Designing Hardware, Journey from Novice to Not-Bad

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OpenElectronicsLab

ADS1290 breakout

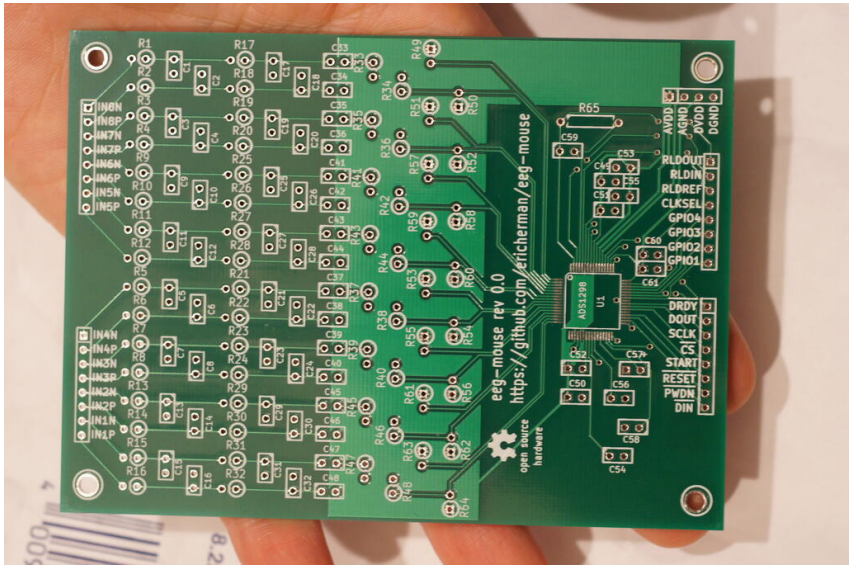


Figure 2: 2012 board

- through-hole with 1 64pin QFP
- 2011-11-26 begin desgin
- 2012-01-23 boards arrive
- 2012-03-04 reading data

https://github.com/OpenElectronicsLab/ads1298-breakout

ExG Version 1

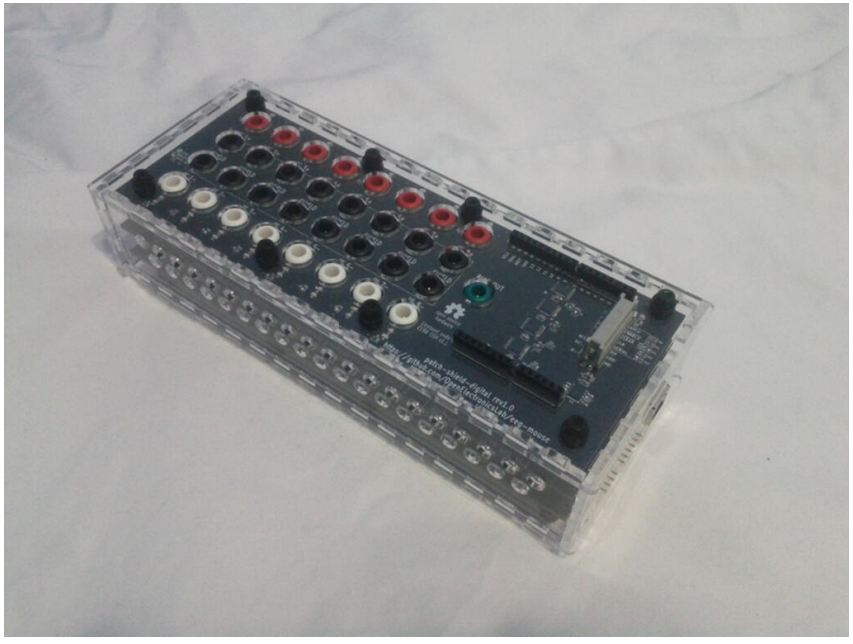


Figure 3: OpenHardwareExG in the case

- 3 boards stacked, but testing of base-board hard
- example usage:
  http://openelectronicslab.github.io/eeg-mouse/

