Electronic Hardware

Onboarding: Electricity

#001

2023

Introduction

Agenda:

1. Fundamental Electrical Quantities
2. Basic Electrical Components
3. Essential Formulas
4. Diodes and LEDs
5. Transistors
6. Series vs Parallel
7. Kirchoff's Laws
8. Batteries
9. PCBs

Goal:

Understand basic concepts of electronics and printed circuit boards

Introduction

Voltage (V): The potential energy needed for current flow

- Think of this as the pressure that pushes electrons
- The amount of energy needed per unit of charge
- Units: Joules/Coulomb = Volts (V)

Current (I): Amount of charge flowing in a time frame

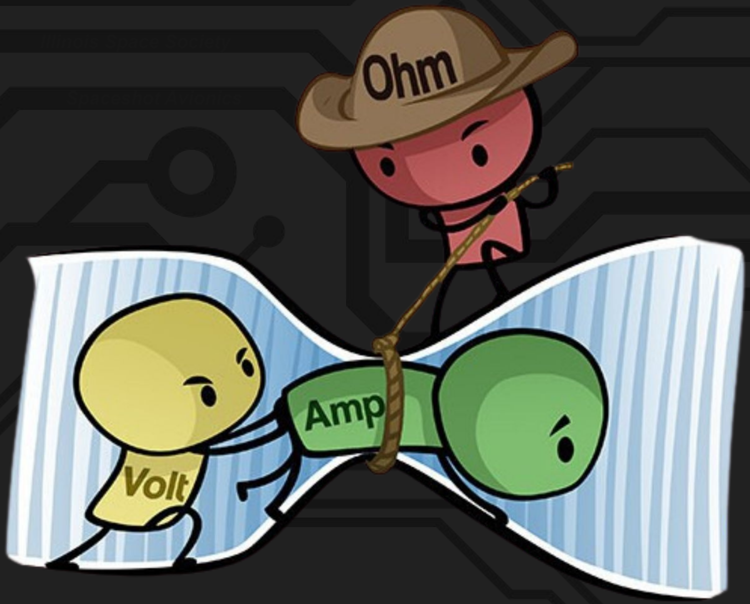
- Movement of electrons through an electrical conductor
- Prefers the path of least resistance
- Units: Coulomb/Second = Amps (A)

Charge (Q): Driving force behind electrical energy

- Determines how much electrical energy is stored
- Units: Coulombs (C)

Power (P): Amount of energy transferred in a time frame

- Movement of energy through a conductor
- Calculated $P = V \cdot I$
- Units: Joules/Second = Watts (W)



Resistors

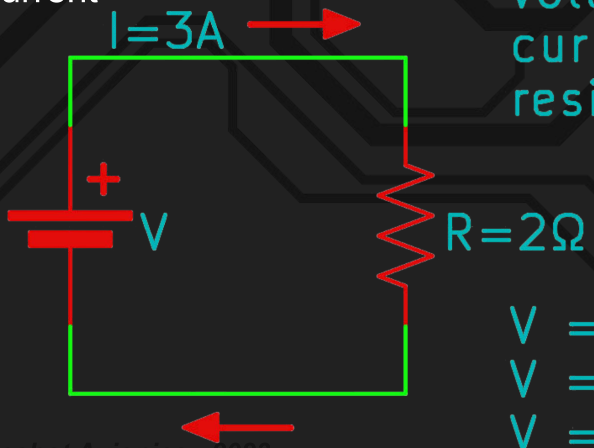
Resistance (R): A material's opposition to charged flow

- Limits the amount of current going through
- As voltage passes through, some potential energy is lost causing a a voltage drop
- Units: Ohms (Ω)

Ohm's Law: A way of relating the voltage *across* and current *through* a **resistive** element

- Works for resistors but NOT for sources
- $I = \frac{V}{R}$
- $V = I \cdot R$
- $R = \frac{V}{I}$

(more details in KVL slide)



voltage: (V)
current: (I)
resistance: (R)

