LECTURE VIII

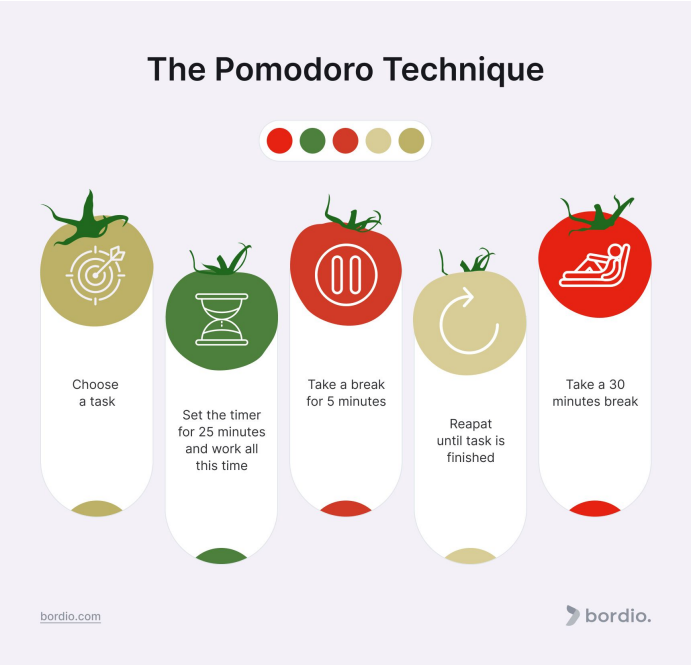
PCB Design Concepts

OPS Instructor Applications!

- OPS Instructor Applications are coming out Wednesday night! The link to apply will be in the discord.
- Being an OPS instructor means:
  - Being able to influence next year's program/curriculum
  - Helping out students new to EECS concepts
  - Being able to join IEEE as an official board member and get to know other cool people!
- Consider applying! Ask any instructor if you have any questions :)
- **OPS Students who have completed their projects have higher priority when applying!**

Challenge Projects!

- **Reminder: Project X is due March 30!**
  - This is a challenge project, so it is optional (but highly recommended!)
- **A second challenge project is on the way as well!**
  - Pomodoro Timer
  - Will also be due March 30
  - ALSO OPTIONAL!

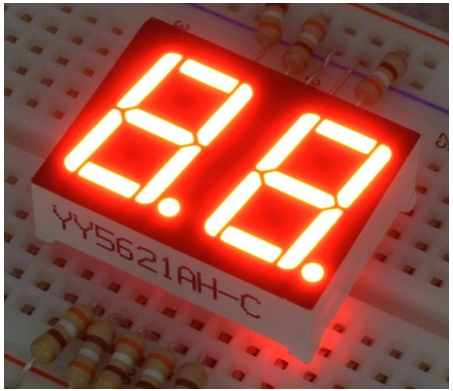


SECTION I

Project VII Review

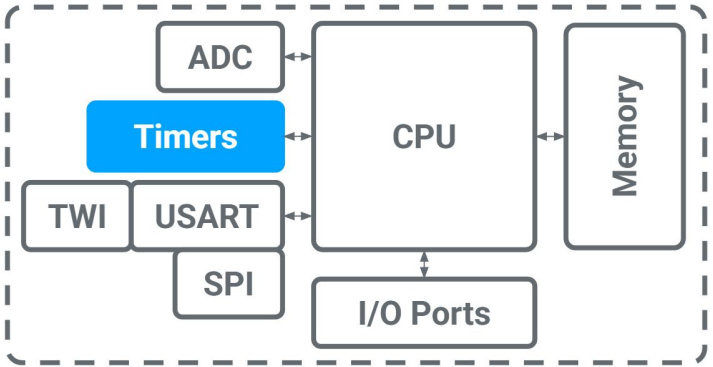
Project 7 Review

- Create a **digital stopwatch** using interrupts, timers, and a 7-segment display
- Due date: 2/23/2026 at 11:59PM



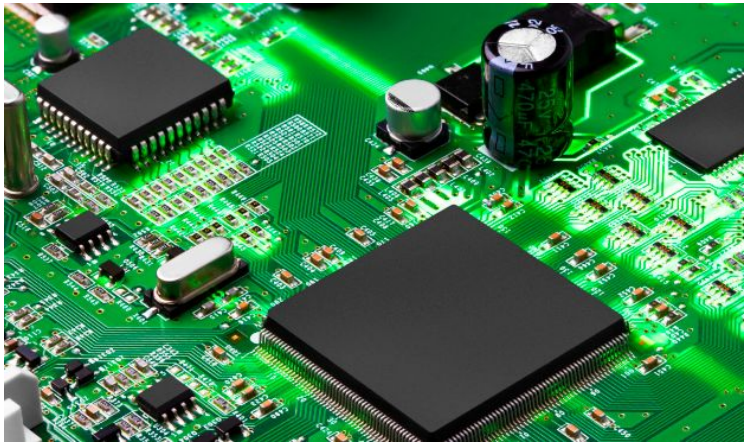
Learning Concepts:

- Interrupts
- Timers
- Arduino IDE Libraries (Continued)



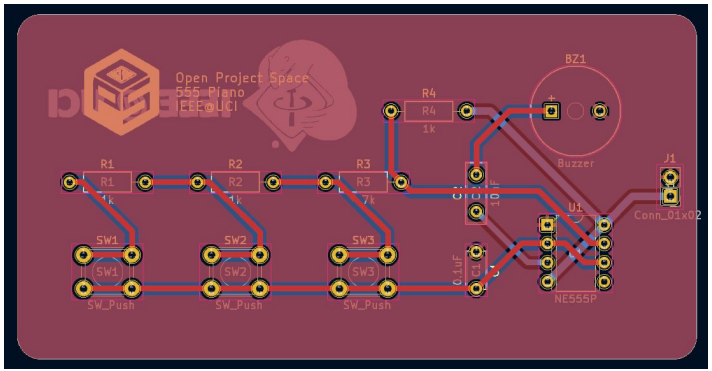
Project 8

- Design a **PCB** for the 555 Blinking LED or Piano.
- Due date: 3/13/2026 at 11:59PM
- This project is optional!



