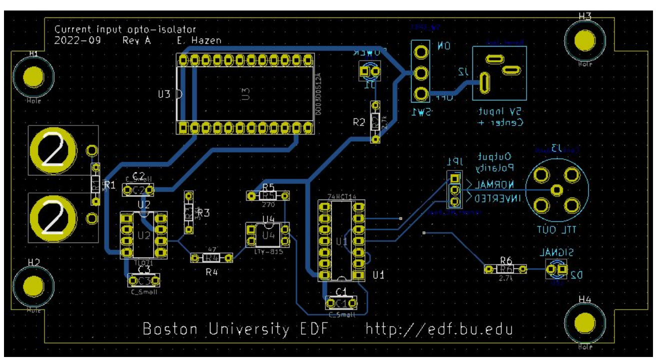
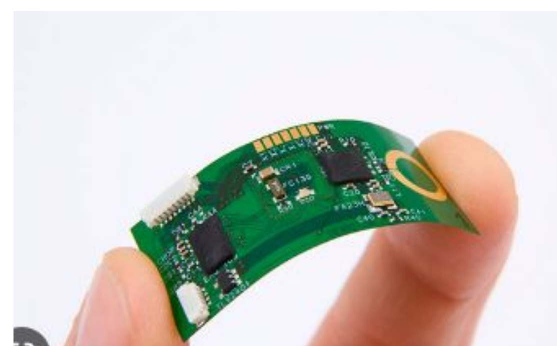
BOSTON UNIVERSITY

Electronics Design and Manufacturing

A brief overview

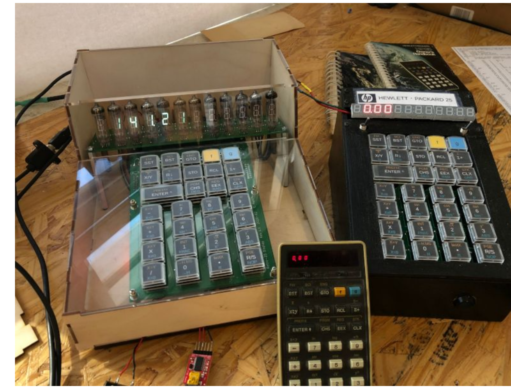
Eric Hazen

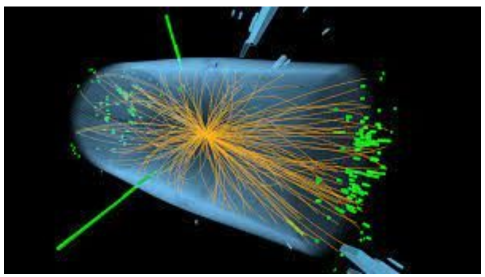




About me…

Professionally, I lead a team which built electronics for the CERN experiments which discovered the Higgs Boson
[edf.bu.edu](edf.bu.edu)
(*now retired)*



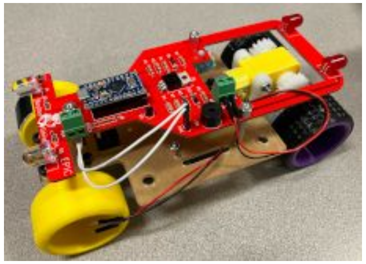


In my spare time, I build retro-electronics
(tube amps, calculators, clocks…)

…and I fly planes and drive my Miata!

Outline

- Electronic Component types



- Design Case Study

- Packaging Considerations

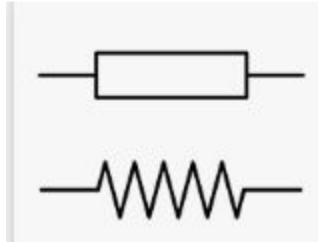
- Power and Cooling

- Summary

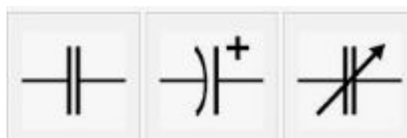
Introduction to electronic components

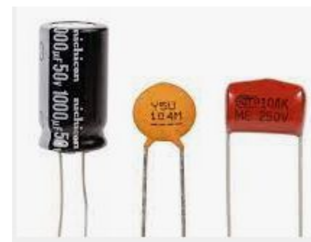
“Passives” - fundamental components

- Resistors
  Resist the flow of electricity

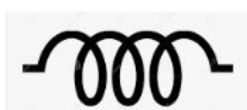


- Capacitors
  Store energy as electric charge



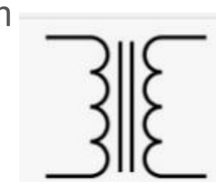


- Inductors
  Store energy in a magnetic field



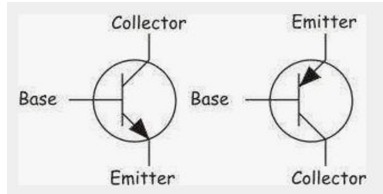
- Transformers

Transfer energy from one circuit to another, with a possible change in voltage

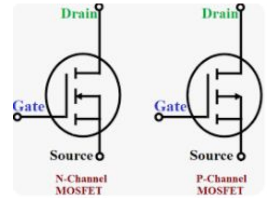


“Active” - Amplification and Switching

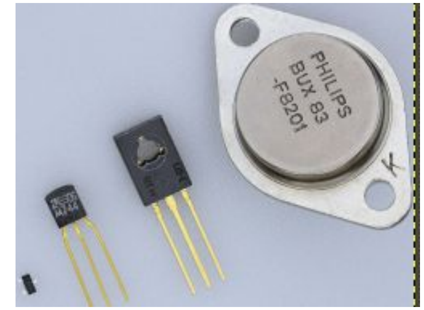
- Transistors
  Small current/voltage
  controls a larger
  current/voltage



BJT (bipolar junction)

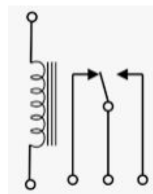


MOSFET



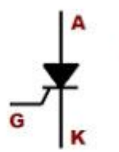
Many package options

- Relays
  Electromagnet controlled
  switch
  (power switching)

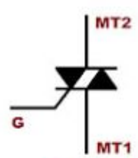


- Other Devices

Diode: rectification
SCR/TRIAC for AC switching
(dimmers, motor control)



SCR

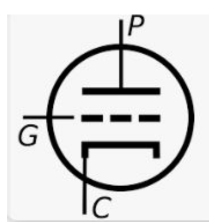


TRIAC


DIODE

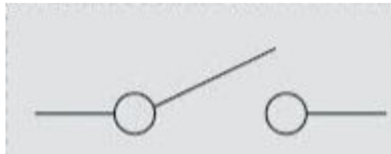
- Vacuum Tubes

  Predecessor to transistor
  Mostly obsolete, except
  Hobbyists and crazy
  Physicists!

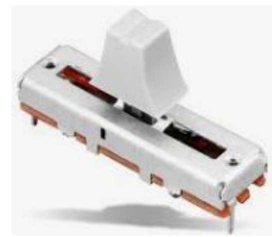


Controls and Displays

- Switches




- Rotary / slide controls
  Encoders provide digital Inputs.
  Potentiometers provide
  variable resistance

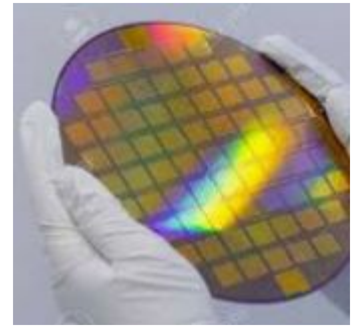



- LEDs



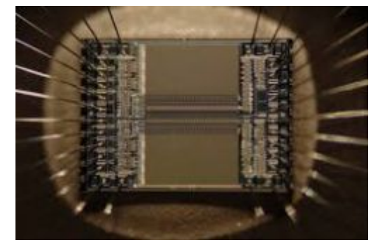
- Displays

Integrated Circuits (ICs, “chips”)



Thousands/millions of components integrated in a small area.