V = I x R
V = 3A x 2Ω
V = 6V

Capacitors

Definition: Component that can temporarily store charge

Capacitance

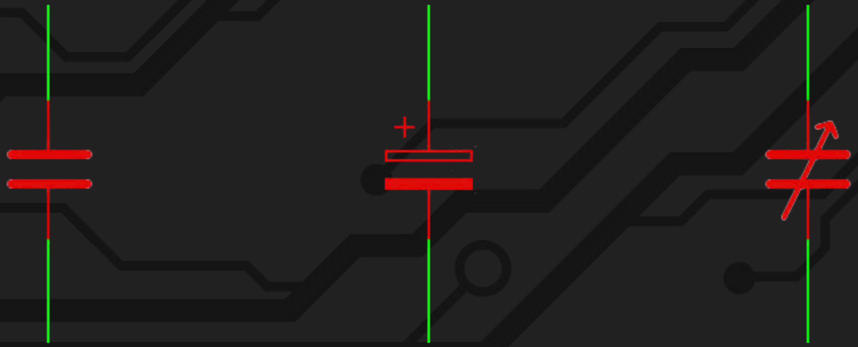
- The ability to store electrical charge
- Capacitance equals charge stored over voltage
- Energy equals half of capacitance times voltage squared

$$C = \frac{Q}{V}$$

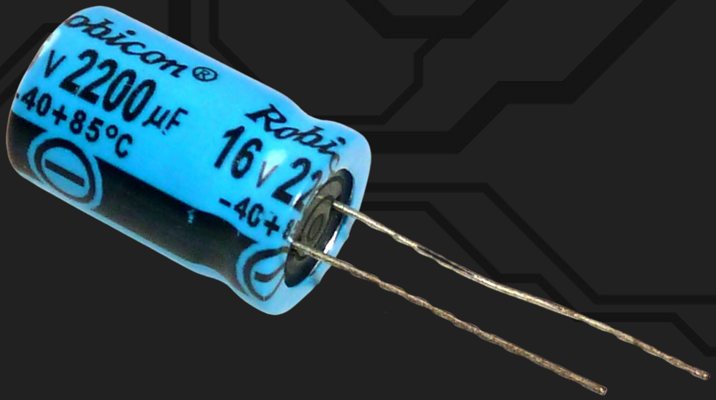
$$E = \frac{1}{2}CV^2$$

Polarized capacitors

- Can only be used in one direction



Fixed Capacitor   Polarized Capacitor   Variable Capacitor



Inductors

Definition: Component that oppose sudden changes in current

Inductance

- The ability of a inductor to induce an opposing voltage to the current
- Induced voltage equals negative inductance times rate of current

$$V = -L \cdot \frac{dI}{dt}$$

Cheat Sheet

	Resistors	Capacitors	Inductors
Function	Resists the flow of electrical current	Temporarily stores charge	Resists sudden changes in current
Units	Ohm (Ω)	Farad (F)	Henry (H)
Series	$R_T = R_1 + R_2 + R_3$	$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$L_T = L_1 + L_2 + L_3$
Parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$	$C_T = C_1 + C_2 + C_3$	$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$
Voltage	$V = IR$	$V = \frac{Q}{C}$	$V = -L\frac{dI}{dt}$
Impedance	R	$\frac{1}{j\omega C}$	$j\omega L$