Learning Concepts:

- KiCAD
- Schematics
- PCB Design
- PCB Manufacturing

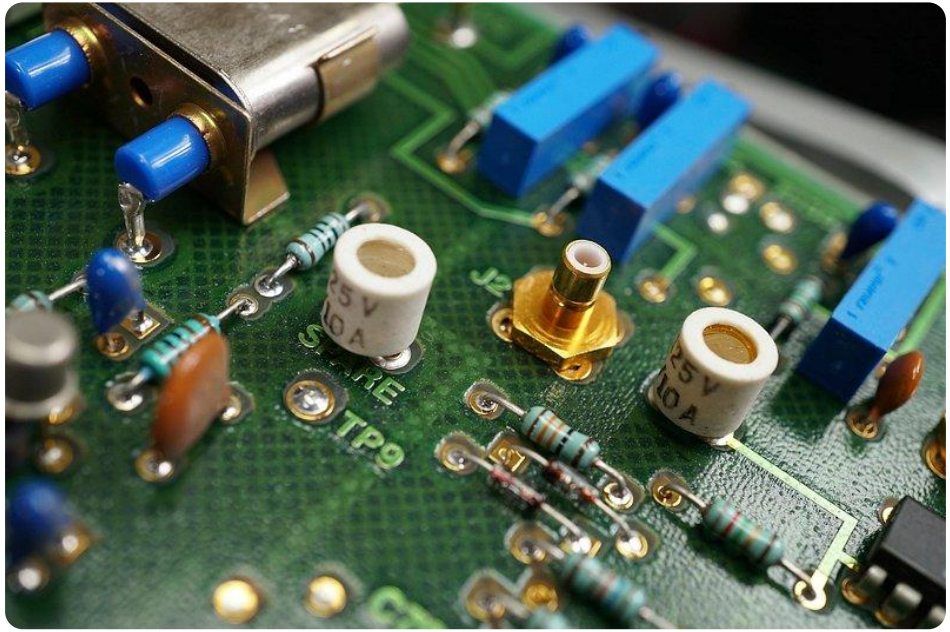


SECTION I

Introduction to PCBs

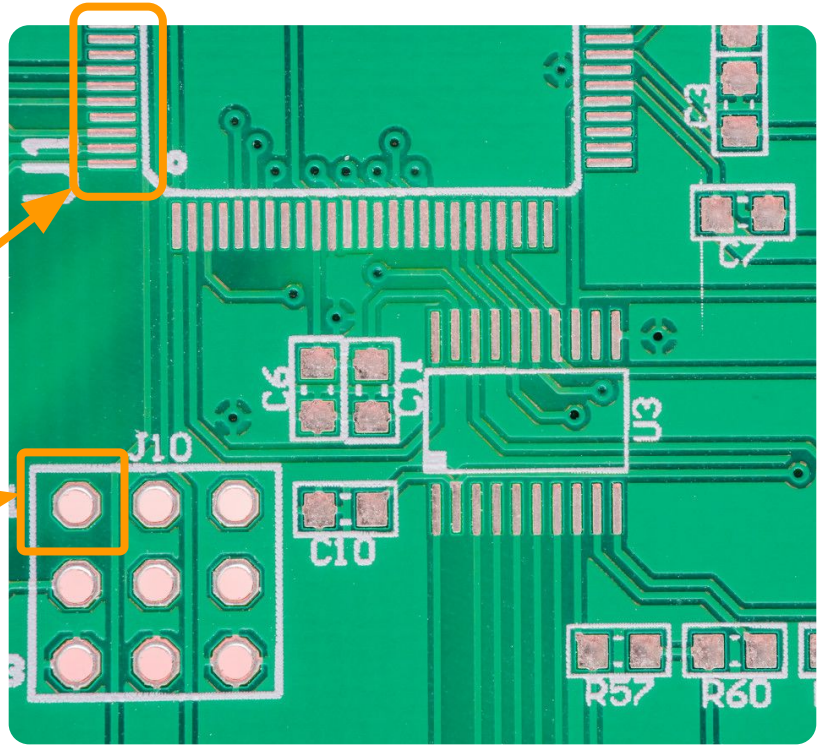
Printed Circuit Boards (PCBs)

- A **printed circuit board** (**PCB**) is an electronic assembly that uses copper conductors to **connect components**
  - It acts as a permanent map in placing and connecting electronic components
  - Made from **multiple**, **alternating layers** of **conductive** (usually copper) and **insulating material**



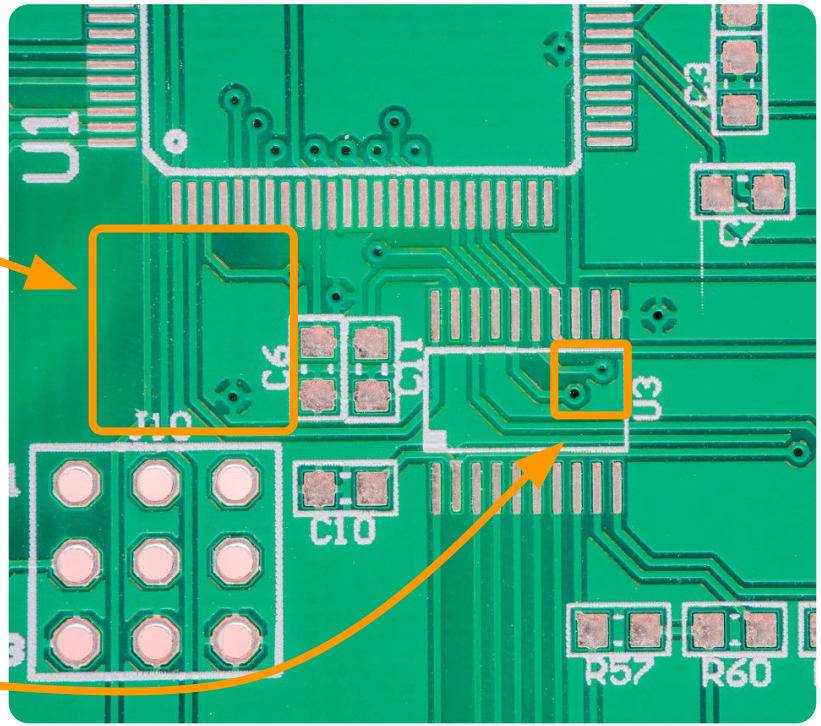
How are Components Connected?

- **Pads** are exposed copper surfaces which connect the leads of the electronic components to the board
  - Some pads are designed for **surface-mounted** (**SMD**) leads while others are for **through-hole** (**THT**) leads
  - Component **leads are soldered to the pads**



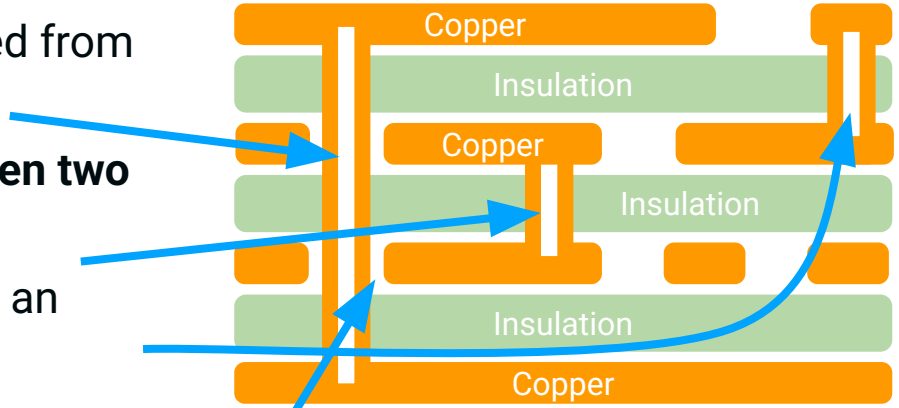
How are Components Connected? (Cont'd)