Etched on circular silicon wafers,
Each containing hundreds of identical ICs



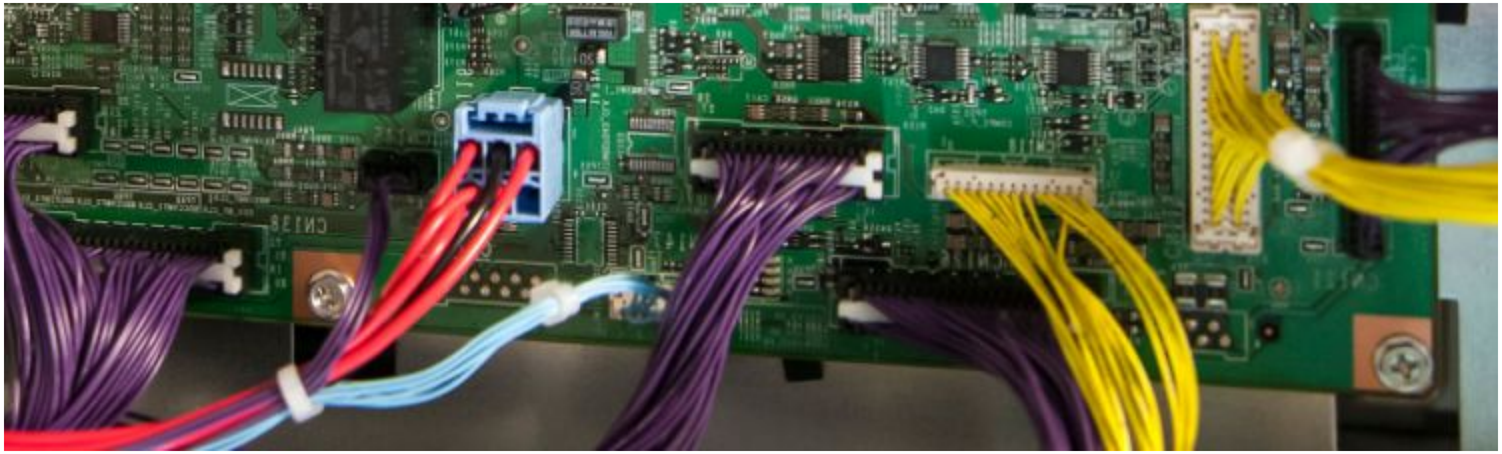
Wafers are diced into individual die

Wires are attached, and usually the dice are moulded in plastic packages suitable for soldering.

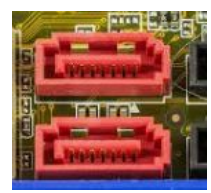
Many factors must be considered when choosing a package, but usually the circuit designer has few choices (it is up to the IC manufacturer).

Connectors

Connectors and cables are often overlooked, but can add substantially to product cost



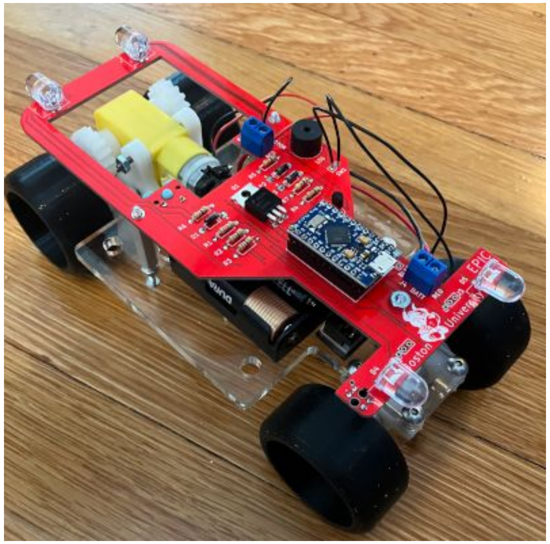
- Connector types
  - Power
  - Low-speed signal
  - High-speed signal
  - Serial data (low wire/pin count)
  - Parallel data (high wire/pin count)
  - Radio Frequency (RF) for antennas and such
- Best to avoid them as much as possible!



A connection on a PC board is “free” while connectors are expensive

Case Study

Model Car
Electronics Design Process



Specifications

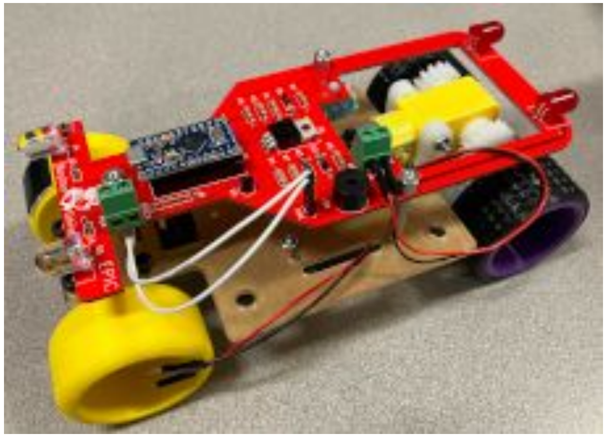
Usually there is a written or verbal specification

In this case…

> “This is a boring car, it needs some electronics!” :)

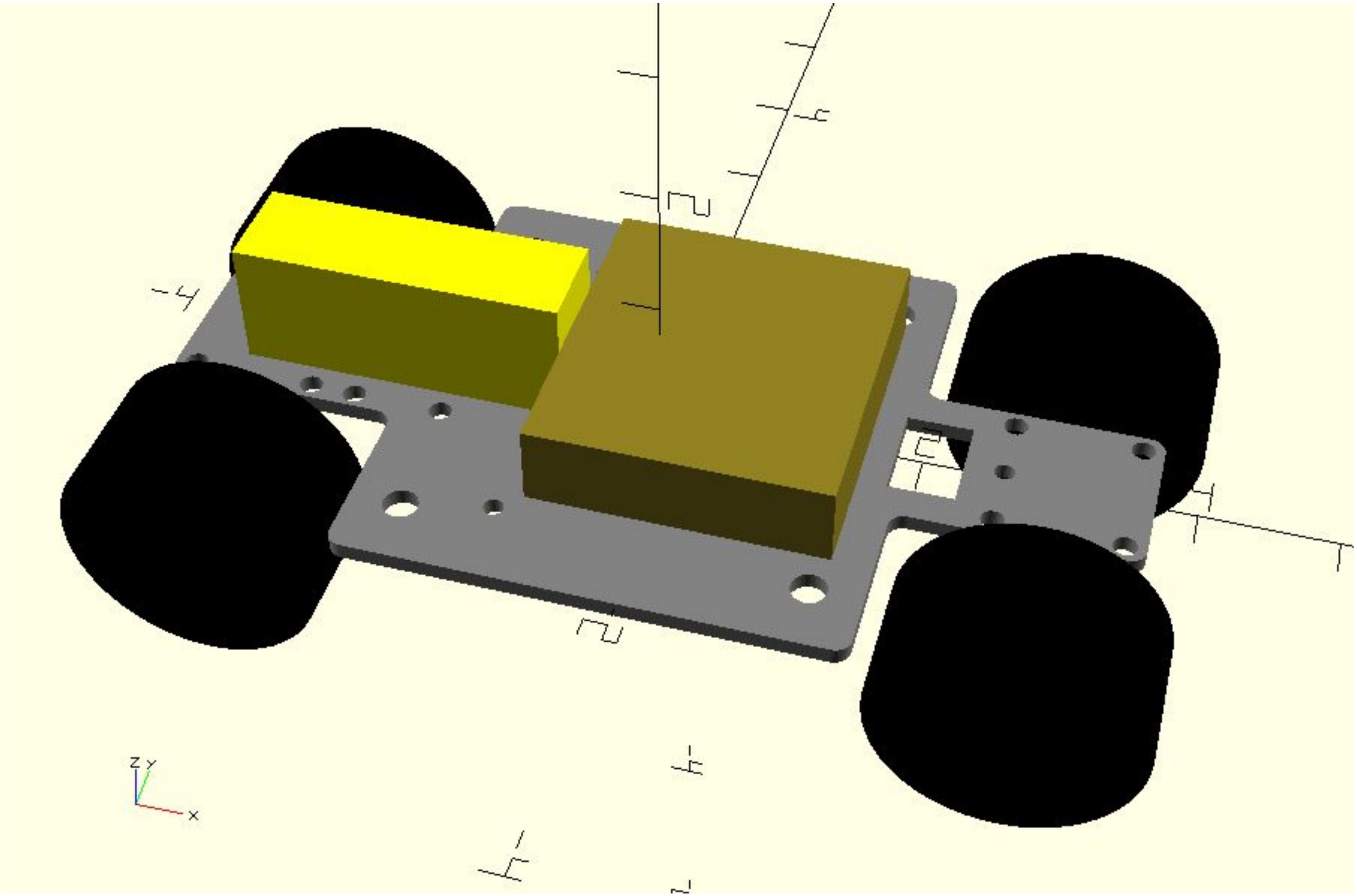
Or…

> “Provide motor control, lights, distance log and audible feedback with a programmable controller”