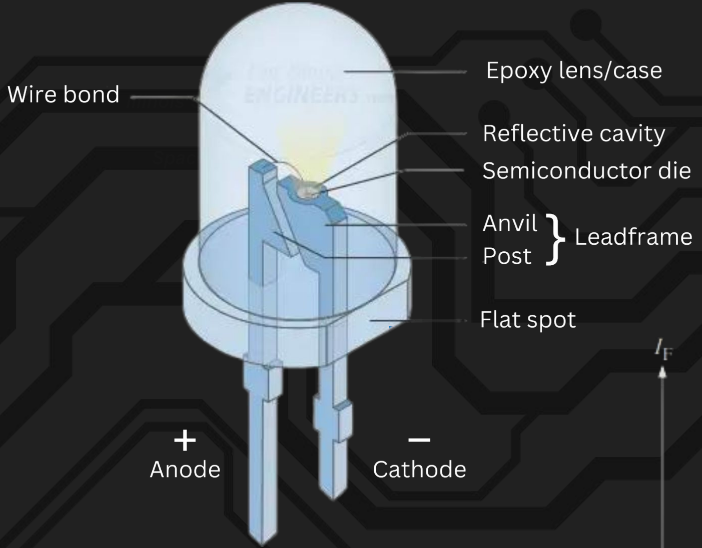
Diodes & LEDs

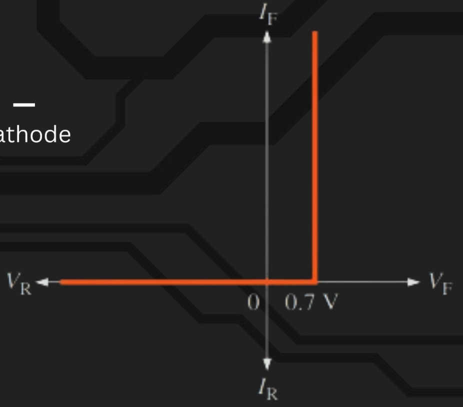
Offset Ideal Model

- A diode is similar to a resistor with the exception that current can only flow in one direction
- Is not bidirectional — a one way switch
- At a set turn on voltage like 0.7 V, current needs to be positive for the diode to be on
    - If not, the diode will be off causing an open circuit

LEDs

- A device that emits light when a current passes through
- However, too much power, and it dissipates as heat, causing the LED to blow up :(
- Resistors are commonly used in series to limit the current

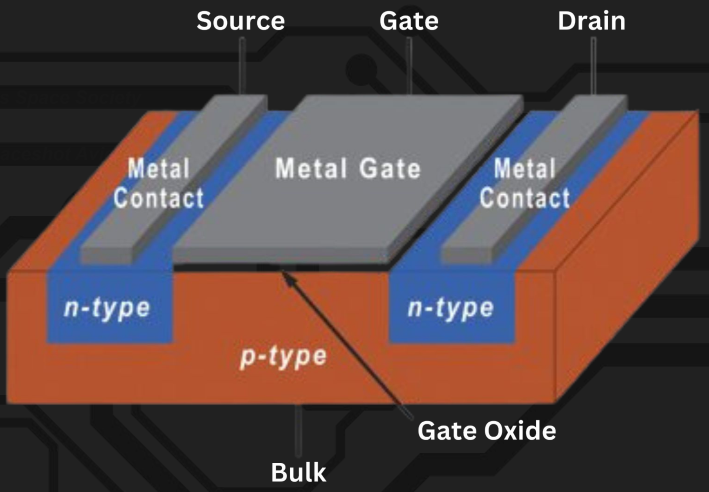


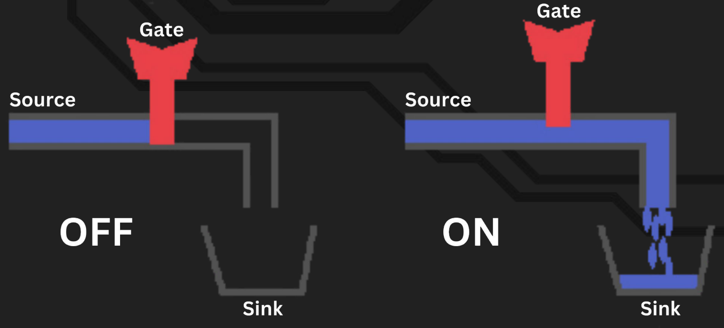


Practical Diode Characteristic curve (silicon)

Transistors: MOSFETs

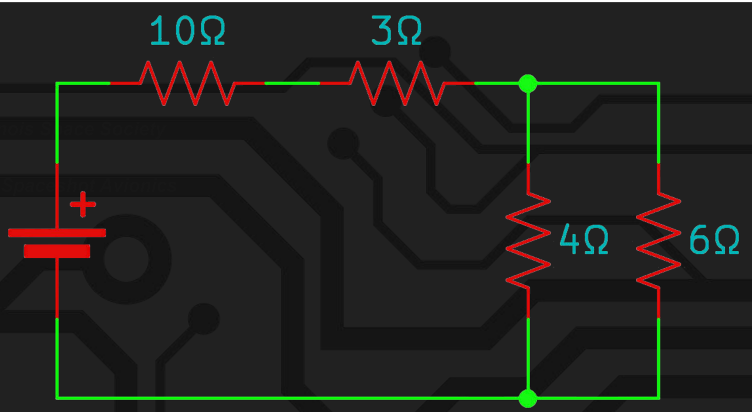
- A MOSFET is a field effect transistor (FET) that either <u>amplifies</u> or <u>switches</u> a signal (depending on its trigger voltage)
- MOSFETs feature 3 pins: the Source, Gate, and Drain
- Just like a faucet, the gated voltage controls the amount of current flowing across the source and drain
- Enhancement mode
  - Device is off when gate voltage is 0, positive voltage causes a triode field to form
- Depletion mode
  - Device is on and a negative voltage is needed to switch the MOSFET off

