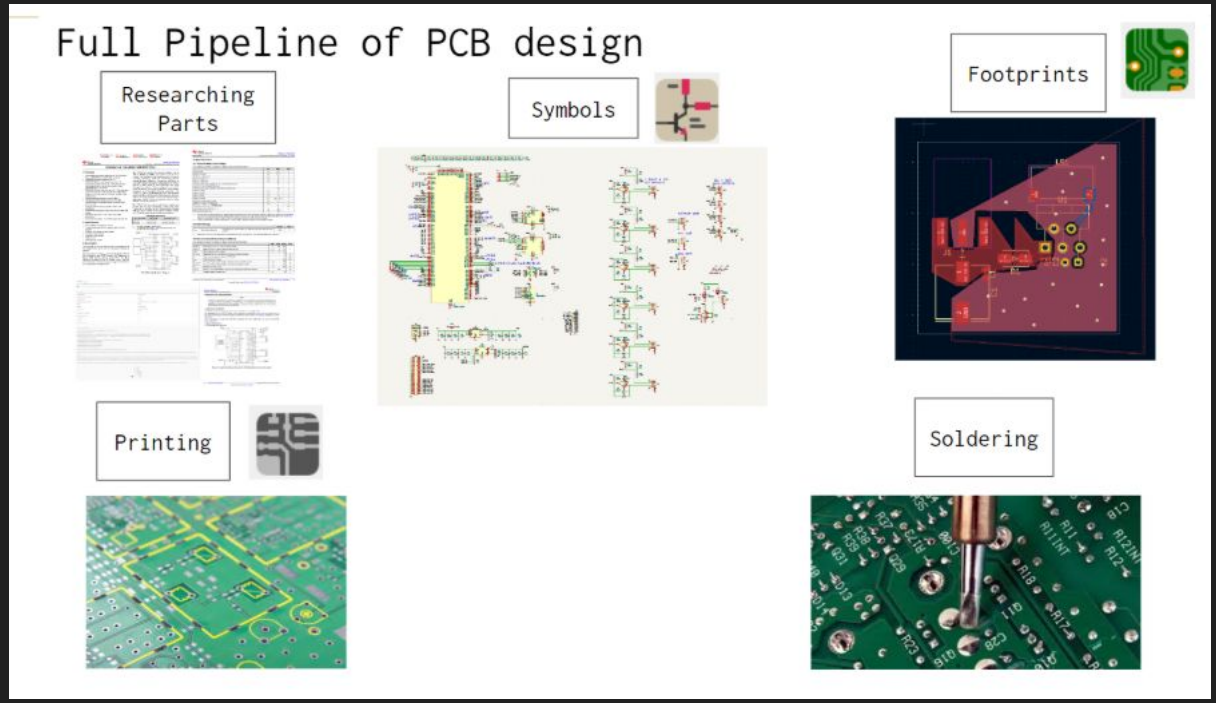
Quick Intro: EDA

EDA: Electronic Design Automation

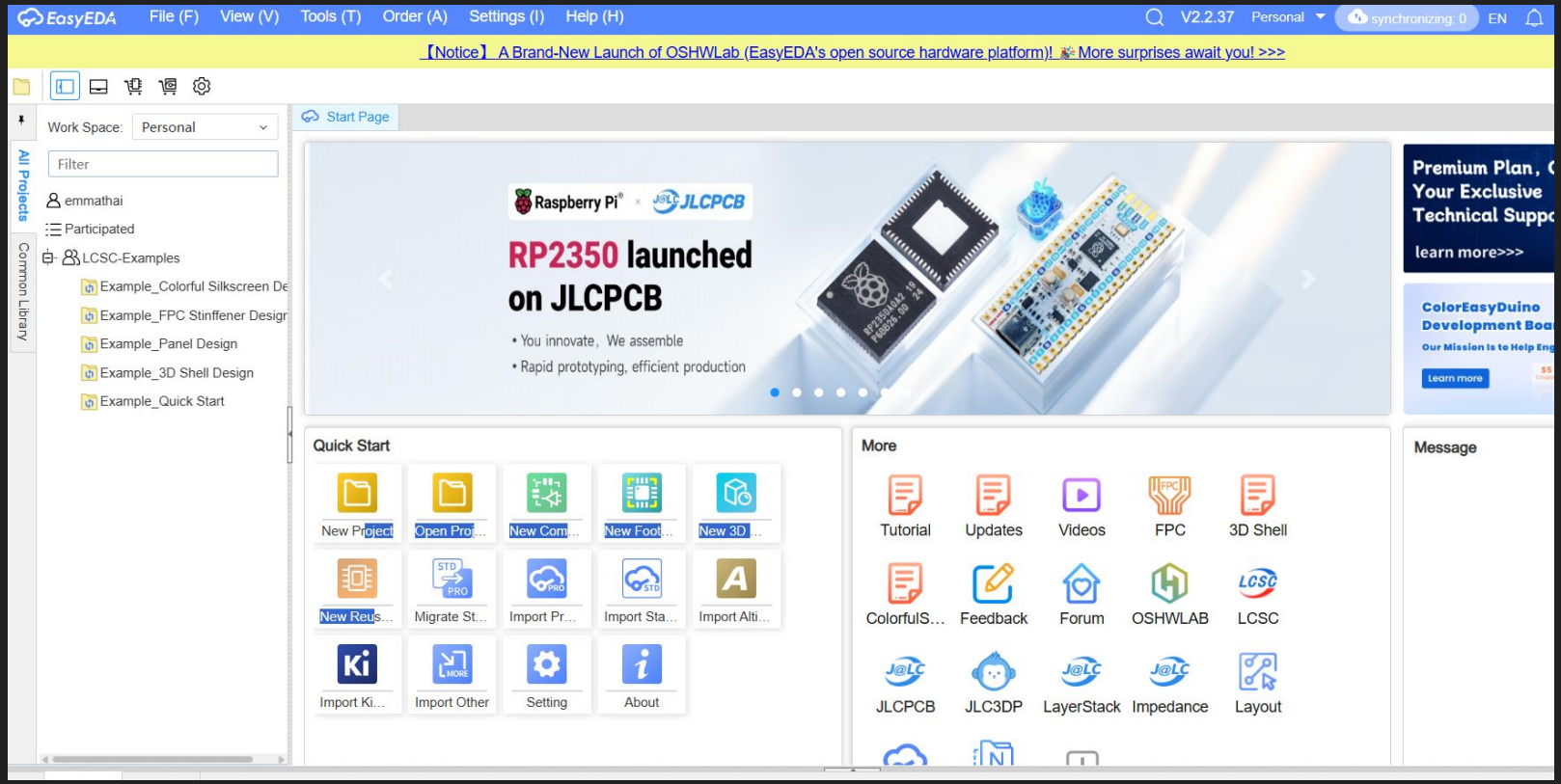
Allows you to design PCBs (Printed Circuit Boards)