https://github.com/OpenElectronicsLab/OpenHardwareExG

ExG Shield

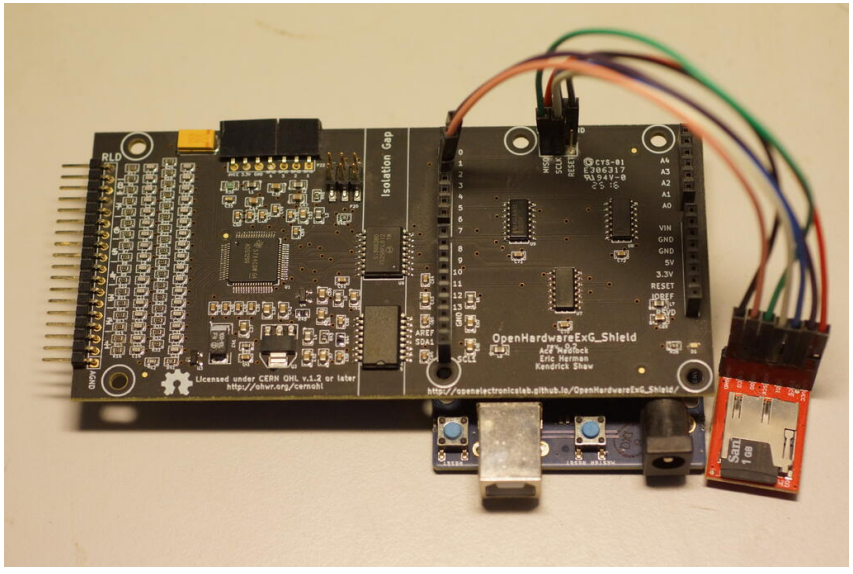


Figure 4: OpenHardwareExG Shield

- designed testing, cheaper and easier for others
- made some errors and three different revs
- example usage: quantified self

https://github.com/OpenElectronicsLab/OpenHardwareExG_Shield

Current Project: Holter Monitor

- asked for advice from Humatem and received some great guidance
- special purpose
- goal of FDA or EC certification
  - EC medical device regulation is currently changing (2020) and we don't really know the process yet
  - Need to design for safety from the start: Plan to do a ground-up redesign with eye on certification once we're happy with the prototype

https://github.com/OpenElectronicsLab/OpenHardwareHolterMonitor

Many excellent FOSS tools to support hardware hackers

- for both hardware and firmware
- Arduino-type boards and tools lower the barrier to entry