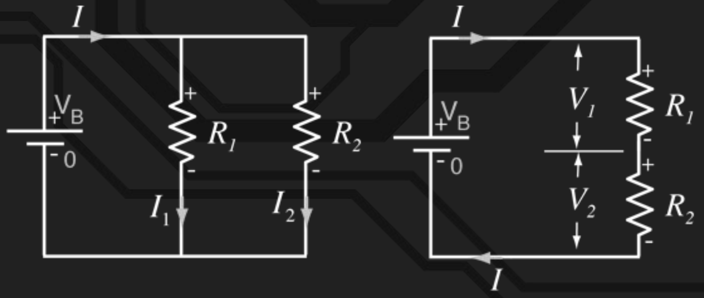




Series vs Parallel

- Components are said to be in series if they are connected by a <u>singular</u> path
- Components are said to be in parallel if they start and end at the same nodes.
  - Nodes are the intersections at junctions
- In the example, the 10 Ω resistor is in series with the 3 Ω resistor, but the 4 Ω resistor is in parallel with the 6 Ω resistor.
- VP of CS (Acronym)
  - Voltage is the same in parallel, while current is the same in series





Parallel resistors

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

Series resistors

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

Kirchhoff's Voltage Law (KVL)

- For any closed “loop” inside a circuit, the sum of all voltages equals 0 V
- The polarities of each resistor is dependent on the current flow defined (blue arrows on wires)

Left Inner Loop

- Ohm's Law for R1: $V_{R1} = I_1 \cdot R_1$

  $V_1 - I_1 \cdot R_1 = 0$

  $10V = I_1 \cdot 100\Omega$

  $I_1 = 0.1A$

  $V_{R1} = 0.1A \cdot 100\Omega = 10V$

Right Inner Loop

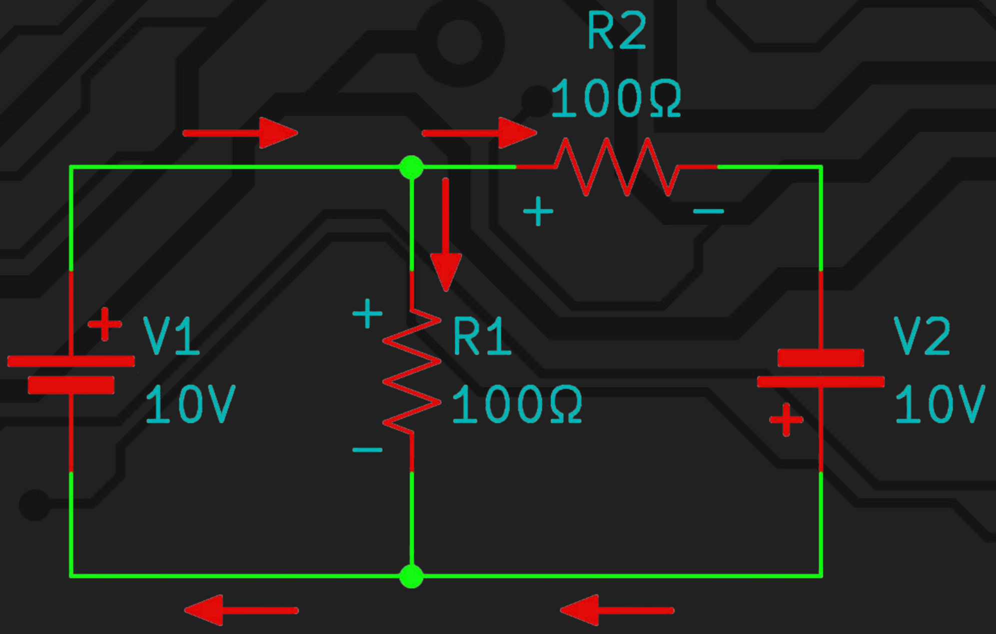
- $V_2 - V_{R1} - I_2 \cdot R_2 = 0$

  $10V + 10V - I_2 \cdot 100\Omega = 0$

  $20V = I_2 \cdot 100\Omega$

  $I_2 = 0.2A$

  $V_{R2} = 20V$



Kirchhoff's Current Law (KCL)