- **Traces** are **copper tracks** which connect pads
  - They are covered by a layer called the **solder mask** (colored green in the image)
- **Vias** are **conductive holes** drilled into the board to **connect different copper layers**



More on Vias

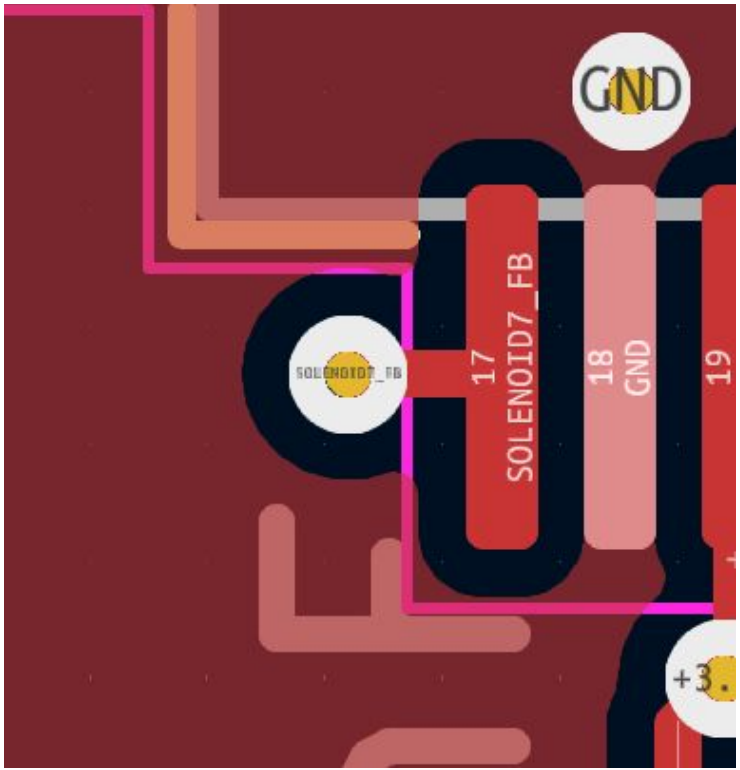
- Common via types…
  - **Through hole via** - drilled and plated from **top layer to bottom layer**
  - **Blind via** - drilled and plated **between two internal layers**
  - **Buried via** - drilled and plated from an **outside layer to an internal layer**
- A **void surrounds the via to prevent a connection** on copper layers which it should not connect
  - Copper layers are not connected from the void



Example PCB Cross Section

How are Components Connected? (Cont'd)

- A **plane** is an **inner conductive layer**
  - Used to create a ground point
- **Fills** are **large areas of copper** used for the same purpose as planes but can be integrated into the **same layer as traces**
  - The transparent shape surrounding the vias and the pads on the right is a Fill, that is used to ground the ground pad



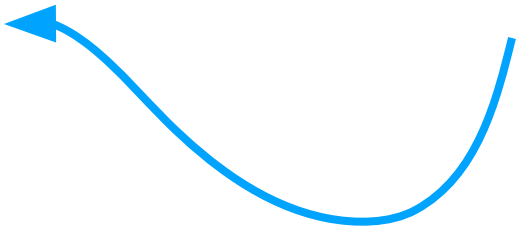
SECTION II

PCB Layers

PCB Stack-Up

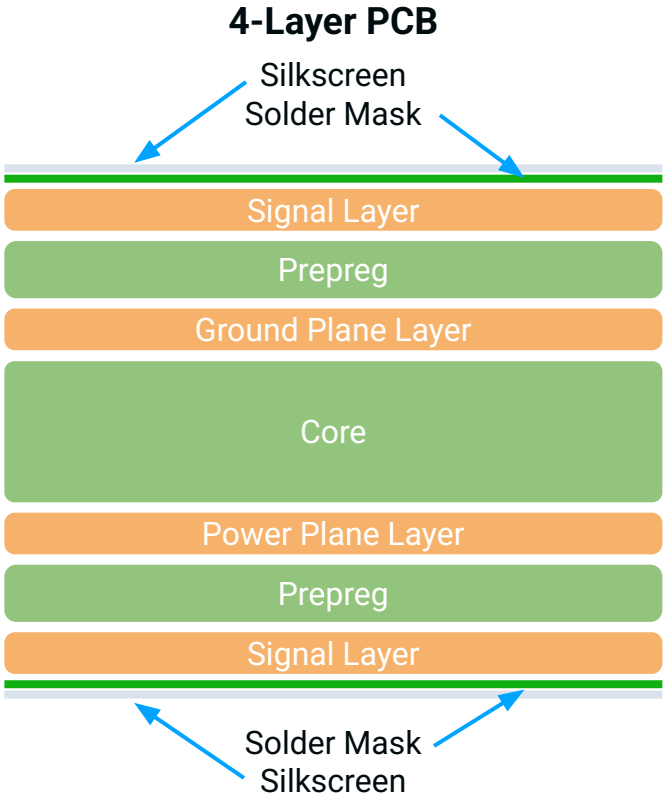
- The **PCB Stack-Up** is the **arrangement** of PCB layers
- Most PCBs have multiple of the following layers:
  - **Copper layer**
    - Signal or routing layer
    - Ground/Power plane layer
  - **Insulation layer**
    - Core
    - Prepreg
  - **Solder mask layer**
  - **Silkscreen layer**

Let's talk about each layer in greater detail



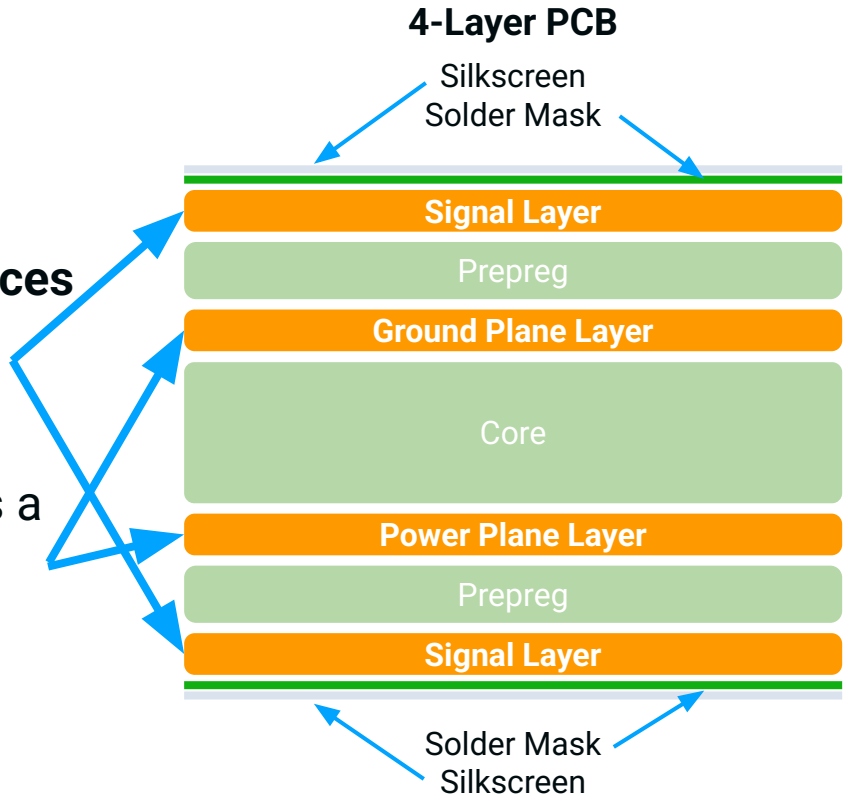
PCB Stack-Up (Cont'd)