KiCAD eeschema

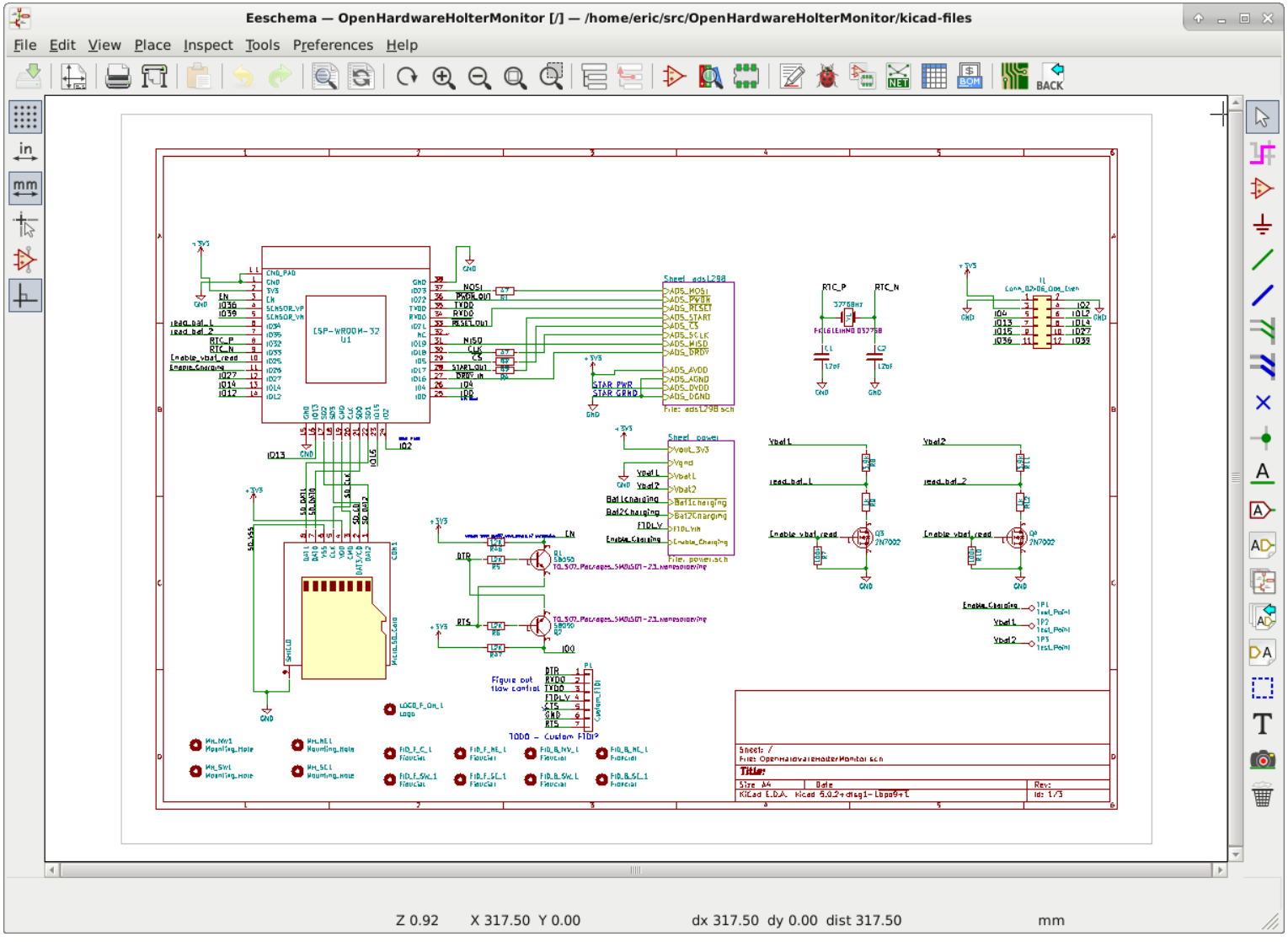


Figure 5: kicad-eeschema-screenshot.png

KICAD PCB

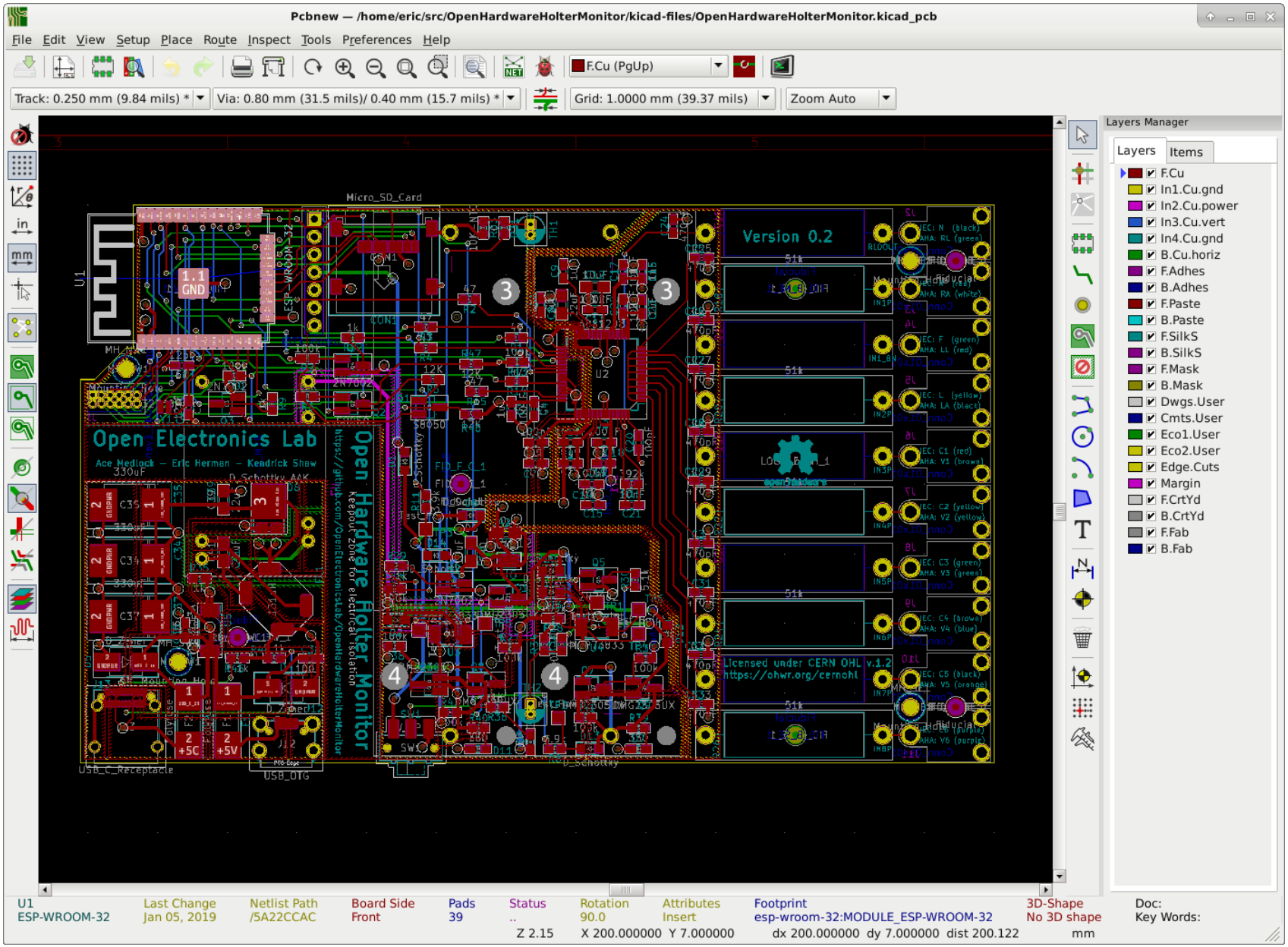


Figure 6: kicad-pcbnew-screenshot.png