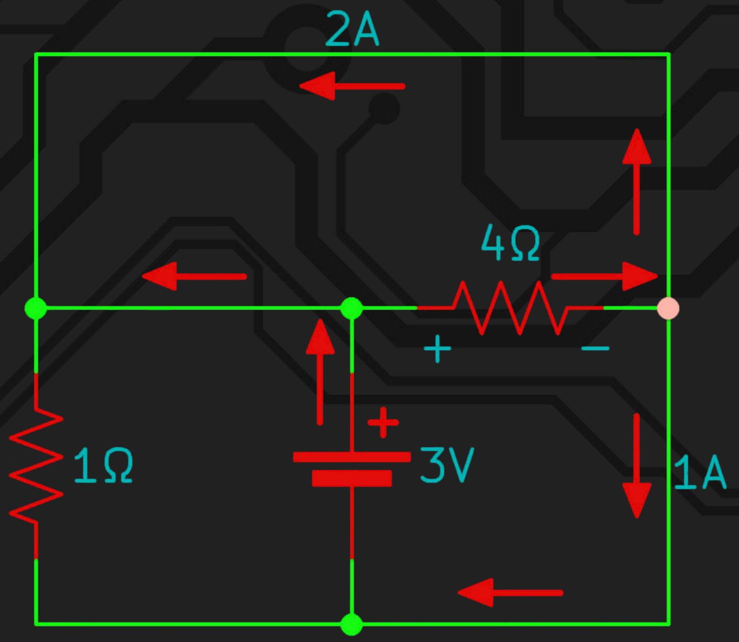
- For any node or junction, the sum of currents leaving and entering equals 0 A
- If current enters a node, we're denoting that as positive. If current leaves a node, then we'll denote that as negative.

Observe the light red node in the example

- $I_{R4} - I_2 - I_1 = 0$
  $I_{R4} = I_2 + I_1$
  $I_{R4} = 2A + 1A$
  $I_{R4} = 3A$

Ohm's Law for the 4 Ω resistor

- $I_{R4} = \frac{V_{R4}}{R}$
  $3A = \frac{V_{R4}}{4\Omega}$
  $V_{R4} = 12V$



Batteries

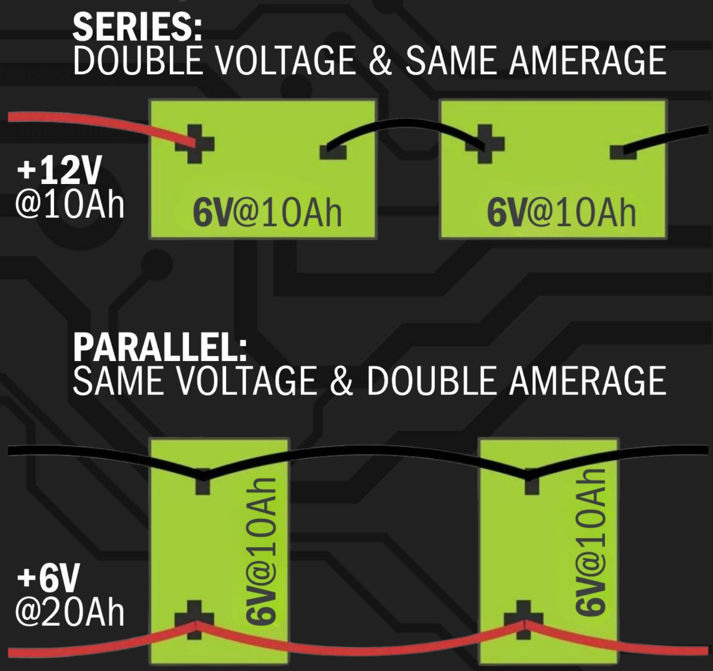
Primary Batteries

- Single cycle battery that cannot be recharged; chemical energy -> electrical energy
- Ex: Alkaline, Dry Cells, Lithium Battery, Lemon/Potato

