Printed Circuit Board Design

ECE 3400
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Agenda

• What is a PCB? Should I use a PCB?
• Design example
  • Component selection
  • Schematic design
  • Layout basics
• Layout Considerations
  • Trace Width, Pours, Thermals
  • Grounding
  • Decoupling
  • High-Frequency considerations
  • 3D Modelling
  • Testing
  • Mistakes
  • Other
• Eagle demo if time
What is a PCB?

- Interleaved layers of copper and insulator
- Number of layers = number of copper layers
Useful Terms

**Trace**
Copper path (equivalent of wire)

**Via**
Hole in board with connection between layers
Useful Terms

Pad
Exposed copper for component placement

Package
Casing for a component with metal leads coming out.
Usually black plastic.

Surface Mount (SMT/SMD)
Components that can be soldered onto pads, not through-holes
PCB Tradeoffs

Pros
• Permanence/Reliability
• **Space-Savings**
• **Simple to Manufacture**
• Immune to movement
• Better grounding

Cons
• **Permanence**
• Lead-Time
• Isolation
• High-Frequency Effects
• Testability
• Thermal Management
PCB Manufacturing

- Etching – Primarily used in industry, best tolerances

- **Milling** – Drill/Cut undesired copper
- Printing – Specialized conductive nano-inks
- Direct Plating
- Direct Cutting
Design Process

1) Specifications
2) Topology & Component Selection
3) Schematic
4) Simulation
5) Layout
6) Print 1:1 on paper and check
7) Export Gerbers and Order
8) Solder
9) Testing/Verification
10) Use
Design Example – IR Hat
1) Specifications

What should it do? How well? In what conditions?

Given: Make a PCB which emits IR at ~10kHz
  • Powered by 9V
  • Mounts to robot chassis
  • Should be detectable from 2 feet away without amplification
  • Cheap

Open:
  • Board dimensions
  • Frequency accuracy
  • Consistency between boards
  • Harmonic content
  • Protection mechanisms
  • Everything else...
2) Topology Selection

At a high level, what will I use to meet the specifications?

• Microcontroller-Based? FPGA-Based? Timer-Based? Oscillator-Based?
• Waveform filtering? Duty cycle?
• Protection?
  • Fuses
  • Diode protection (Real diodes or ideal diode?)
# Component Selection

Look on Digikey, Mouser, Ebay, Alibaba, etc.

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<thead>
<tr>
<th>Part Number</th>
<th>Image</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Quantity Available</th>
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<th>Packaging</th>
<th>Series</th>
<th>Part Number</th>
<th>Type</th>
<th>Count</th>
<th>Frequency</th>
<th>Voltage</th>
<th>Current</th>
<th>Temperature Range</th>
<th>Operating Range</th>
<th>Package / Case</th>
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## Component Selection

Always make a bill of materials (BOM)

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<th>Ref Des</th>
<th>Qty Owned</th>
<th>Qty to Order</th>
<th>Manufacturer</th>
<th>Part #</th>
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**Total Cost**

- $30

**For Ordering**

- **Diagey Part Number**
- **Quantity**

  - 2560-21752-1-ND
  - 12
  - 1497-1205-1-ND
  - 2
  - MNVR2005SFT15S1CST-ND
  - 10
  - MCT0683-5.6K-5CYT-ND
  - 10
  - 490-4533-1-ND
  - 10
3) Schematic Design
4) Simulation

- Can verify analog functionality and simple digital
- Recommend LTSpice due to real component models but many options... (Pspice, PartSim, PLECCS, EasyEDA, Autodesk Circuits, etc.)
4) Simulation
5) Layout

How do I want to physically place my components?
6) Print and Check
7) Export Gerbers

Gerber files are what the fabrication house uses to make the board.