- We will analyze an example stack-up for the **4-layer PCB**
  - An "*x*-layer PCB" contains *x* copper layers
- Note the **alternating pattern** of conductive and insulating layers



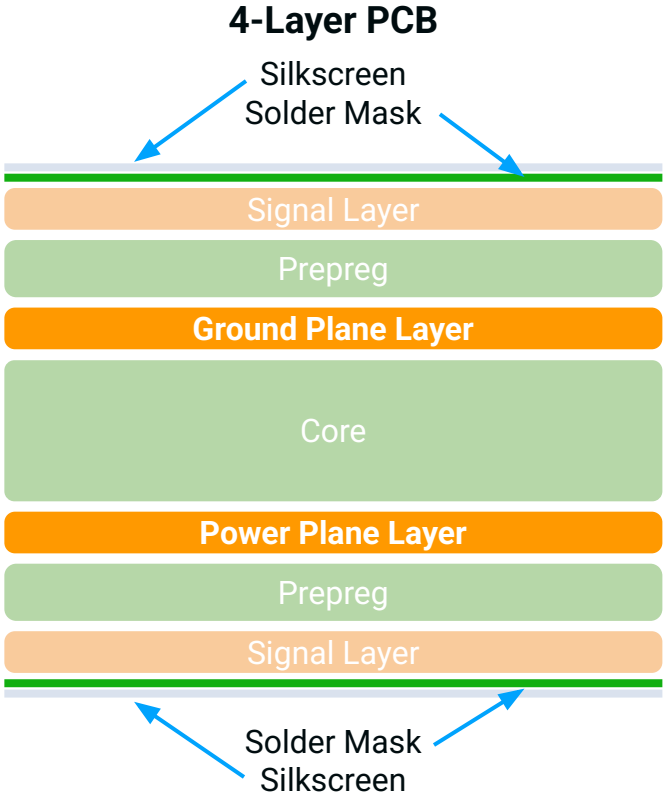
Copper Layer

- Each **copper layer** facilitates current flow between circuit components
- There are two types of copper layers:
  - A **signal/routing layer** is where the **traces and pads** are etched for connecting components
  - A **ground/power plane layer** serves as a **path to the common ground or power** voltage



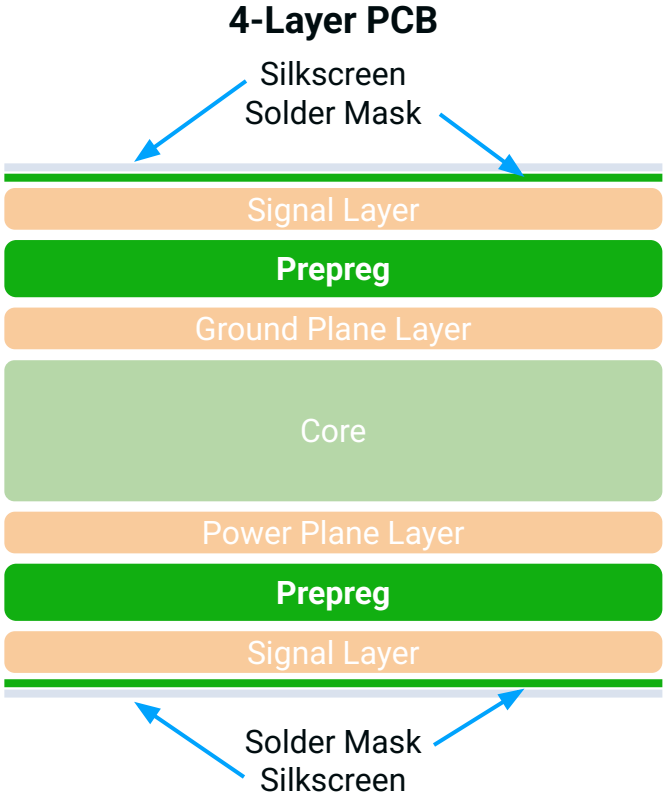
Copper Layer (Cont'd)

- **Why bother with a ground or power plane layer?**
  - Ground/power planes reduce electromagnetic interference (EMI) and improve the board's heat dissipation
  - A ground plane separating layers of high speed signals can decrease the amount of EMI leaking from one signal to the other



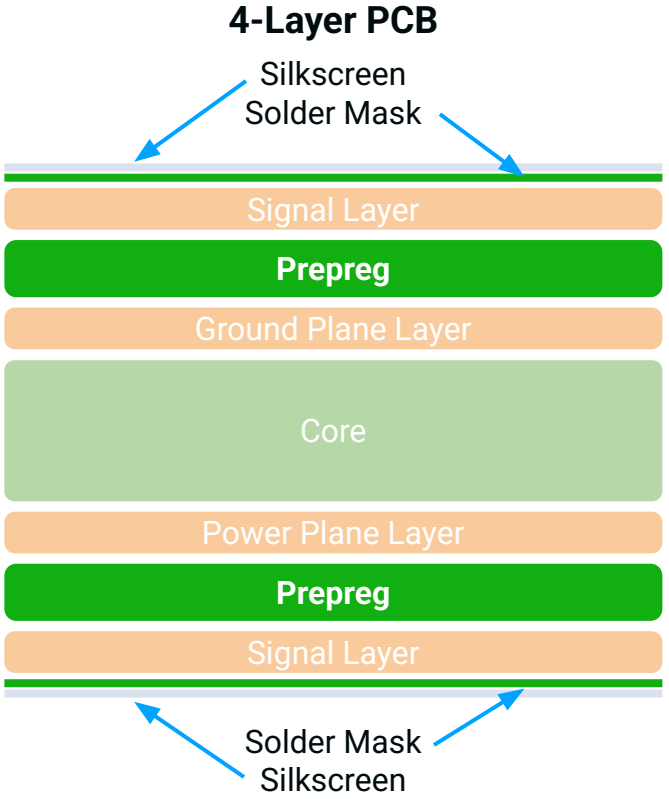
Prepreg Layer

- **Prepreg** is **an insulator layer** that separates the copper layers and acts as the “glue” to hold the core and copper layers together
  - It is **uncured** and contains resin which is responsible for its “sticky” property
  - When cured with heat and pressure, prepreg bonds all the layers together