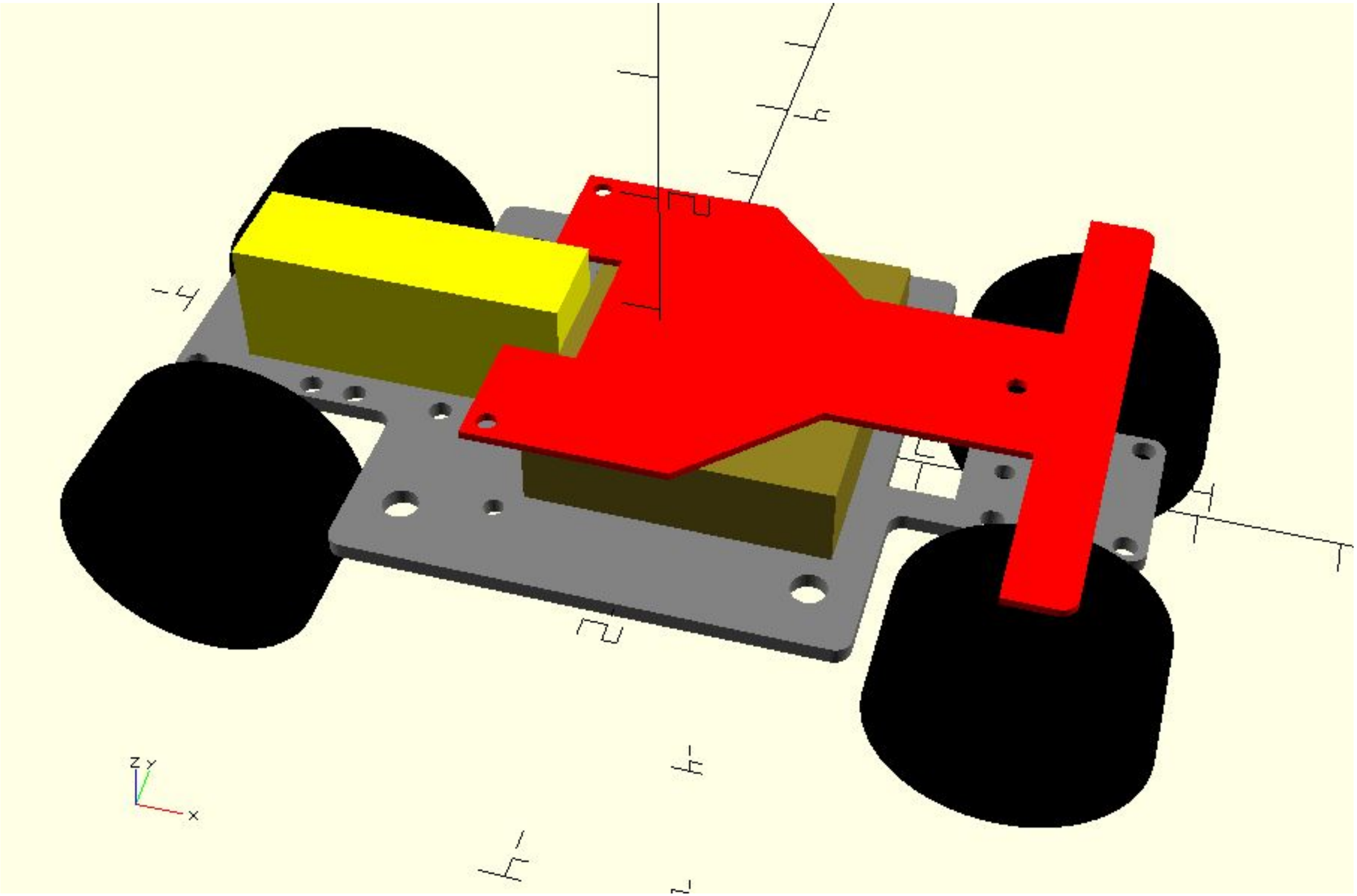
Mechanical Considerations

Start with a simple CAD model of
the mechanical part of the system.



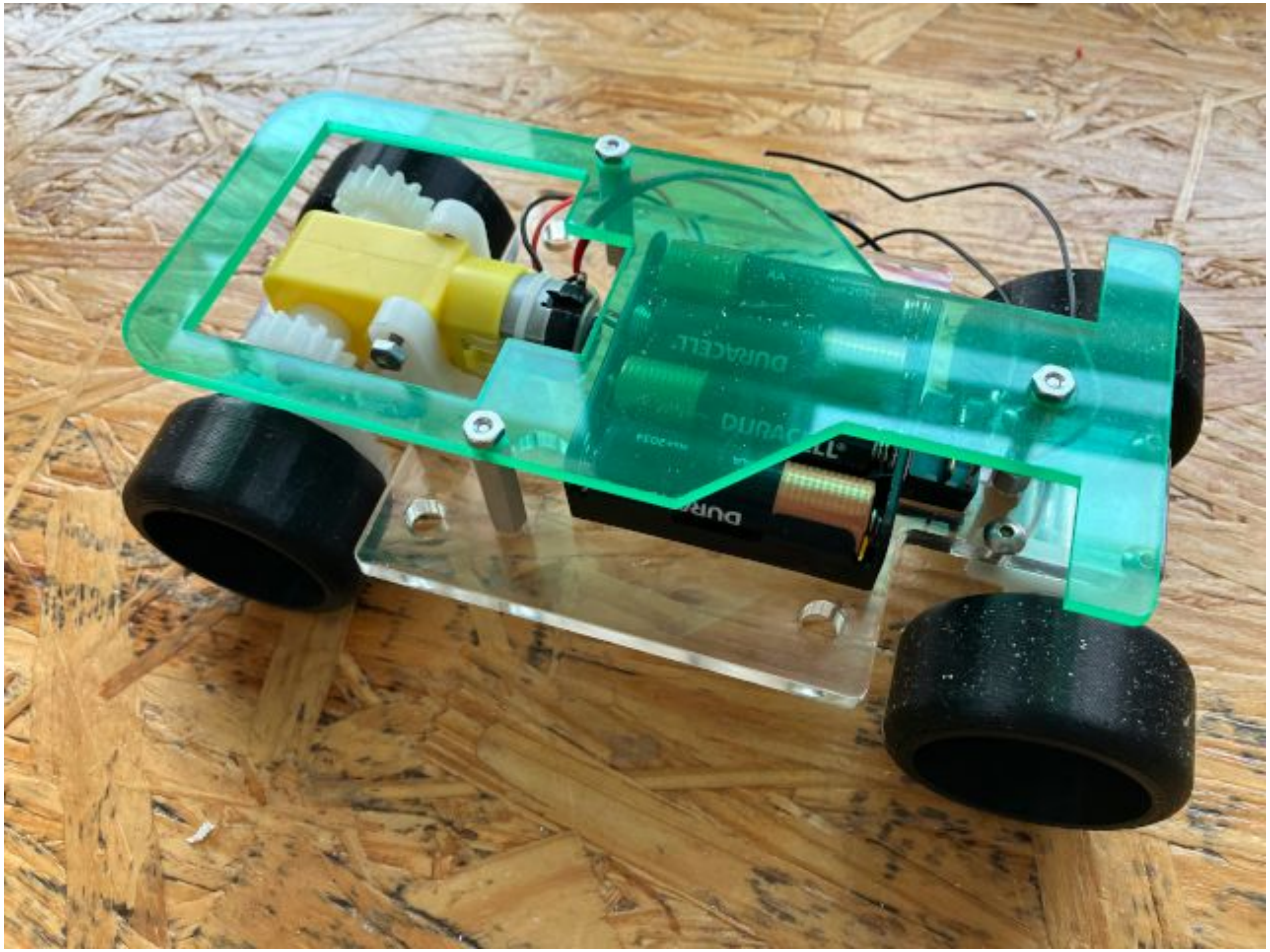
Mechanical Considerations

Then, design the outline of the PC board and add to the model. Adjust as needed in the 3D model package