Populated PCB

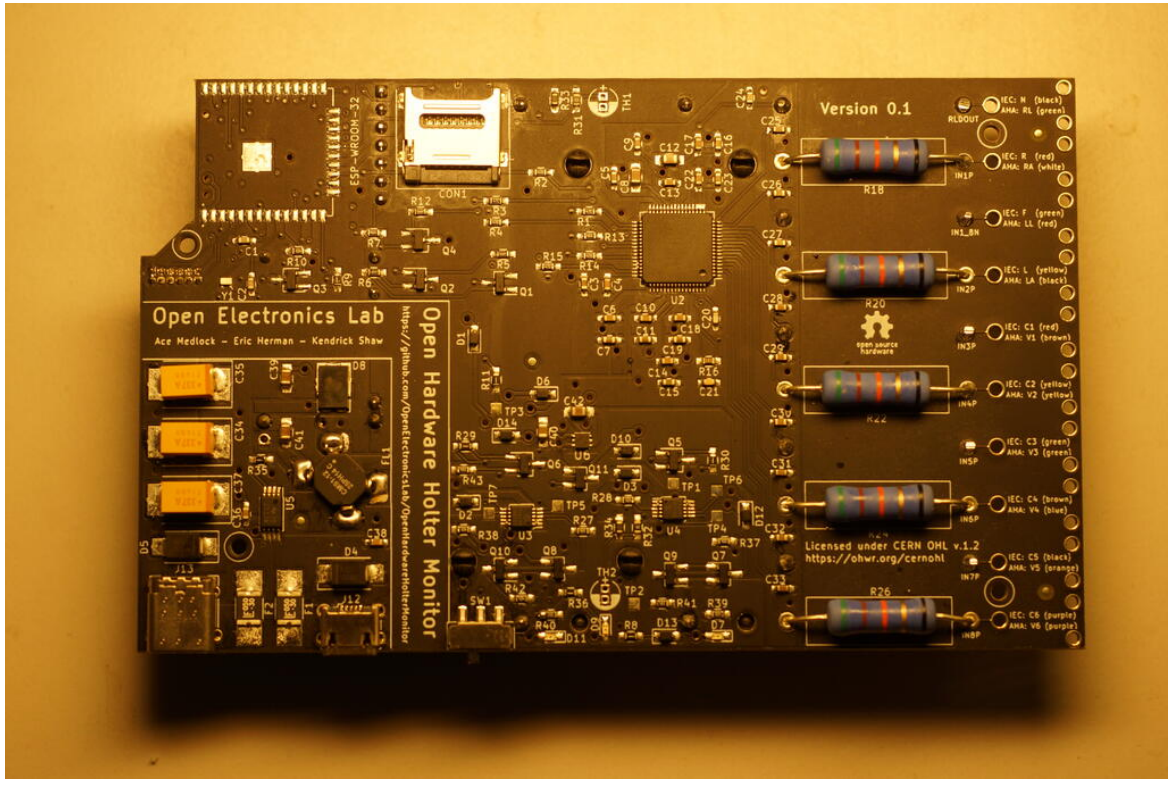


Figure 7: populated-holtermonitor_small.jpg

Arduino build environment

Figure 8: arduino-build-screenshot.png