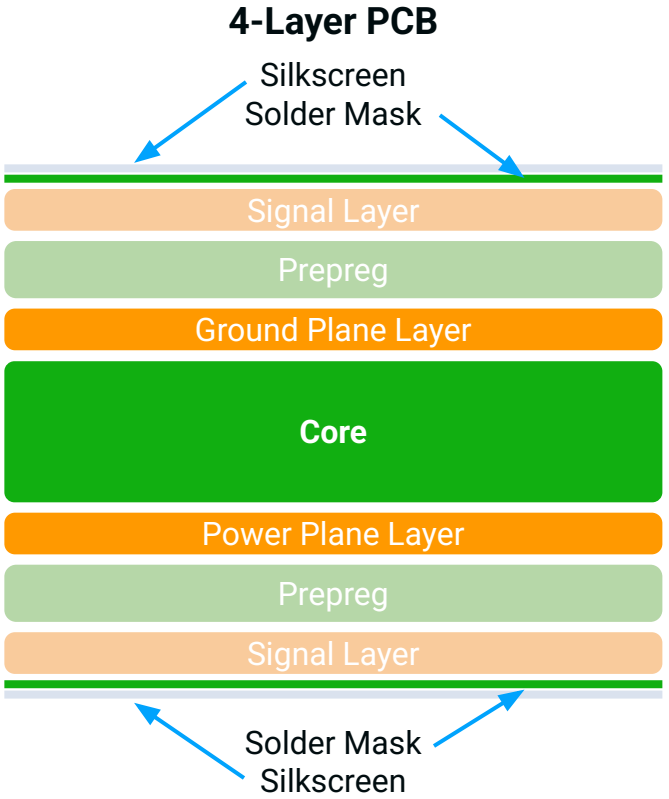
Prepreg Layer (Cont'd)

- Prepreg is made of **substrate** (insulating material)
  - Common substrates are…
    - **Fiberglass-epoxy** (often FR-4)
      - Most often used
      - Cheap
    - **PTFE (known as Teflon)**
      - Better thermal stability and anti-electrical properties than FR-4 but much more expensive



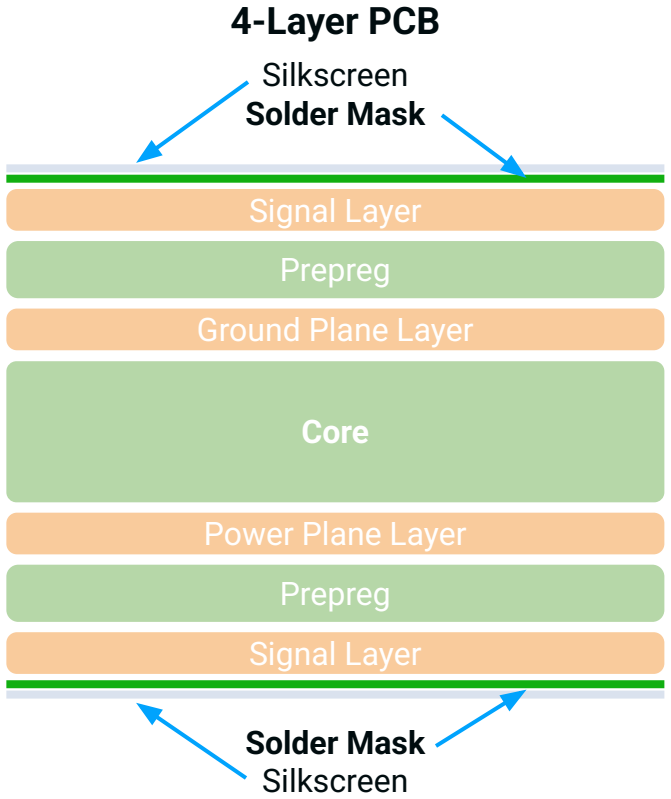
Core Layer

- **Core** is an **insulator layer** made of multiple prepreg layers pressed together, **plated with copper layers on either side**, and **cured**
  - It technically incorporates the two adjacent copper layers
- In a 2-layer PCB, **usually** only one core exists
- In a 4-layer PCB, **usually** only one core exists, separated by prepreg on either side



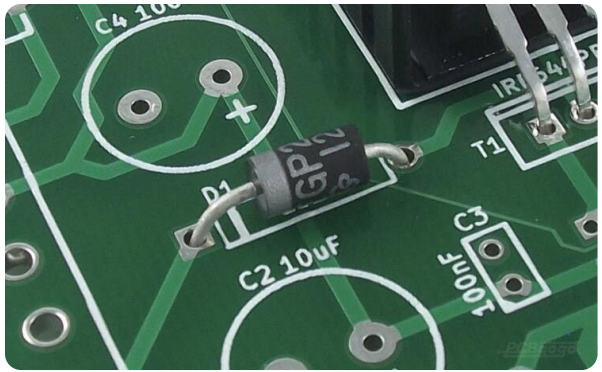
Solder Mask Layer

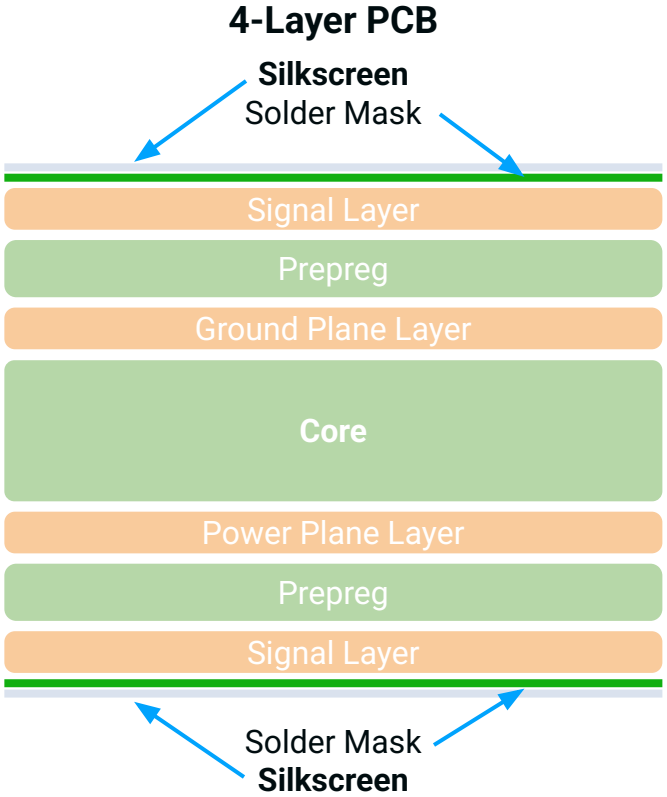
- Both outer copper layers are covered by a **solder mask layer**
  - It is a thin resin or filler that is used to **protect outer traces from oxidation** and **prevent solder bridges** between pads
  - It is the green material you see on the surface of the PCB (can be made into a different color :00)