Workflow:

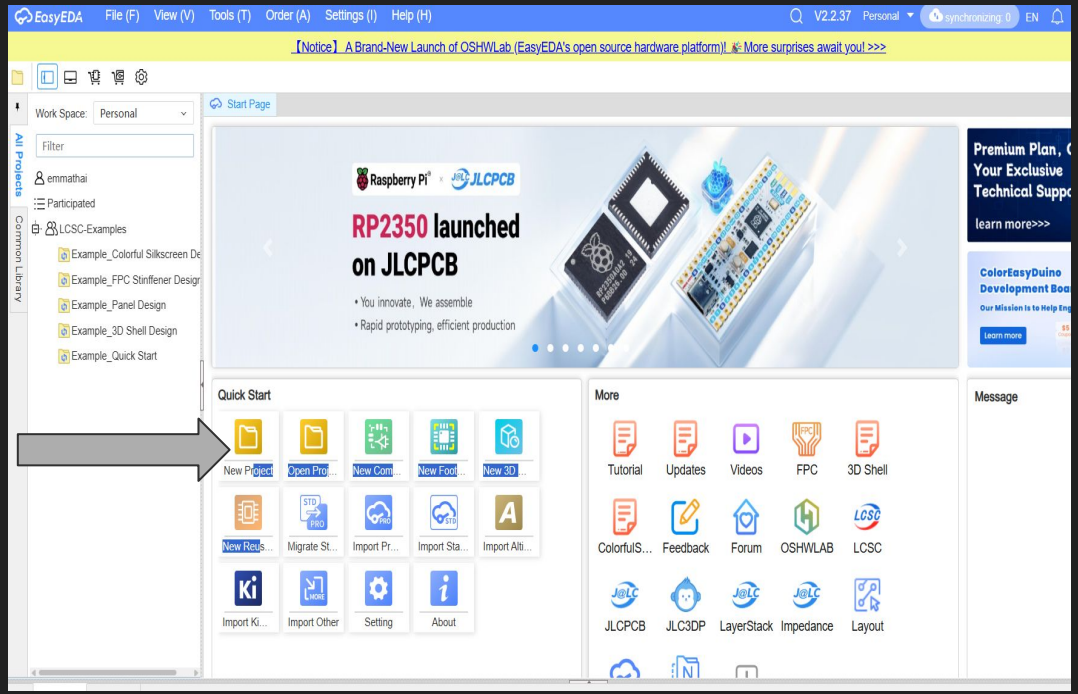
1) Circuit diagram/Schematic
2) PCB
3) Export “gerber” files for printing
4) Assembly and testing