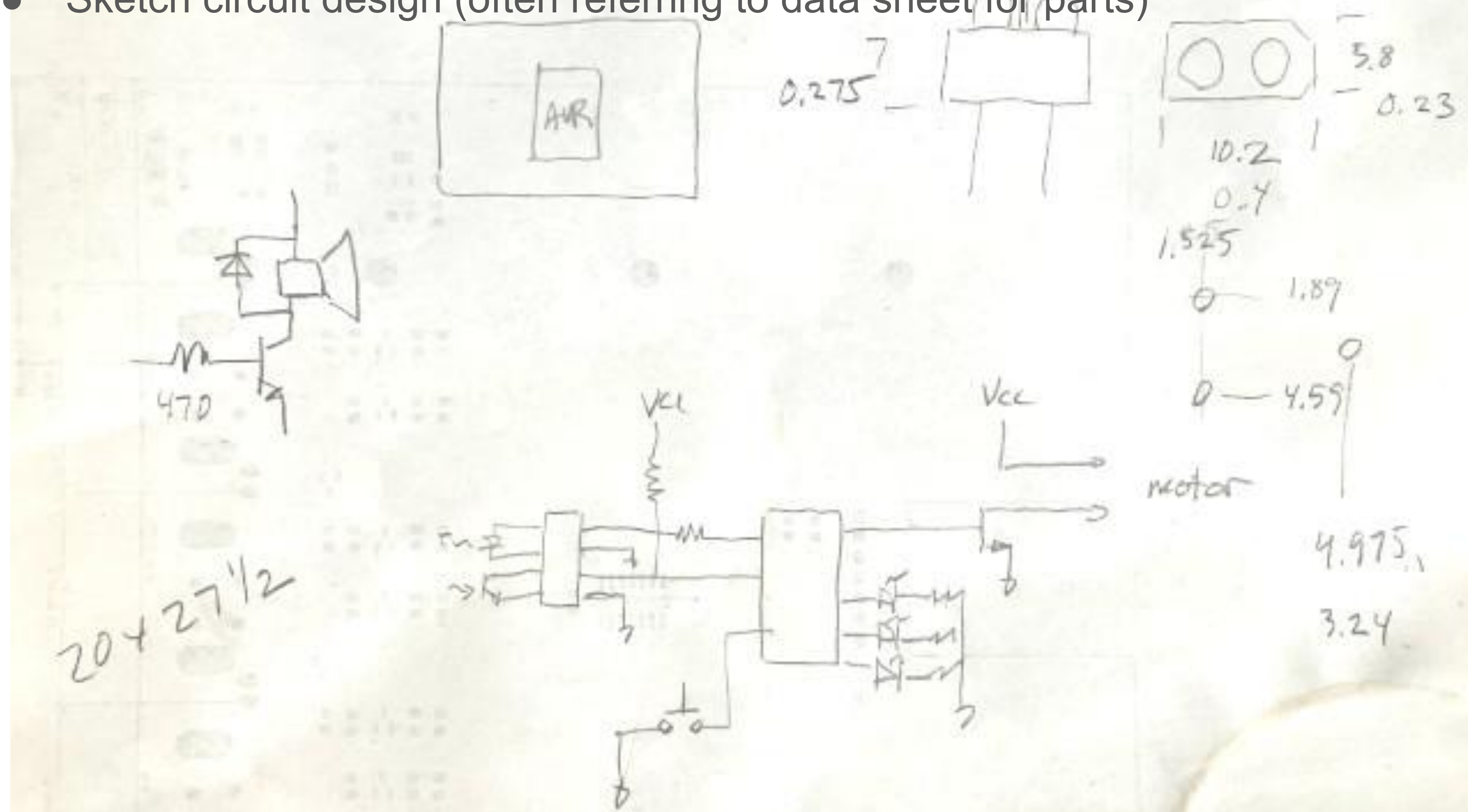
Mechanical Considerations

It is recommended to make a mechanical mock-up of the electronics to be sure it fits.
In this case I laser-cut a piece of acrylic the same dimensions as the PCB… it fits!



Conceptual Design

- Evaluate functionality (what does it have to do?)
- Choose parts (Consider function, cost, availability, mechanics)
- Sketch circuit design (often referring to data sheet for parts)



These are my notes from this project, with real coffee stains!

Capture Electrical Schematic

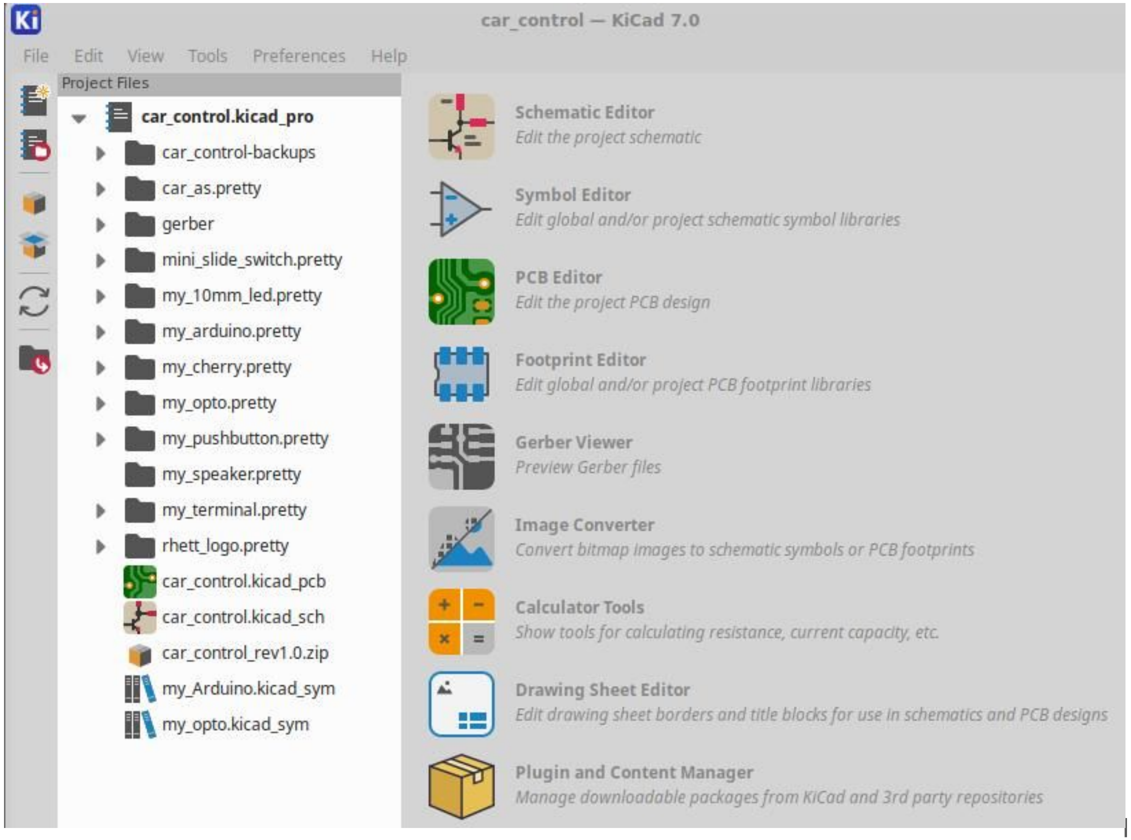
- Primarily for humans to read (though software can read it too…)
- Shows the logical connections between parts
  (unrelated to the final physical layout)
- Use “schematic capture” software (in this case, the free “KiCAD” schematic)

Sales pitch:

KiCAD (www.kicad.org) is a free, open-source electronics design package which runs on all popular OS (Mac, Windows, Linux)

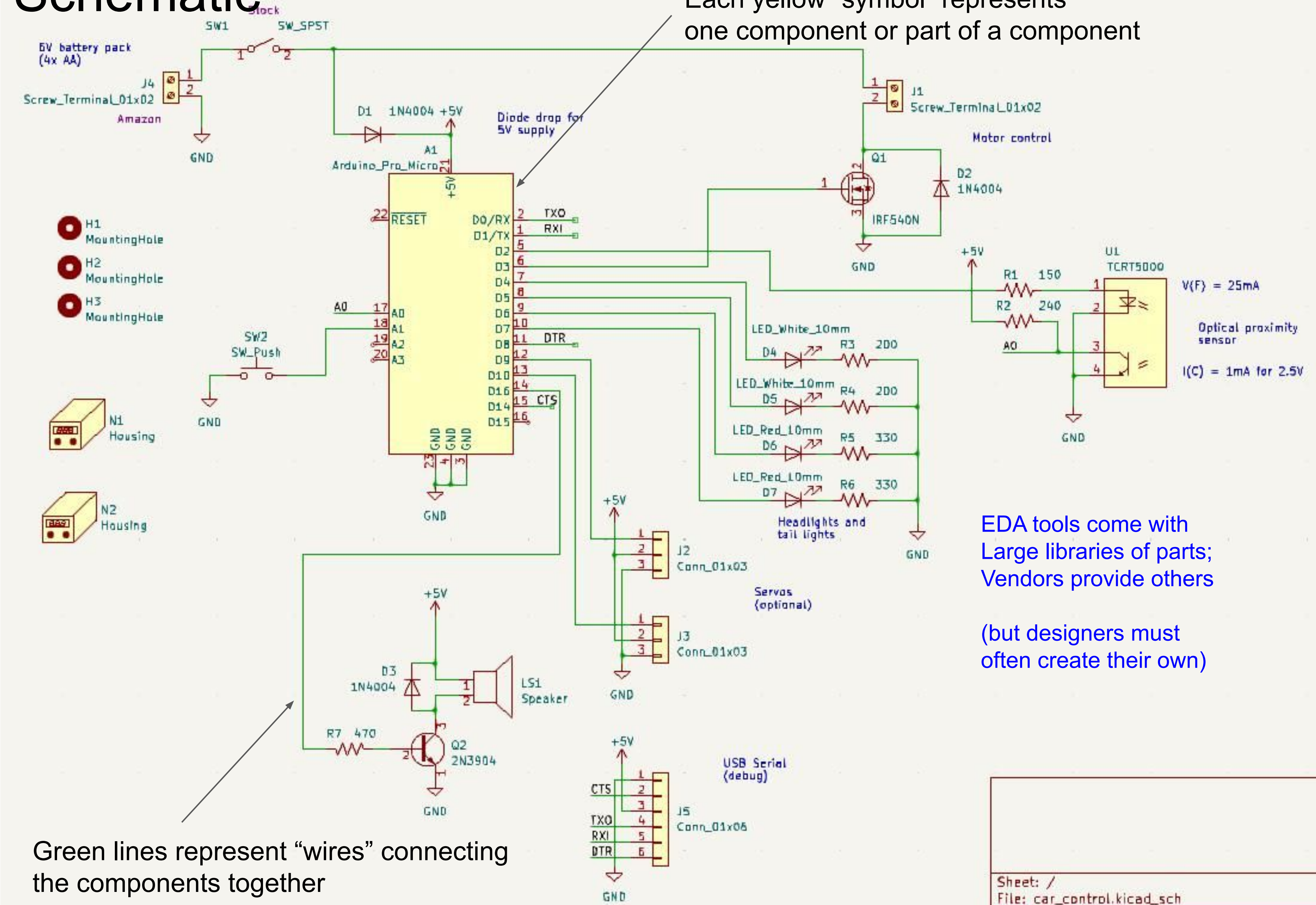
We use it extensively

For more sophisticated projects we use proprietary tools (Altium, Mentor, Cadence…)