Silkscreen Layer

- The **silkscreen** is a layer of ink traces (often white) used for symbols, logos, and other component markings
    - It is the outermost layer on either side of the board





SECTION III

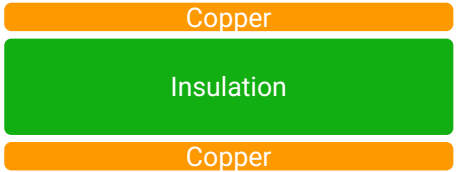
PCB Fabrication

Fabrication Process Overview

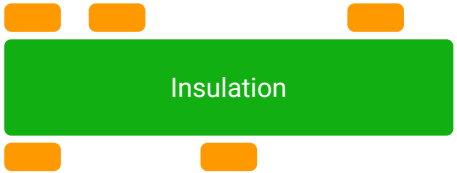
2-Layer PCB

1. **Raw materials are cut** into boards and **holes are drilled**

2. Core, prepreg, and copper **layers are set and cured** (lamination)



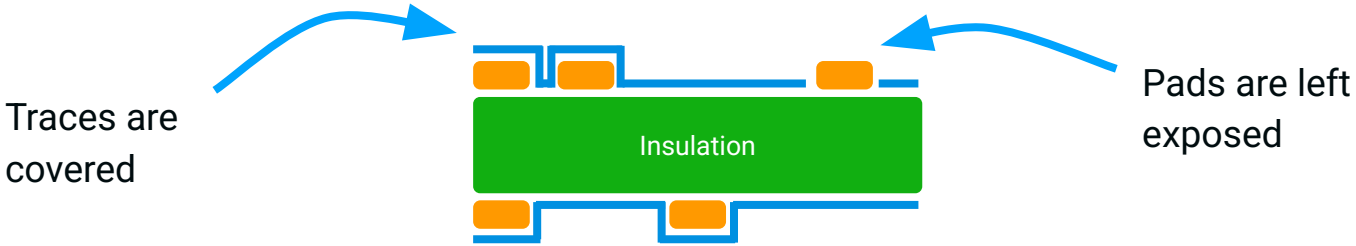
3. Copper layers are **etched** to remove excess copper, **leaving only the traces**



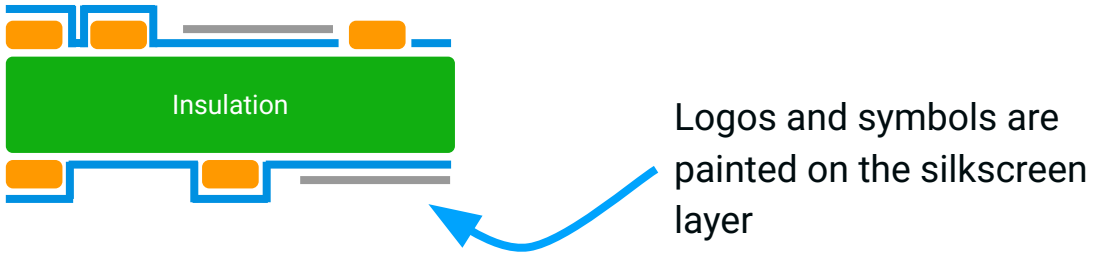
Fabrication Process Overview (Cont'd)