OpenSCAD

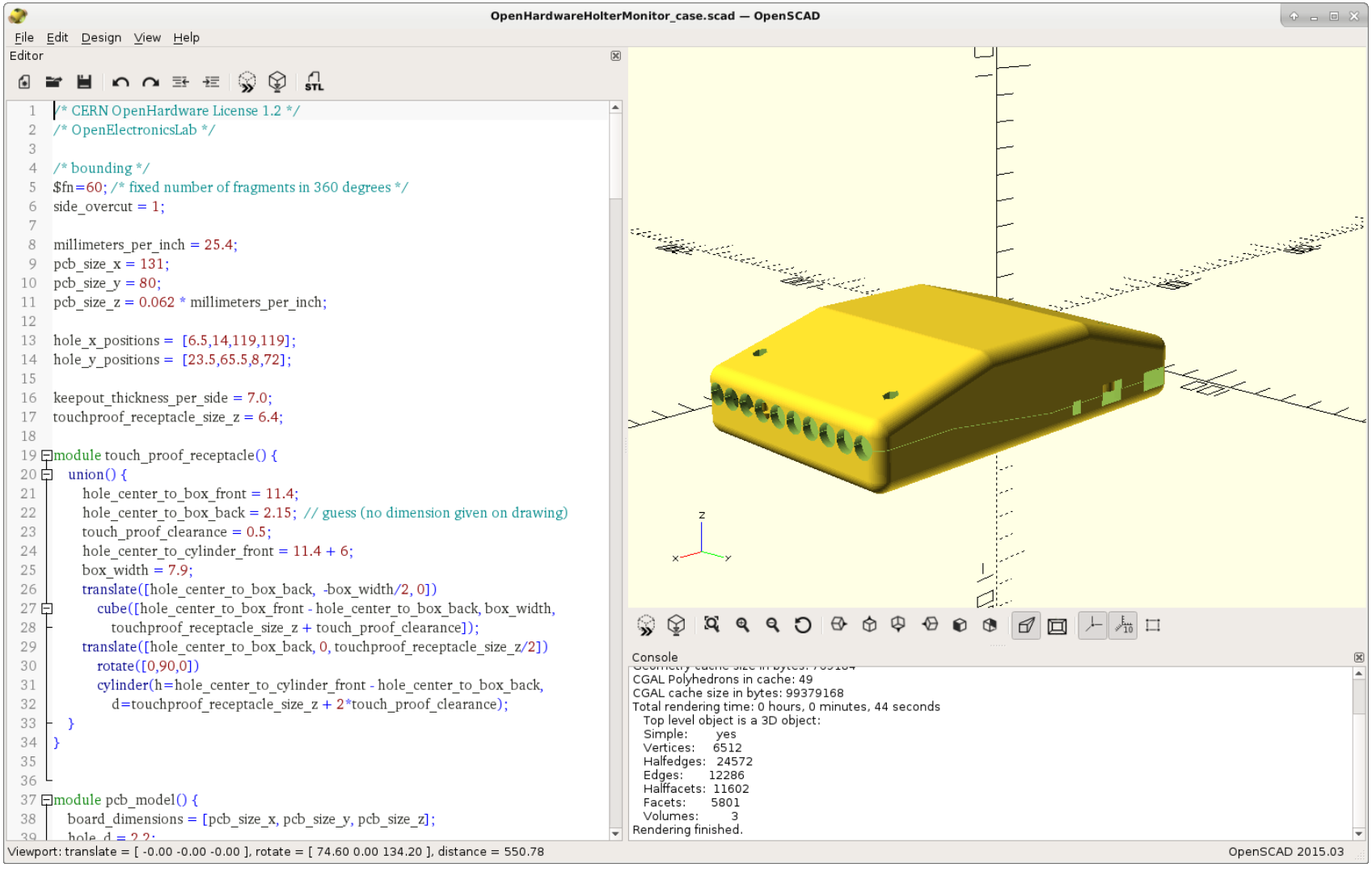


Figure 9: openscad-screenshot.png

Learning surface mount soldering

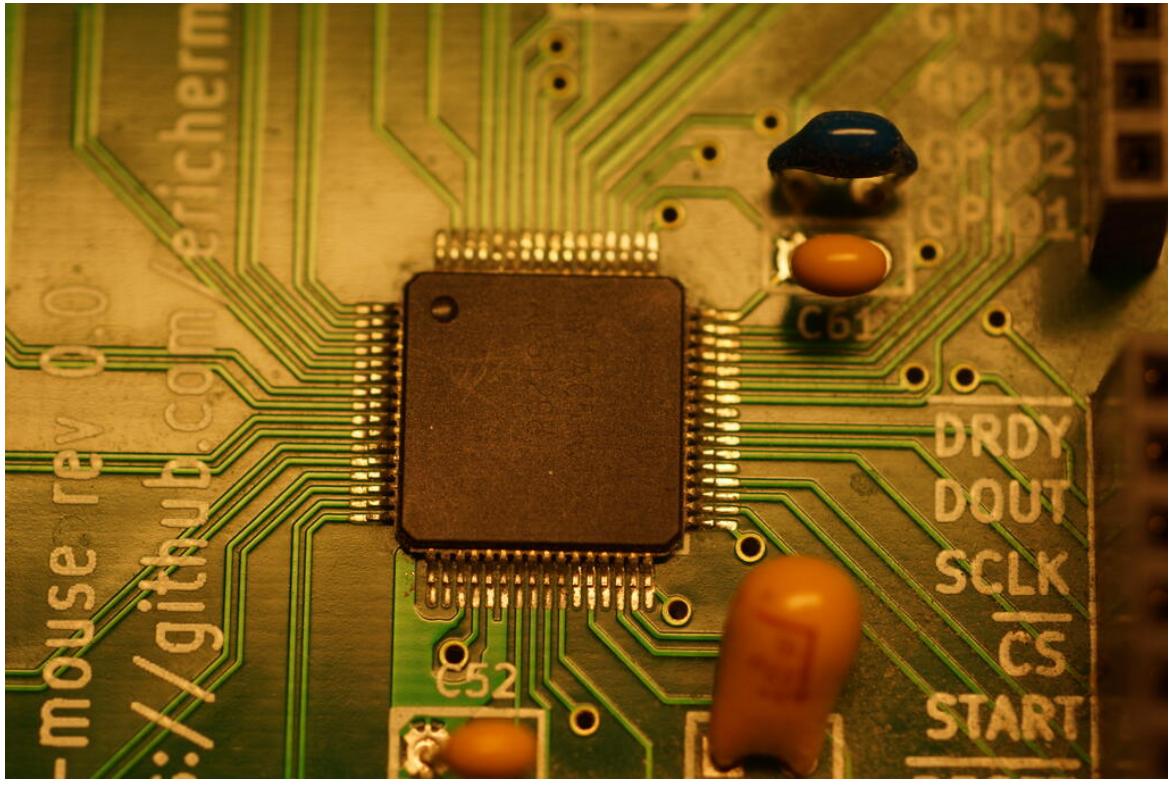