Schematic

Each yellow “symbol” represents
one component or part of a component

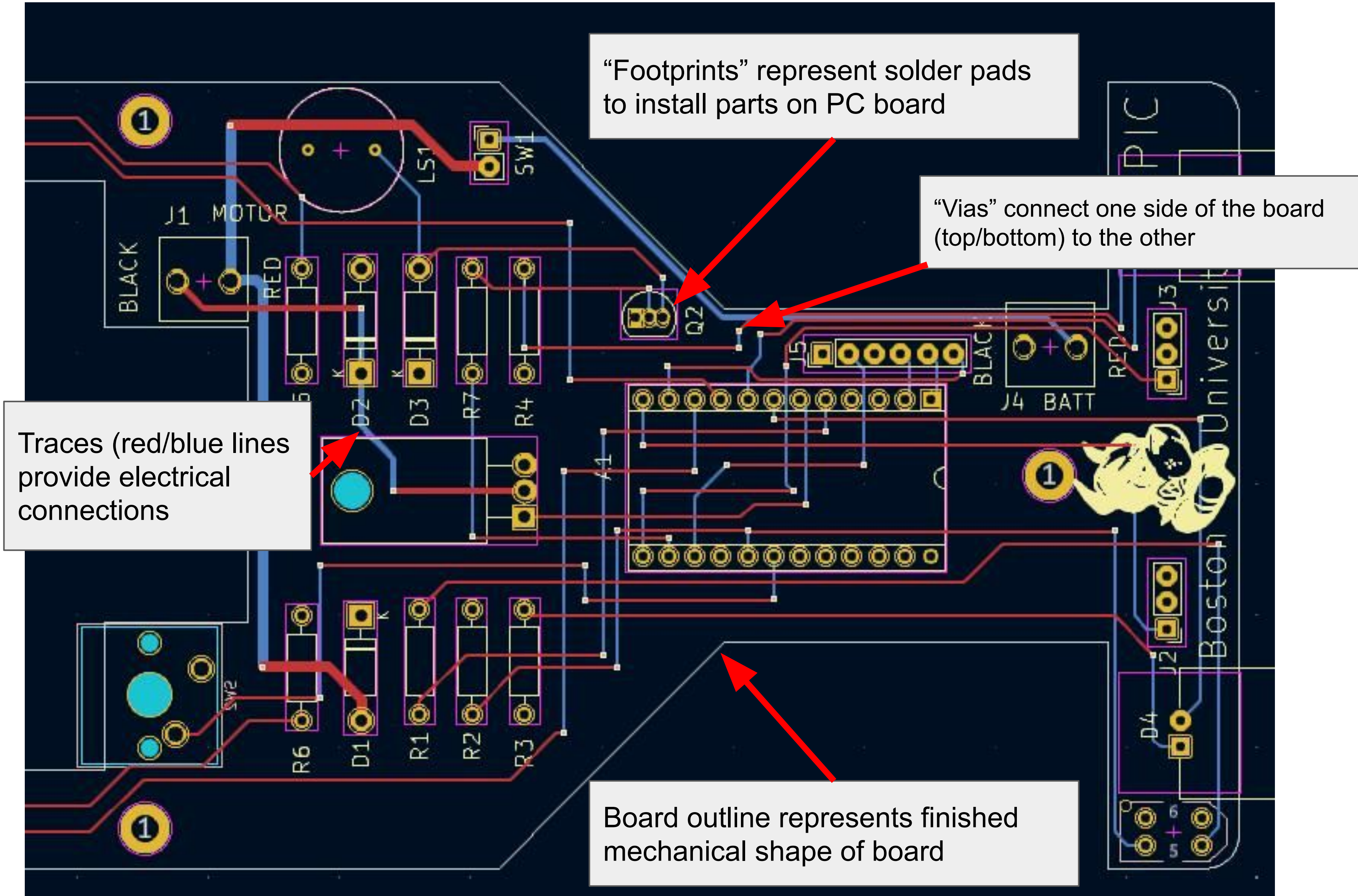


EDA tools come with
Large libraries of parts;
Vendors provide others

(but designers must
often create their own)

Green lines represent “wires” connecting
the components together

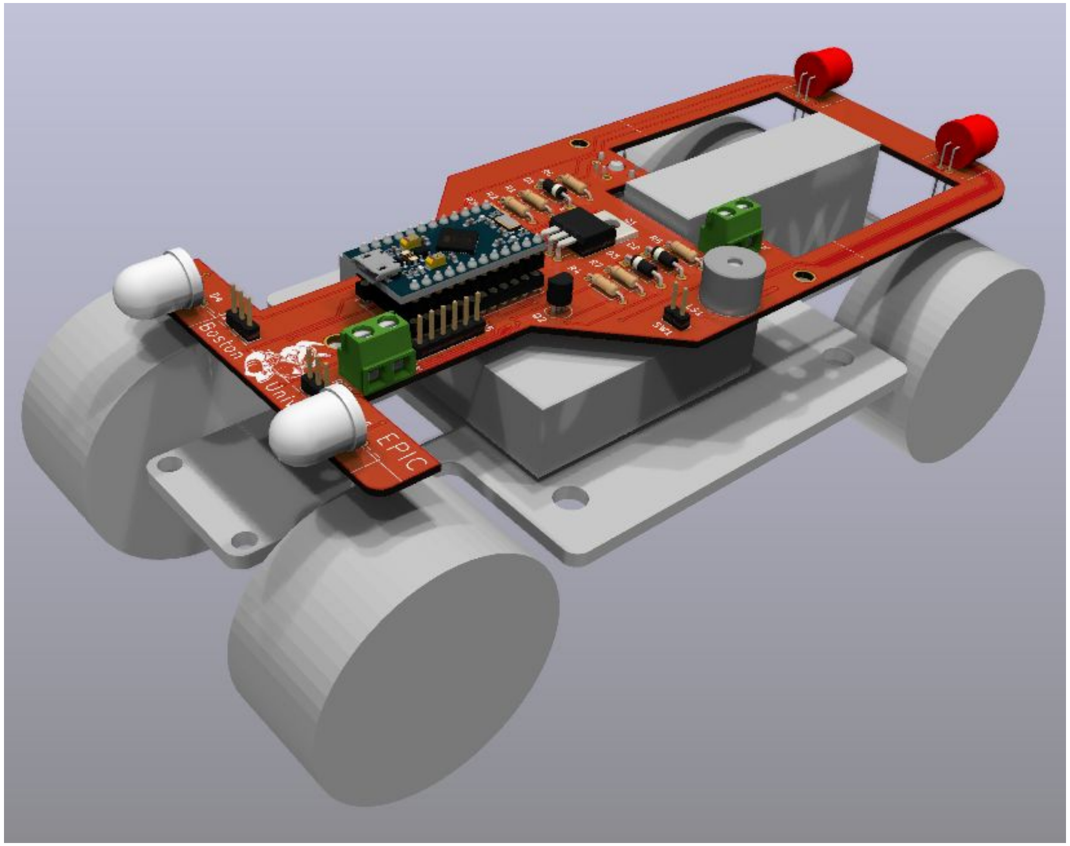
Physical Design ("Layout")