- Generate Gerbers
- Create zipped folder
- Check that they are correct ([http://www.gerber-viewer.com/](http://www.gerber-viewer.com/))
- Upload to website
7) Order

Advanced Circuits, Seeedstudio, Oshpark, PCB Minions, ......
8) Solder

Your board looks like this when you get it back
8) Solder

• Always do SMD components first!
• Usually smaller $\rightarrow$ bigger, IC’s first then resistors/caps
• Once finished with SMD, shortest $\rightarrow$ tallest thru-hole components
• Can solder and test incrementally
• Need to see a proper fillet!
8) Solder

Methods

Soldering Iron
- Melt solder onto pad
- Add flux (optional)
- Pick component with tweezers and hold lead against pad
- Re-melt solder so that it joins lead and pad

(Multiple other techniques)

Solder Paste
- Place paste on all pads (can use stencil)
- Place components onto paste
- Cook
9) Testing & Verification

1) Using your eyes and a multimeter you should:
   • Visually inspect all solder joints
   • Check continuity between each lead and pad (Should be <1ohm)
   • Check discontinuity between adjacent leads (Should be infinite resistance)

2) Do an initial power-on test
   • Use a regulated voltage source!
   • If voltage varies or current is high, turn it off!
   • Check voltage of test-points and rails

3) Test functionality incrementally
10) Use

- Diagram your board for ease of use
- Follow ESD guidelines
- Use plastic mounting screws
- Avoid bending board
11) Reflect

Problems with design...
- No protection
- Inaccurate frequency
- Harmonic content
- Fab house mistake
- What else?
Layout Considerations

- Trace Width, Pours, Thermals
- Grounding
- Digital vs. Analog
- Decoupling
- High-Frequency considerations
- 3D Modelling
- Mistakes
- Other
Trace Width, Pours

• Usually start at 10mil
• Thicker traces for higher power
  (https://www.4pcb.com/trace-width-calculator.html)
• Use pours when possible for greater than ~500mA
Thermals - Simple

FET has on-resistance of 1ohm. Average current is 1A.  \(\rightarrow\) Power dissipation is 1W

Too much power? Check Datasheet:

Yes. Add heat-sink.
Thermals - Detailed

Hand Calculations:

LTSpice Thermals:

FEA Models:

Increasing Accuracy & Complexity
Grounding

Make one layer a complete ground plane if possible!
Otherwise be very careful with connections
Grounding

Common mistake...
Digital vs. Analog

Digital: High-frequency, high-harmonic-content waveforms
Analog: Sensitive to ground & Vdd references
Decoupling

Why does every board have so many caps?
Decoupling

What is the transfer function?
Decoupling

What is the transfer function?
Decoupling

What is the transfer function?

The bigger the capacitor, the larger the time constant.
Decoupling

What is the point of large capacitors?

\[ Q = CV \]
\[ V = \frac{1}{C} \int i \, dt \]

The bigger the capacitor, the smaller the voltage rise.
Decoupling

In summary:

- Place at least one capacitor between every analog voltage and ground
- Place larger capacitors near power input pins
- Place smaller capacitors next to IC
- Good rules of thumb
  - 2.2-10uF next to power input or IC power rail
  - 100nF-1uF along long traces
  - 10nF-100nF next to IC
High-Frequency Considerations

Take ECE 4330 – Intro to Microwave Engineering

Until then …

• Keep traces short
• Avoid vias
• Can via-stitch grounds alongside
• Impedance matching is important – sets trace width
• Keep sensitive analog and high-frequency digital apart!
3D Modelling

• Can find or make 3D models for every component.
• Can export entire board into solidworks/inventor
Dealing With Mistakes

• Solder wires onto pins
• “Floating components”
• Cut traces or pins
Miscellani

- Gold substrates
- Flexible boards
- Stacked boards
- IC Specifics
- Process Variation
- Many-Layer
- And more...
How can you use a PCB on your robot?

• Amplifier/filter for your microphone circuit
• Amplifier for your treasure circuit
• A tidy base station voltage divider
• The whole thing...?
Happy PCB-ing!
References

Board Manufacturing
• https://www.4pcb.com/media/presentation-how-to-build-pcb.pdf

Decoupling

Soldering
• https://www.build-electronic-circuits.com/smd-soldering/
• https://www.youtube.com/watch?v=3NN7UGWYmBY
• https://www.youtube.com/watch?v=z7Tu8NXu5UA
Class References

Tutorials

Burn List