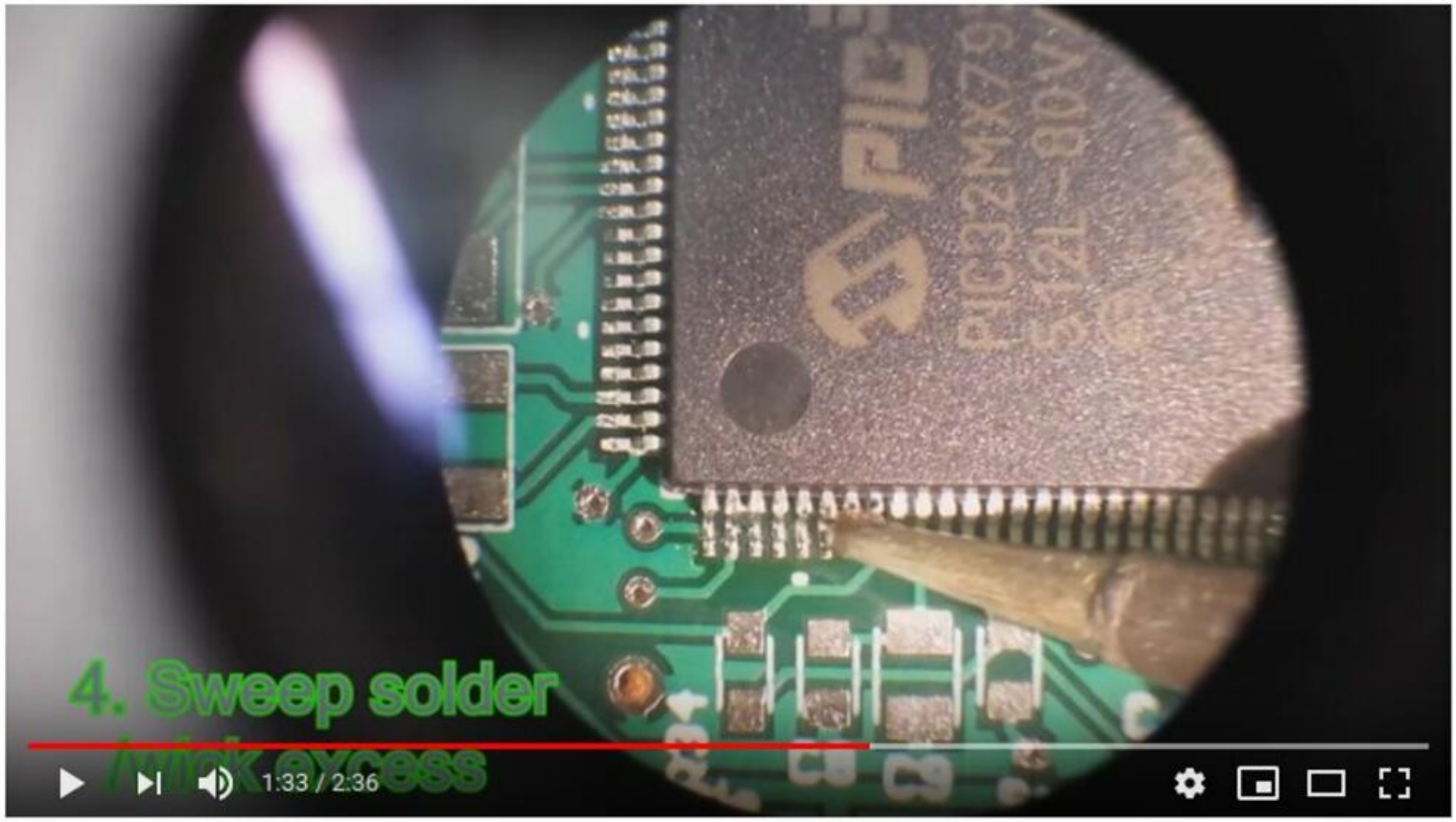


Figure 10: rev0: through-hole except the chip

Learning surface mount soldering

- "Pin sweep" method of soldering ICs
- I learned it by watching YouTube!