Secondary Batteries

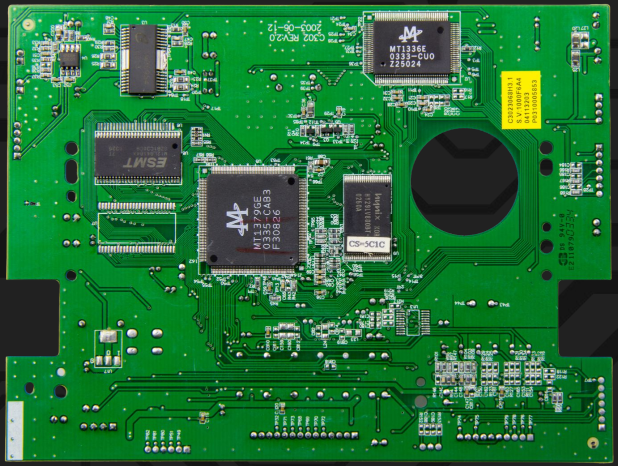
- Multicycle batteries that can be recharged; chemical energy -> electrical energy
- Ex: Lithium Ion Batteries, Nickel Metal Hydride, Lithium Polymer

In the electronics world, batteries are used as a type of voltage source, providing power to an entire circuit



Printed Circuit Boards (PCBs)

- Components go on contact points on the board
- Traces of copper are etched into the board to connect components
- Power and signals go through traces
- Uses solder to attach components to contact points
- Found in almost every electronic device



PCB Layers

Silkscreen

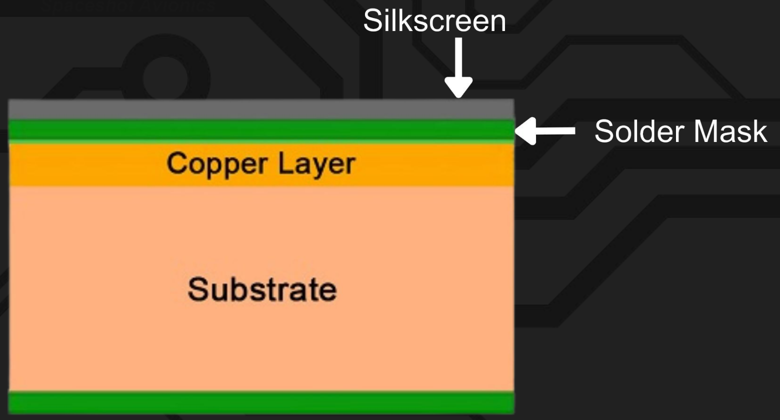
- Layer of ink trace on top of solder mask
- Used to display labels or other information about the PCB

Solder mask

- Green layer covering the copper to prevent unwanted electrical connections

Copper layers

- Layer under the solder mask, traces of copper etched to create electrical connections on board
- Thickness of copper is measured in oz per unit area, with 1 oz being the standard
- Greater thickness is needed for higher current and heat dissipation requirements



Multilayer PCBs

Multilayer PCBs

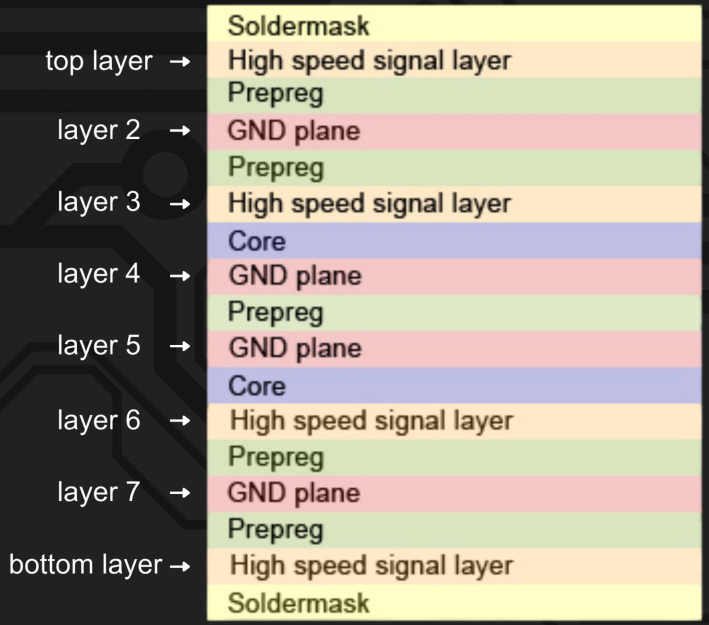
- More layers means more traces per area, increasing efficiency
- 2 layer PCBs: low cost and simple design, 2 signal layers
- 4 layer PCBs: more expensive, dedicated internal ground and supply layers
- 6+ layer PCBs: complex and expensive, dedicated internal ground and supply layers, more signal layers than 4 layer PCBs