2-Layer PCB

4. The **solder mask is applied** to outer copper layers



5. The **silkscreen is painted** onto the solder mask

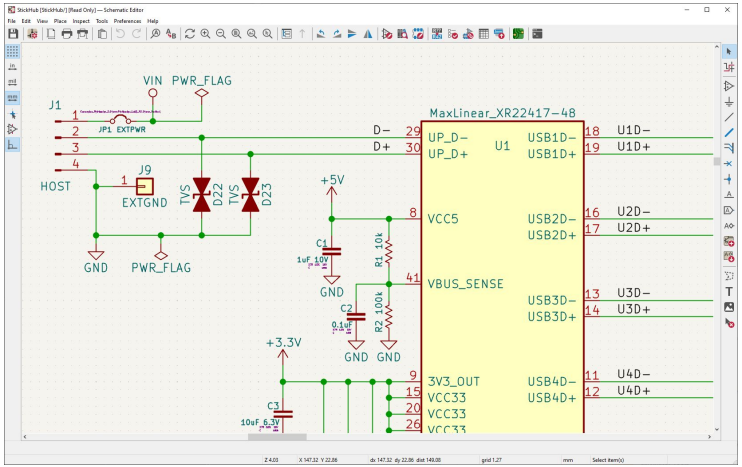


SECTION IV

PCB Design Process

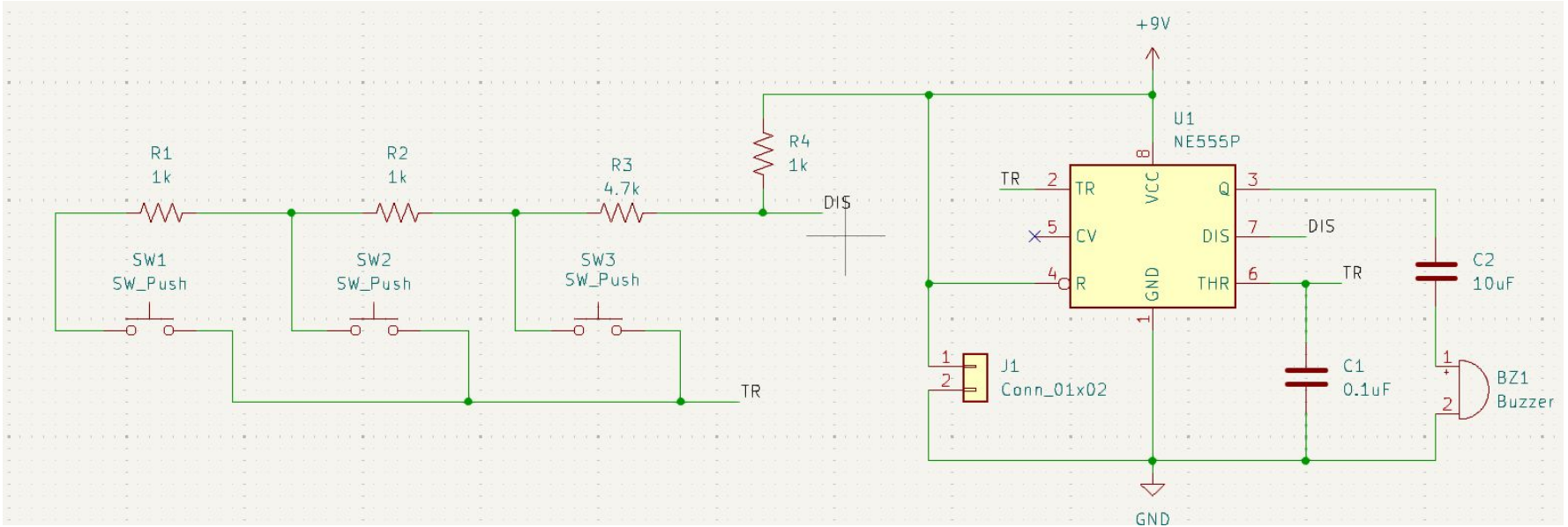
PCB Design Process

1. **Identify the components** and **circuit diagrams** you will use
    - Prototype the design on a breadboard
2. **Schematic capture**
    - Use CAD software to create digital schematics from the circuit diagrams
        - This software falls into a category of tools called **Electronic Design Automation** (**EDA**)



KiCad Schematic Capture

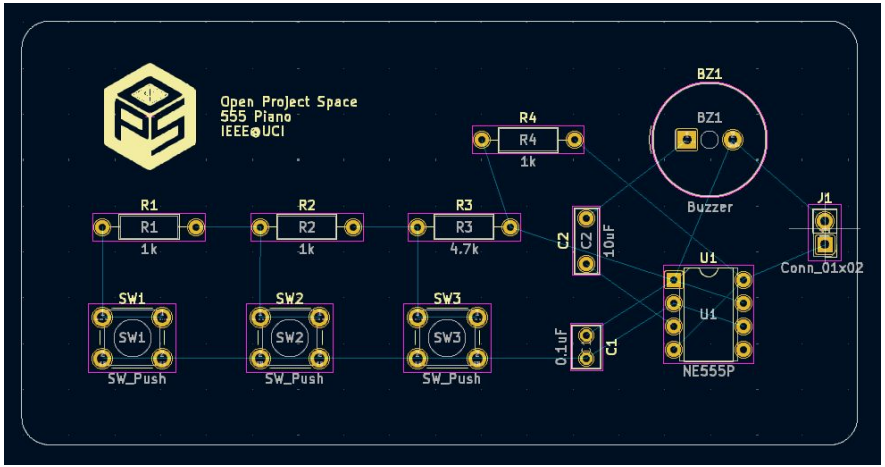
PCB schematic



This look familiar?

PCB Design Process (Cont'd)

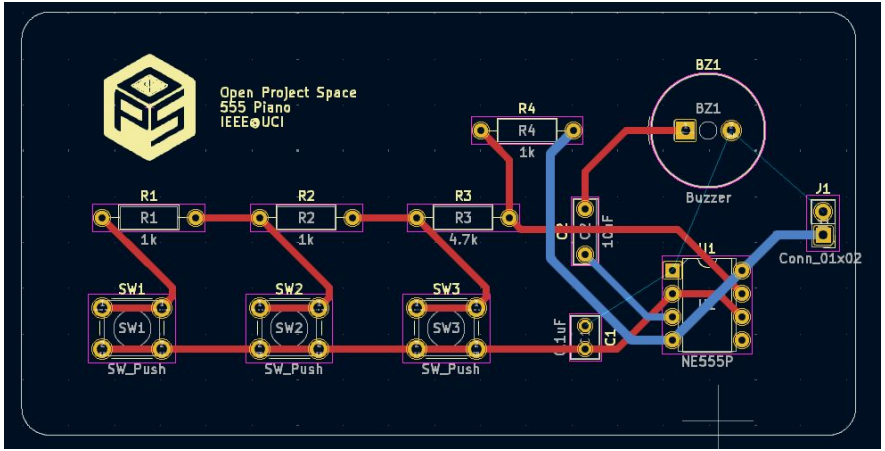
3. **Component placement** and **routing**
    - Arrange the components on the PCB layout; when placing components, consider (in order of priority)...
        - The board shape
        - Connector locations
        - Heat dissipation requirements



KiCad Component placing

PCB Design Process (Cont'd)

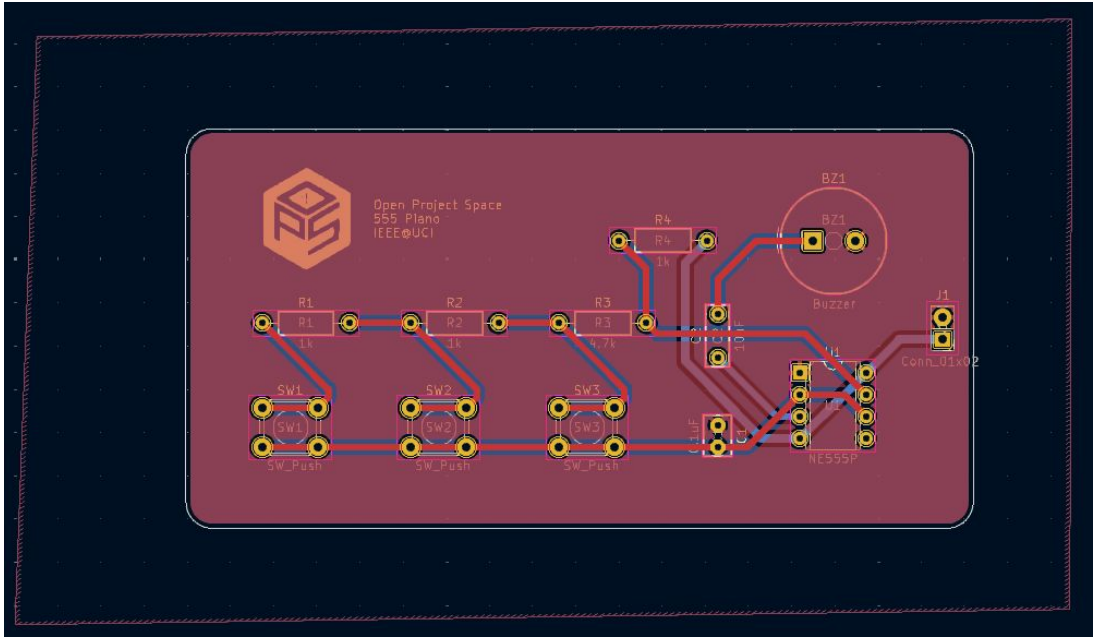
3. **Component placement** and **routing** (Cont'd)
   - Route the traces between component pads
   - EDA tools will make sure the layout conforms to the schematic you defined
   - **DESIGN RULES CHECK (DRC)**
     - Checks if there are any tolerance errors or unconnected components



KiCad Routing

PCB Design Process (Cont'd)

- Fill zones
  - Fills in the rest of the empty pcb with copper
  - Can connect component together
  - We normally used the top and bottom fills with ground