How to solder tiny surface mount IC chips

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Learning surface mount soldering

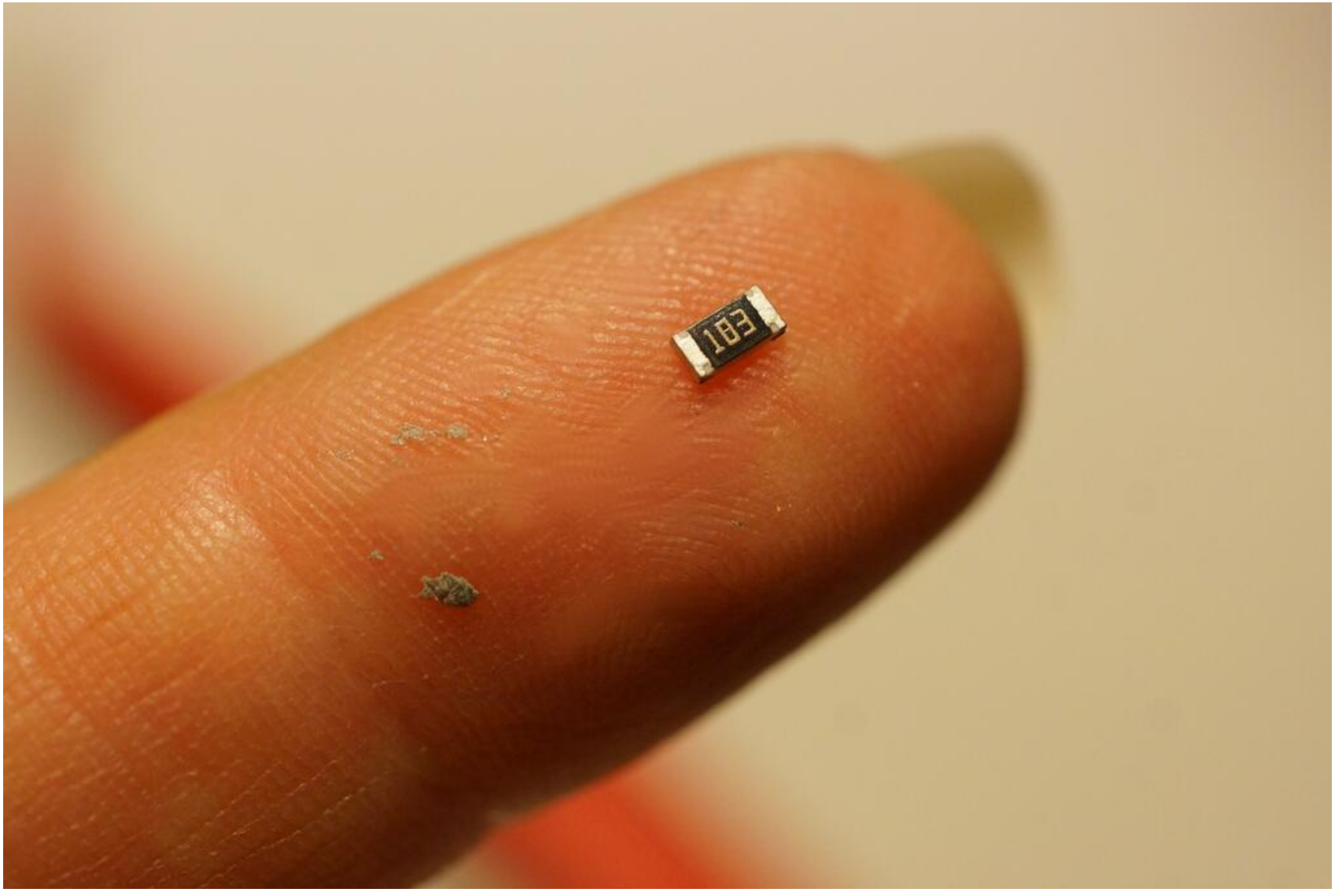


Figure 11: 0603 surface mount resistor