Core

- Rigid dielectric material between copper layers that acts as an insulator to prevent connections between layers

Prepreg

- Glass fiber reinforced with resin that binds cores and layers together
- Also acts as an insulator, but is less rigid than a core



Surface Finishes

Surface Finishes

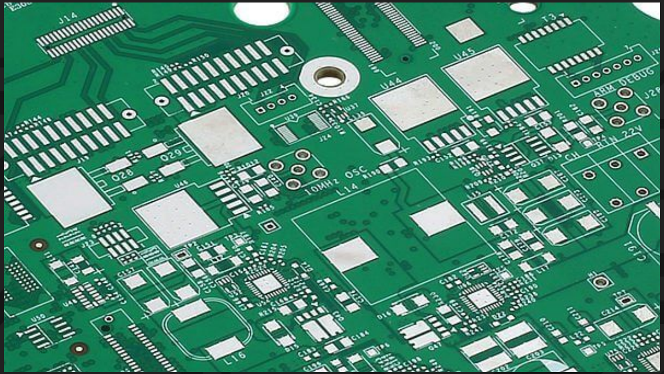
- Coating over bare copper to protect it from oxidation

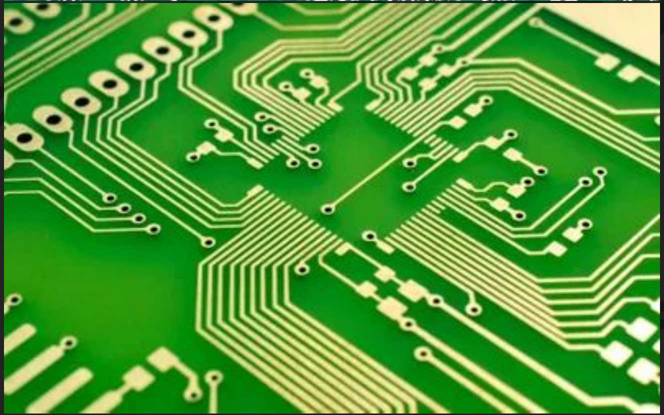
Hot Air Solder Leveling (HASL)

- Traditional finish, board is put in a molten solder bath, covering all exposed copper with solder
- Lead-free HASL uses solder with no lead

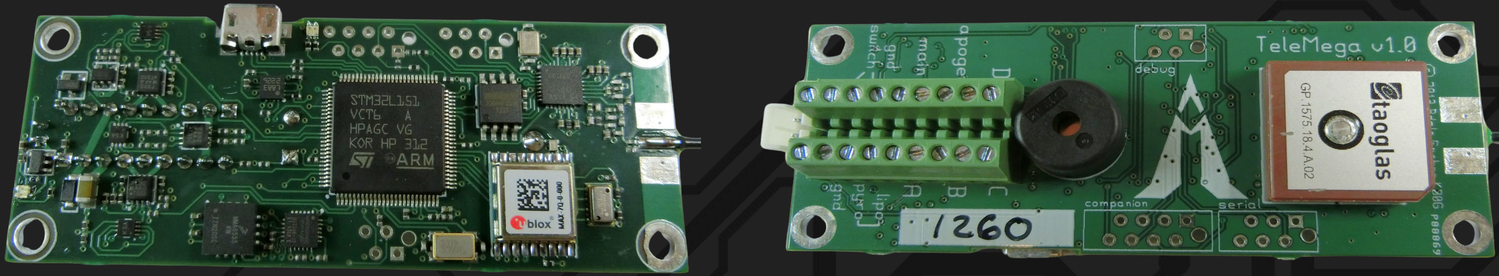
Electroless Nickel Immersion Gold (ENIG)

- A light gold coating on top of a nickel coating
- The nickel protects the copper while gold protects the nickel from corrosion
- ENIG considered better than HASL because it provides a smoother finish, has a longer shelf life, and provides additional shock protection
- One downside is that it is considerably more expensive than HASL





Examples



Altus Metrum TeleMega Altimeter

PerfectFlite StratoLoggerCF Altimeter

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