Mechanical Considerations

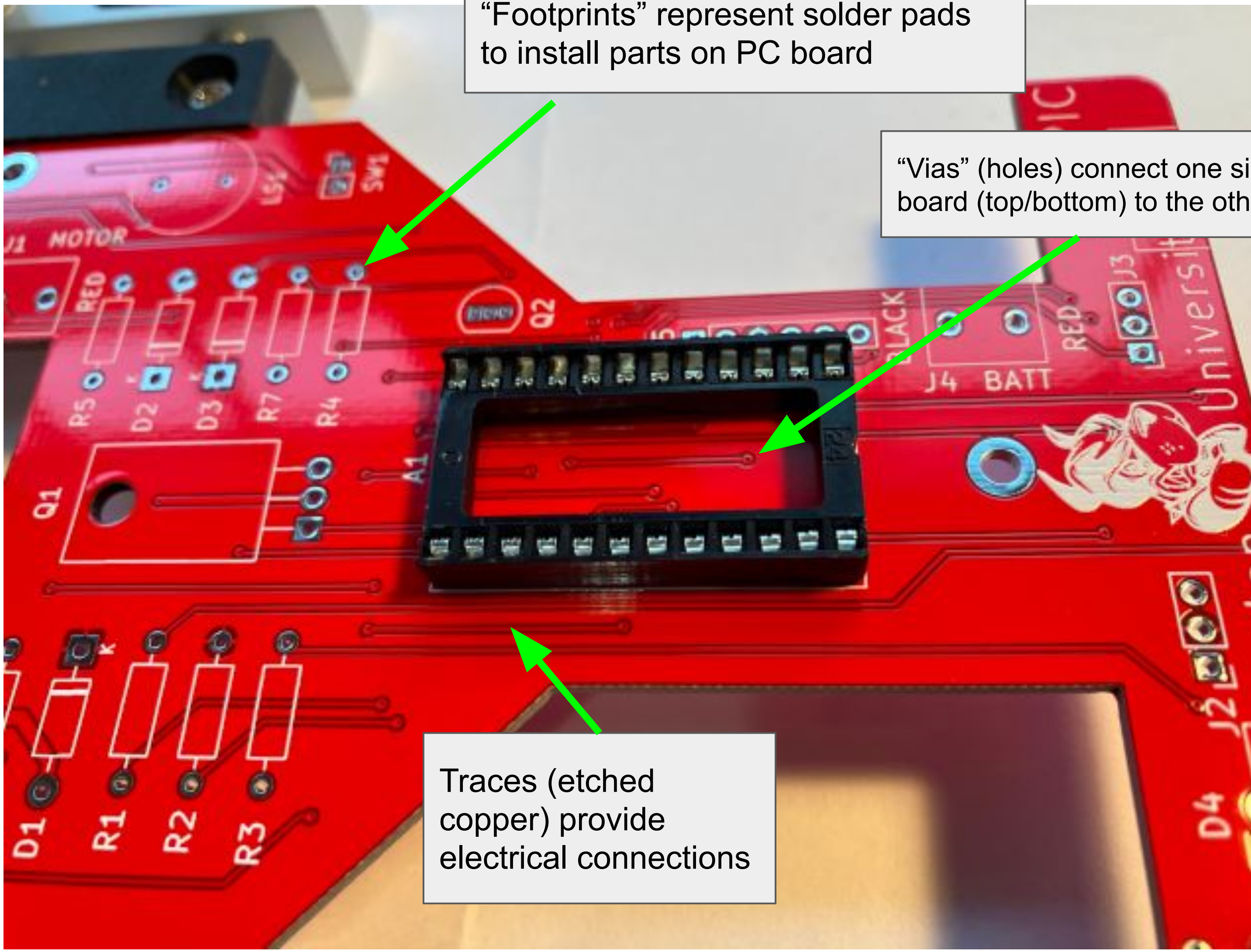
Export 3D model of completed PCB design and integrate with mechanical model

Looks good! Let's build it!



Electronic / Mechanical design tool integration is revolutionary!

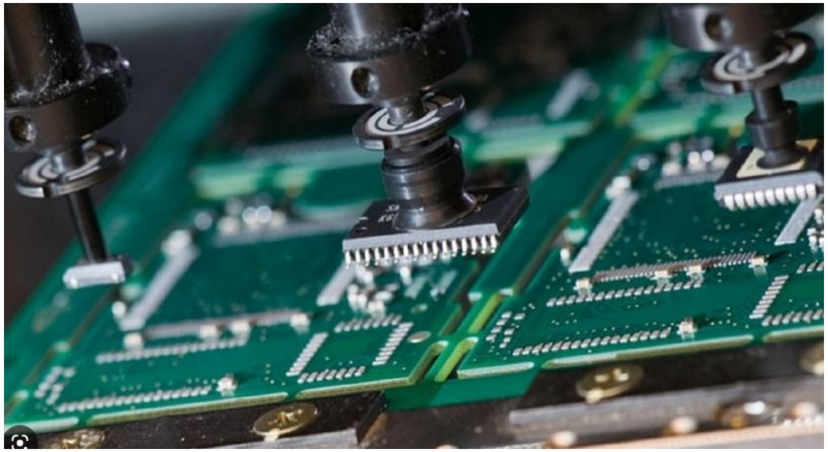
Bare PCB after fabrication



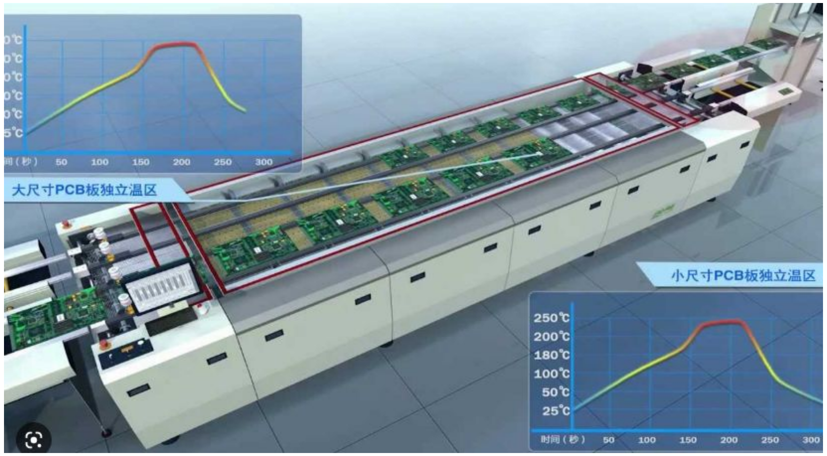
“Footprints” represent solder pads to install parts on PC board