Step 1: Log into Easy EDA (free account)



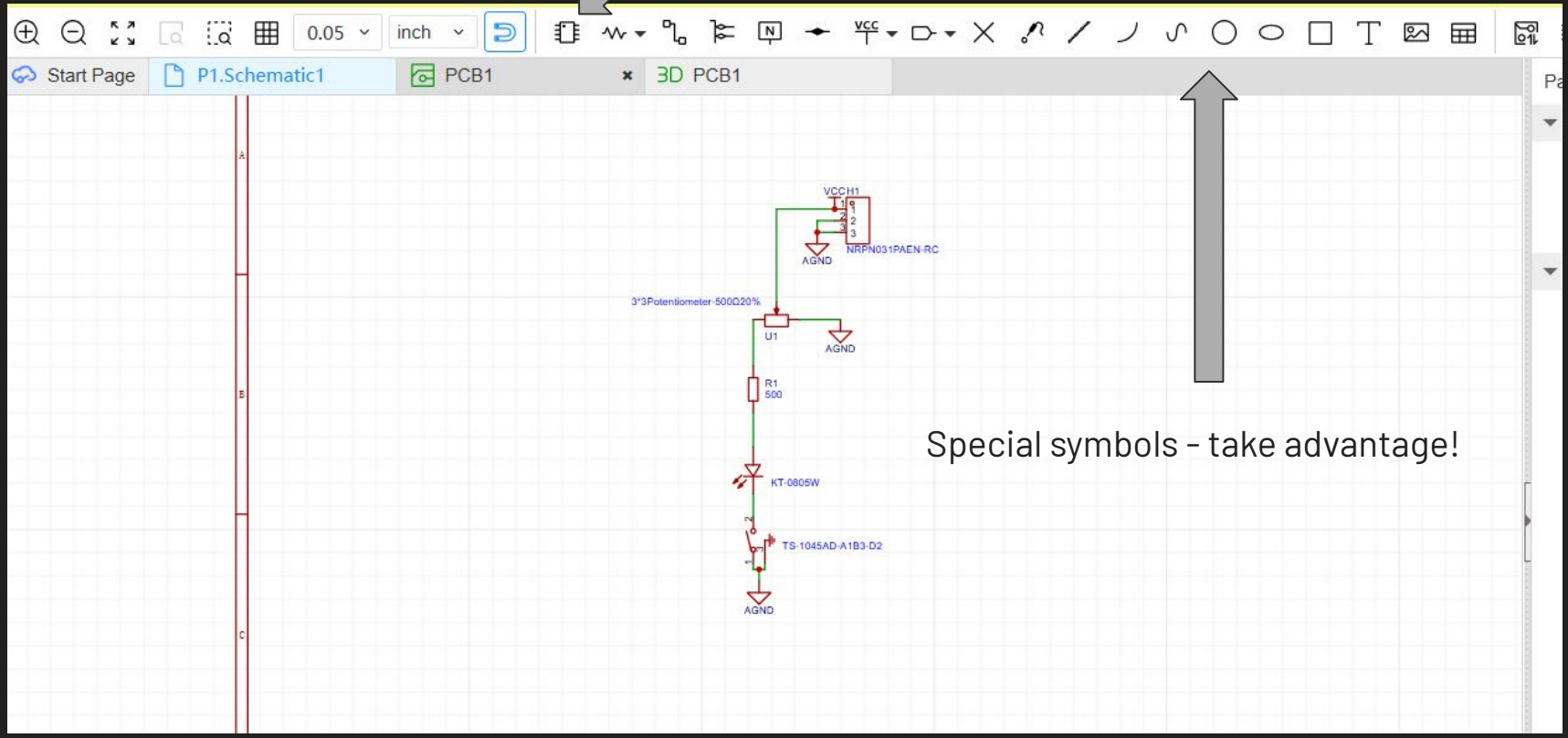
Step 2: Start a Project



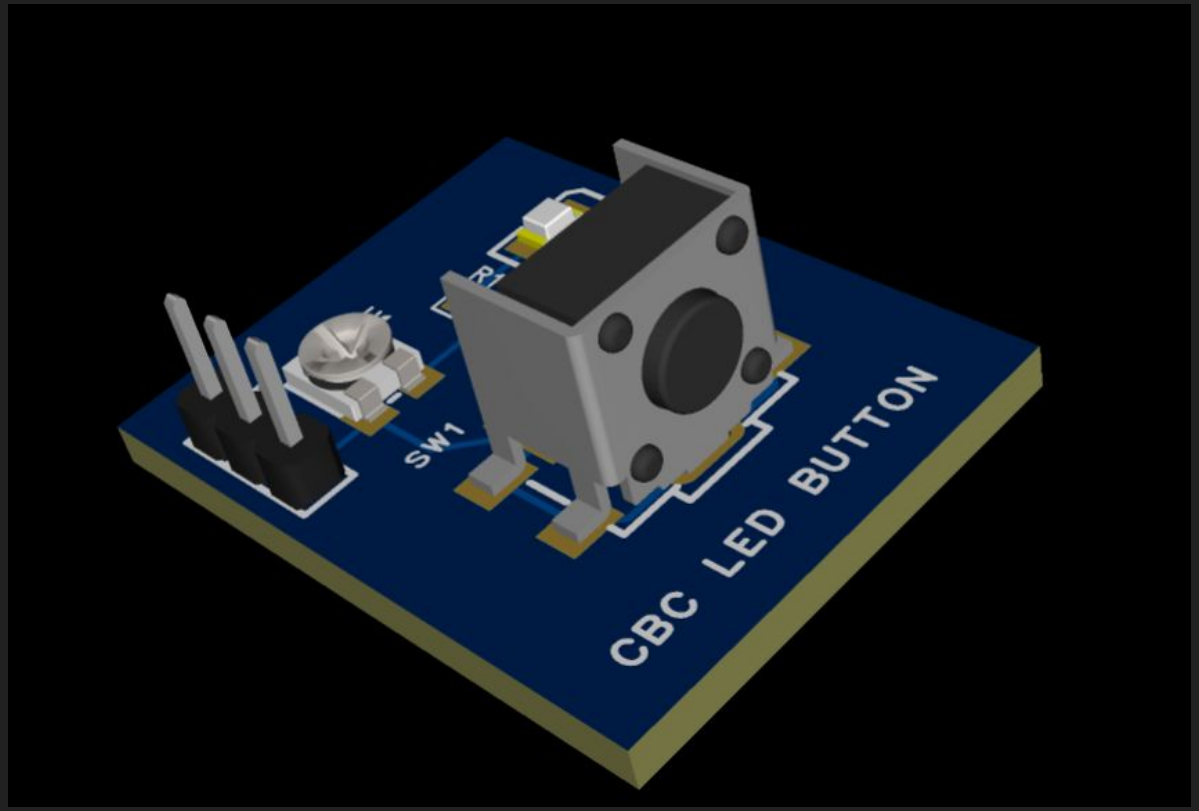
Can be given any name!

Step 3: Schematic

Search for components, using names



Step 5: Admire your handiwork :)



Interested in printing?

Speak to me afterwards!