KiCad Fill zones

PCB Design Process (Cont’d)

4. **Verification**
    - EDA software will have design rules checking tools to make sure components are properly connected and traces correctly routed
5. **Generate the manufacturing files**
    - EDA software will create the files which you share with a manufacturer
    - These files are used by machines for automated PCB fabrication
6. **Fabricate the PCB**

PCB EDA Software

- Popular PCB design software are…
  - Altium Designer (free for UCI students!)
  - Autodesk EAGLE
  - KiCAD EDA (Free)
- We will use KiCAD for this course
  - It is an open source schematic capture and PCB design tool

PCB Manufacturers

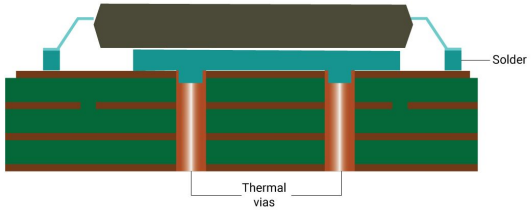
- JLCPCB
  - Inexpensive 2-layer FR-4 boards
  - Fast manufacturing and shipping
  - Used by hobbyists
- PCBWay
  - Better for more precise design requirements (small traces, vias, etc.)
  - Advanced manufacturing options

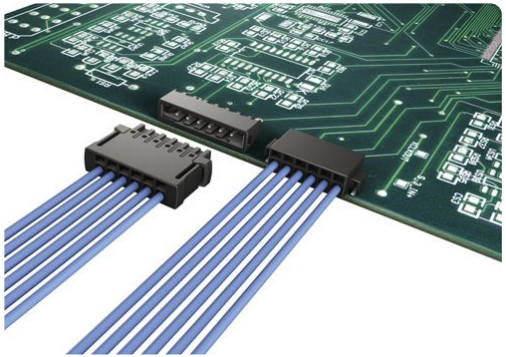
SECTION V

PCB Layout Tips

PCB Layout Tips

- **Use thermal vias to help cool components**
  - **Thermal vias** (unconnected vias) move heat away from components through the board layers
- **Place board-to-wire connectors** near the **edge** of the PCB
  - It's harder to connect wires in the middle of the PCB





PCB Layout Tips (Cont'd)

- **Use ground fills or planes** to reduce electrical noise and improve signal integrity
  - **Electrical noise** - random variations in voltage and current, which affects sensitive components
  - **Signal integrity** - how well a signal maintains its original characteristics (strength, shape, timing) from sender to receiver
- **Leave space between** pads and traces
  - Make sure that the pad and trace spacing **adheres to design constraints** (devices packaging, manufacturer requirements)

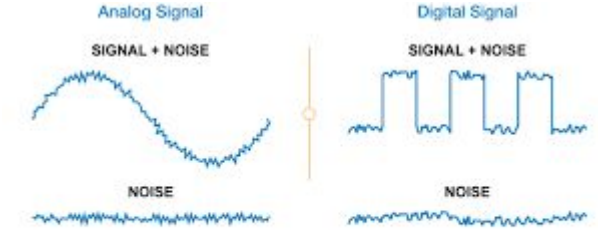
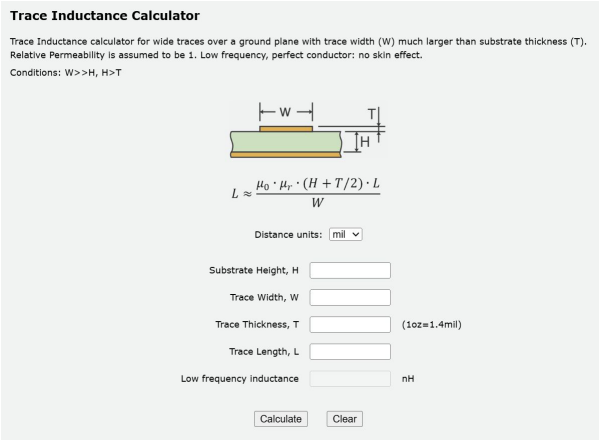
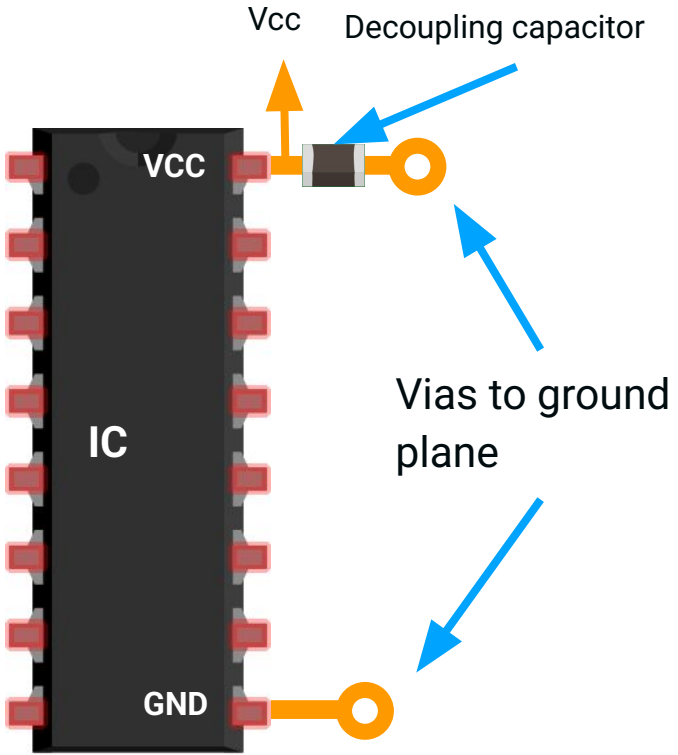


FIGURE 1. Noise in Analog and Digital Signals



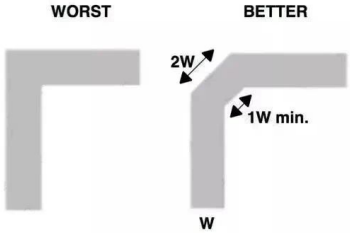
PCB Layout Tips

- **Use decoupling capacitors on ICs**
  - **Decoupling capacitors** help **reduce electrical noise** in power supply signals
  - **Ensures a clean and stable power supply** for the IC, preventing unexpected behavior and malfunctions
  - Place the capacitor **between the VCC and GND pins** of the IC



PCB Layout Tips (Cont'd)

- **Avoid 90° trace angles**
  - Use 135° angles instead
  - The corners of 90° angles are narrower than the standard trace width; traces should be consistent widths
  - 90 degree are harder to etch as a trace
- **Make the power and ground planes big as possible**
  - Reduces heat buildup from high current
  - Improves signal integrity
  - Signal traces, which are low current, may be narrower



Setting up KiCad

- **Get out your laptops!**
- We will be setting up KiCad
    - This tutorial will be available on the project page when it releases

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