“Vias” (holes) connect one side of the board (top/bottom) to the other

Traces (etched copper) provide electrical connections



Circuit Board Assembly

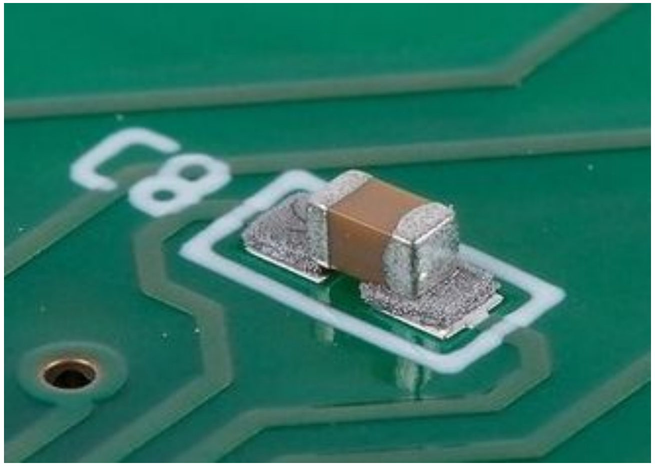


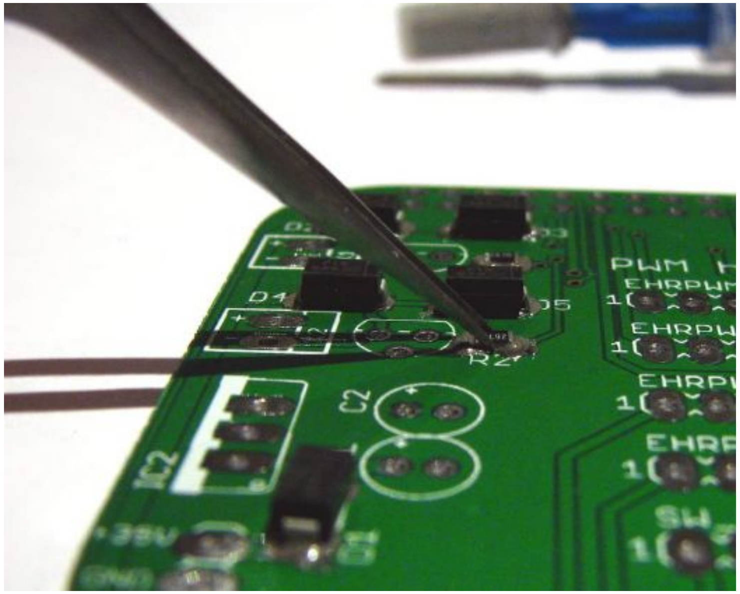
Component placement

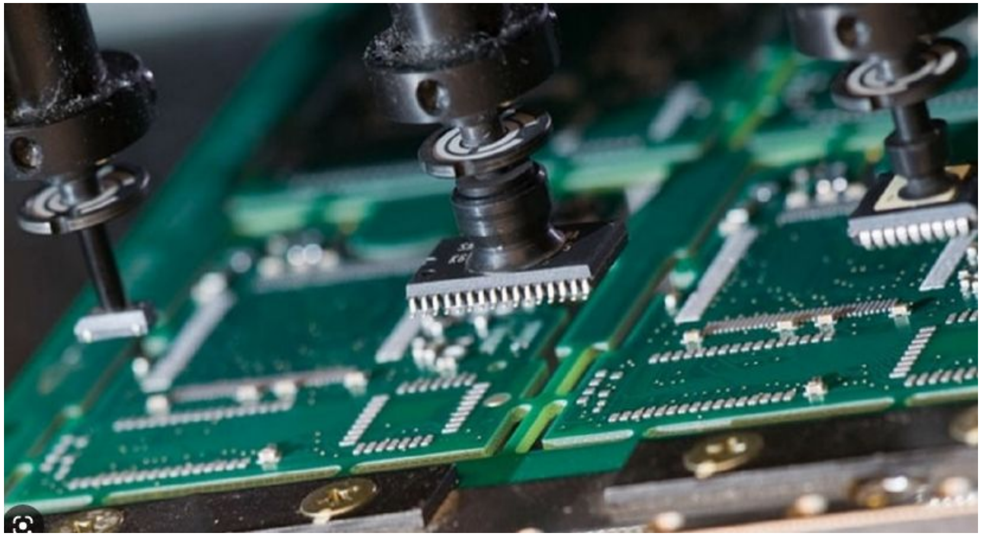
Automatic placement typically used for production

- Typically done by outside company (“assembly house”)
- Requires some data preparation:
  - X/Y/side/rotation file
  - Solder paste mask

- Can also be done by hand



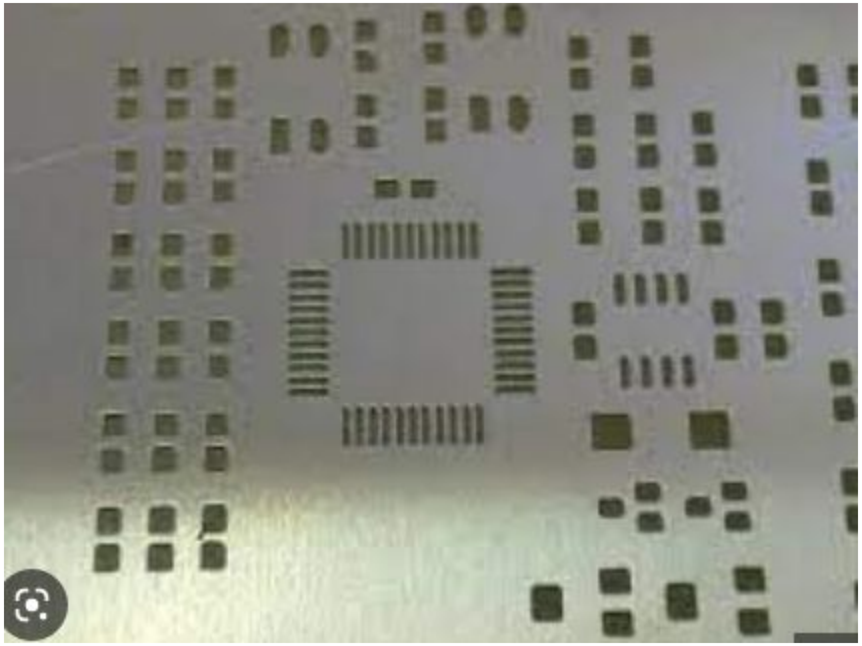




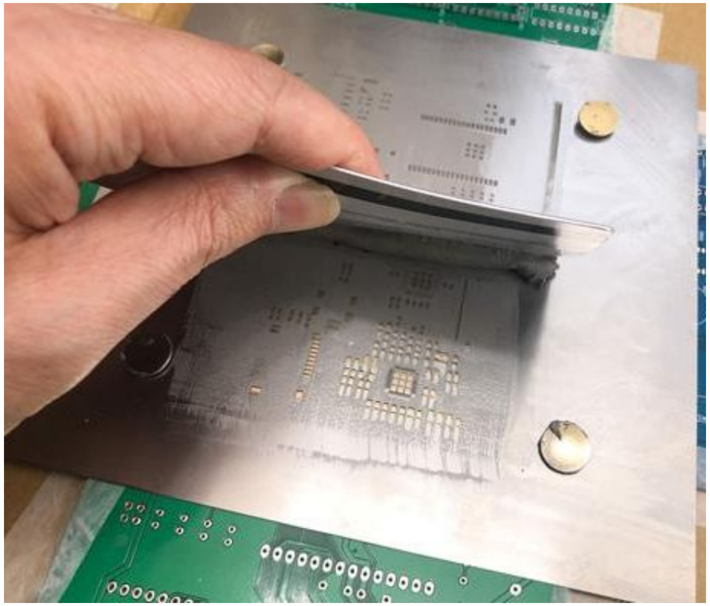
Solder paste application

For production, and most surface-mount parts,
Solder paste is used.

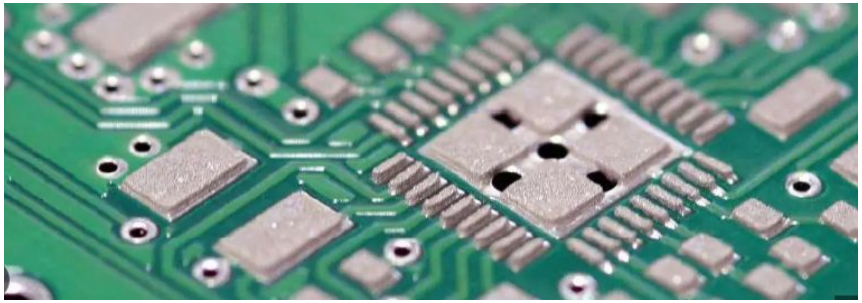
A metal stencil is generated from the “paste mask”
Layer in the PCB design file



Solder paste is applied by hand or
By machine using the stencil

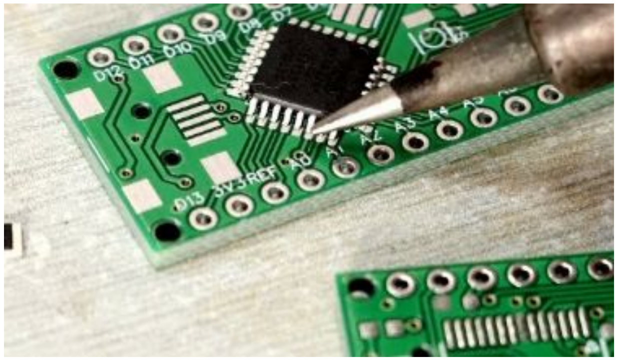


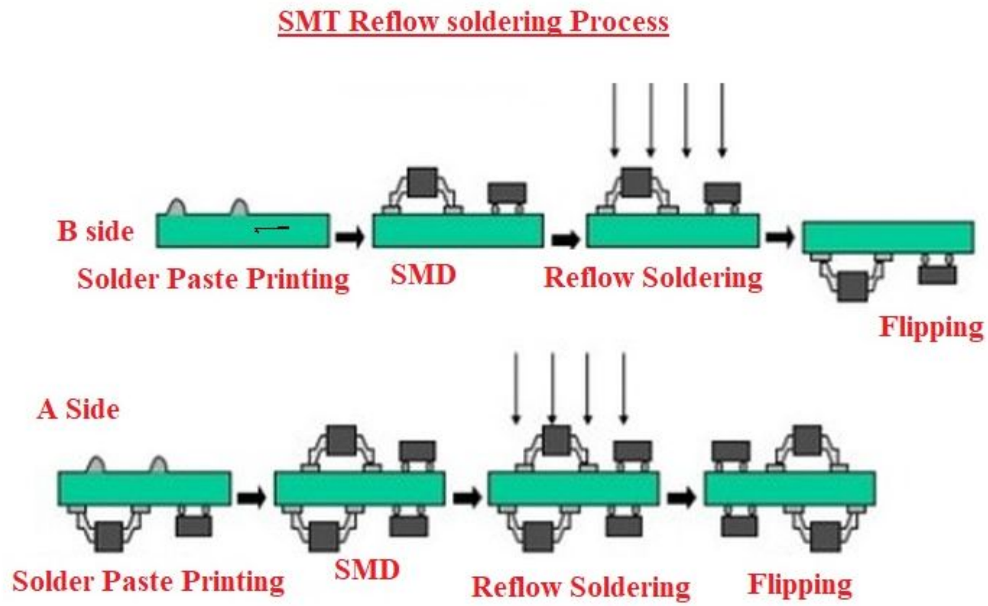
Stencil thickness and opening size provides
good control of solder paste quantity



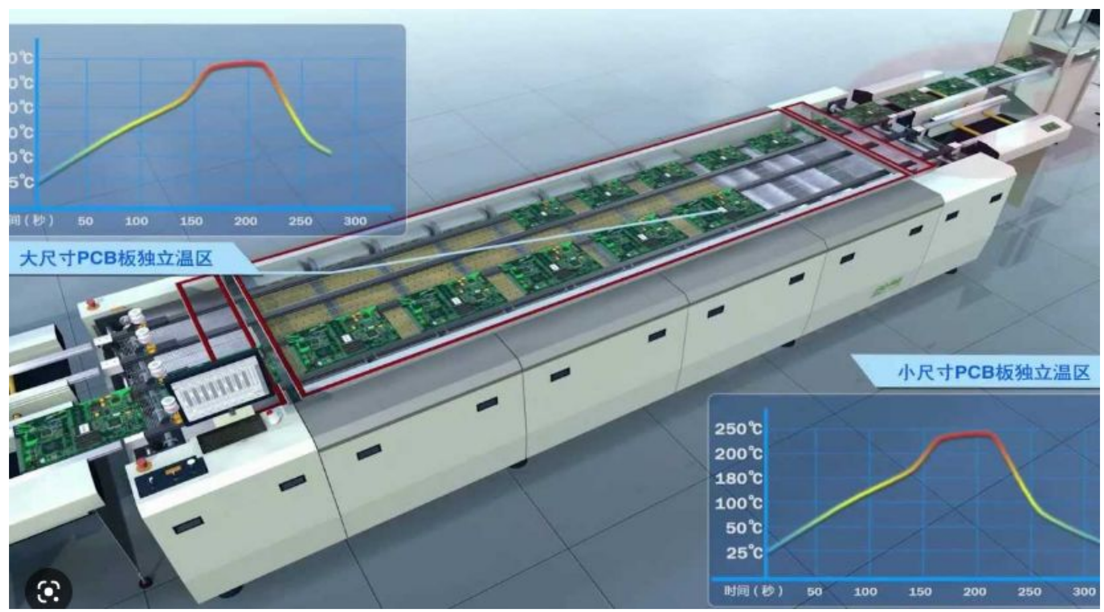
Soldering

Can be done by hand (carefully!)





Or more often in a reflow oven.
Large commercial ones have programmable temperature profile, which is necessary for reliability.



DIY soldering

Lots of hobbyists make their own ovens
Using a toaster oven with attached PID control

This can work but usually isn't very reliable

Other techniques using irons or hotplates
can work too

Assembling the Cars!

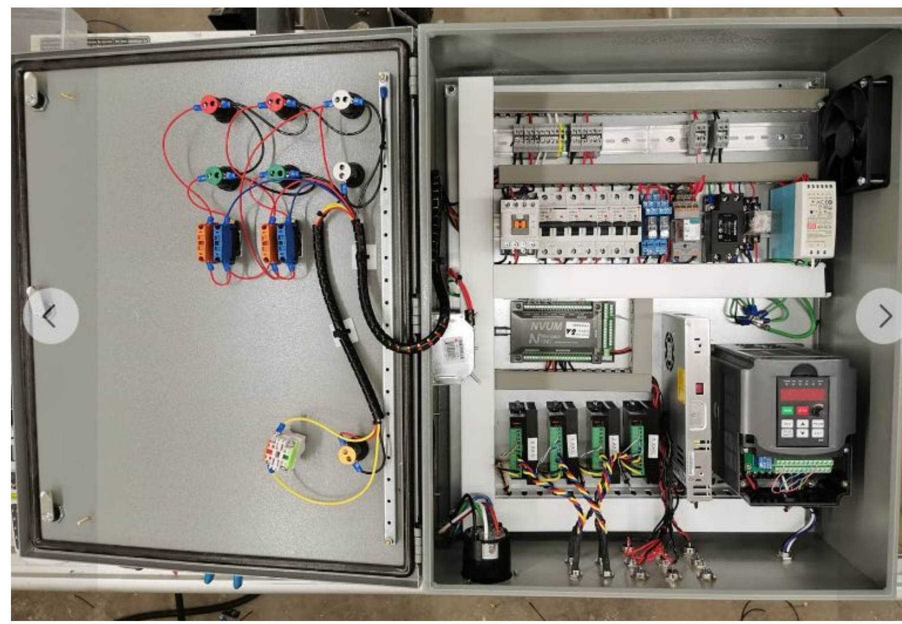
It was a team effort! Next year maybe we'll have you folks do some of it :)

Packaging Considerations

- Mechanical — PCBs need protection from vibration and significant shock to avoid broken connections
- Environmental — Electronics must be protected from moisture, heat, chemicals and even direct sunlight
- Interface — Controls, displays, connectors must be accessible while maintaining above protection
- Power/Cooling — All electronics produces heat. Power dissipation above a few mW must be considered in package design. Fans should be avoided wherever possible.

Packaging options

- Moulded plastic case
  - Board should be conformal coated to prevent moisture damage.
  - Appropriate for consumer applications with low environmental stress
  - DIfficult to moisture/weather proof
  - Typically custom design/manufacture
- Metal enclosure
  - For industrial applications with high environmental stress
  - Typically off-the-shelf enclosure with custom machining (though sometimes a full custom design)
  - Relatively easy to waterproof



Packaging Options II

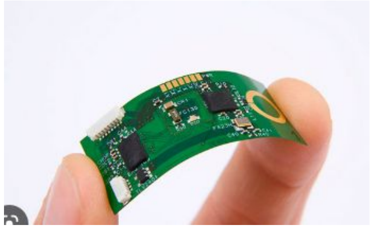
COB: Chip glued to PCB under “glob”

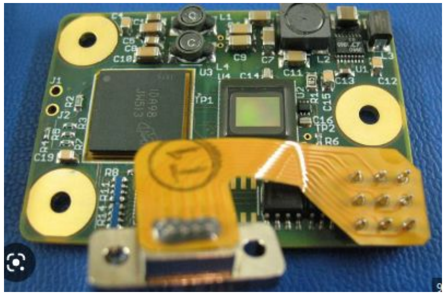
(vs traditional soldered package)

- Chip-on-board (COB)
  Less expensive than traditional soldered packages for very large volume manufacturing

- Flexible circuits
  Many applications:
  - Portable electronics
  - Wearable electronics
  - Interconnections

  Design similar to standard PCBs
  Still have to consider environmental protection



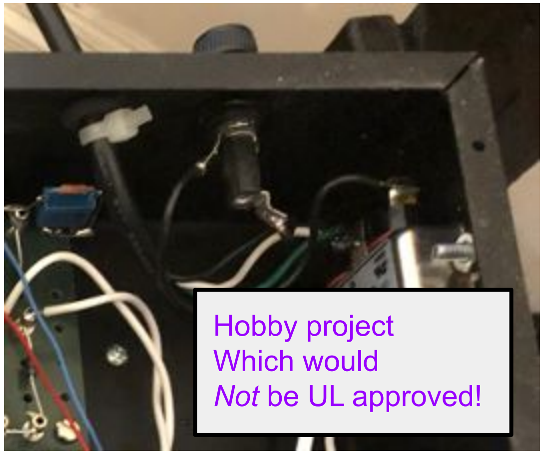


- Potting / Encapsulation
  Provides environmental protection (moisture, vibration)

Power

- Power - essentially two choices:
    - [AC power](#)
      Best to avoid anything with AC inside the box
      (needs regulatory approval)

      Use a “brick” or “wall wart” supply



-
    - [Battery power](#)

      Many types. Must consider:
        - Suitability for use case (voltage/current)
        - Replaceable vs rechargeable
        - Charging options
        - Gas emitted during charging
        - Possibility of catastrophic failure
          (fire, explosion)
        - User experience (battery life, charging time)
        - Battery “fuel gauge”

Cooling

Most power in electronics is dissipated as heat (except for some exceptions such as motors, lasers).

- First, try to minimise power to simplify cooling!
- Cooling options
    - Passive cooling (ambient air)
    - Active cooling
        - Forced air cooling (fan)
        - Liquid cooling
        - Heat pump
- When do I need active cooling?
    - Typically < 1W total can be passive
    - Above this you have to engineer the cooling into the product
- Additional considerations
    - Ambient operating temperature range
    - Fans require power and make noise
    - Over-temperature shutdown to prevent damage or fire

Heatsinks can improve both passive and active cooling

Avoid this!

Fans can cool individual heat loads

Or the entire enclosure

Summary

- Consider the electronics from the start of the design process
- Encourage the EE to minimise power and maximise mechanical robustness
- Think about power and cooling very early, along with the user experience.
- Build a mock-up or simulator to test ideas and validate simulation/estimates.