Solder paste

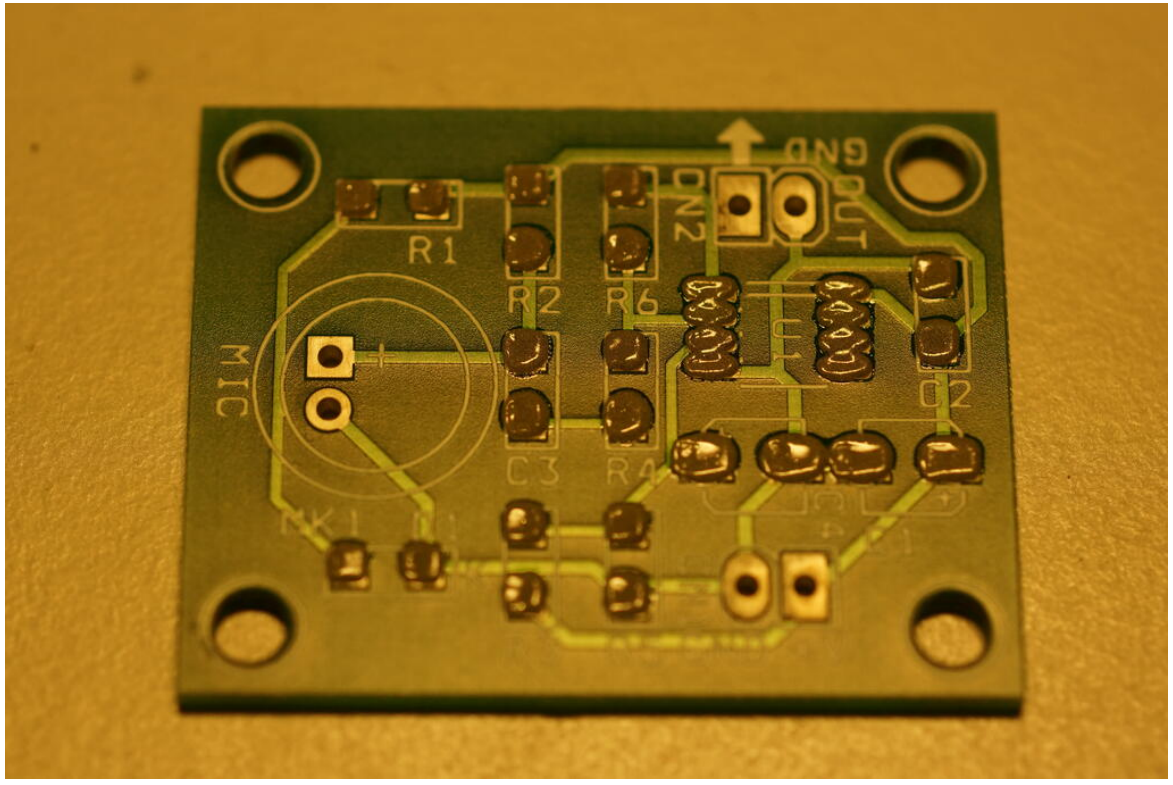


Figure 12: solder paste

Solder paste

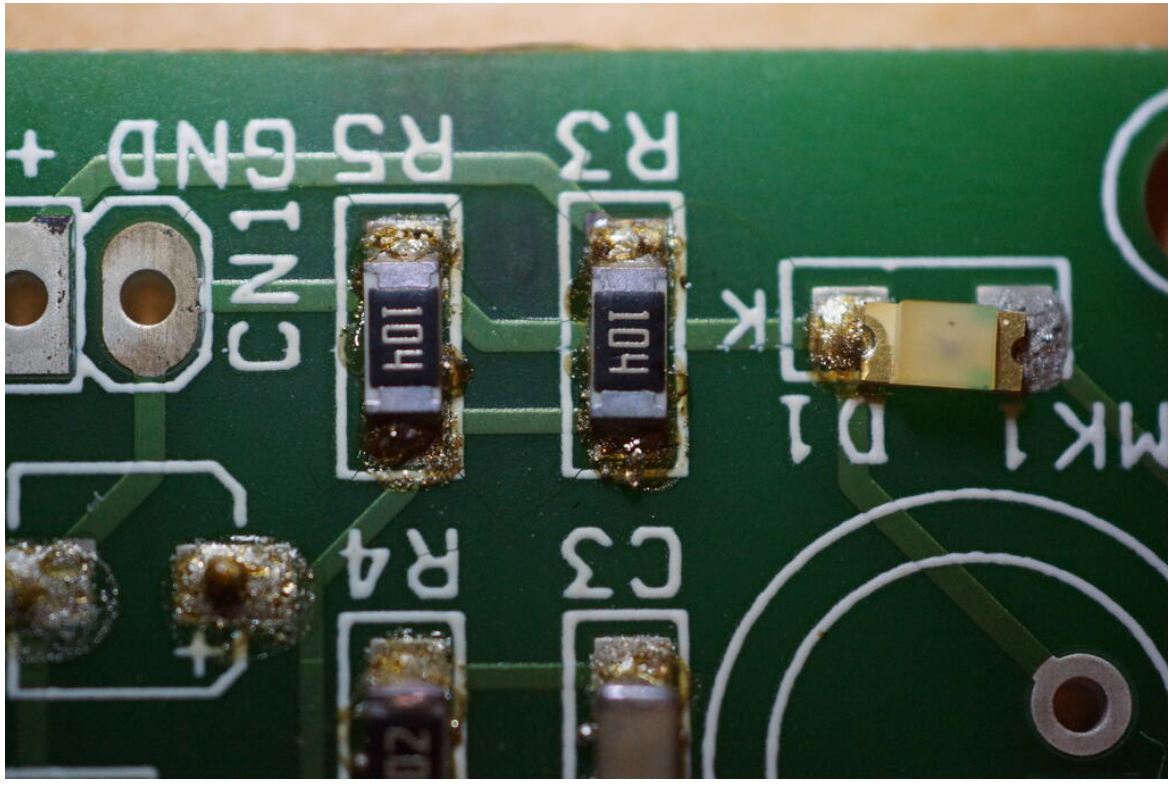


Figure 13: surface mount components soldered with solder paste

Solder paste

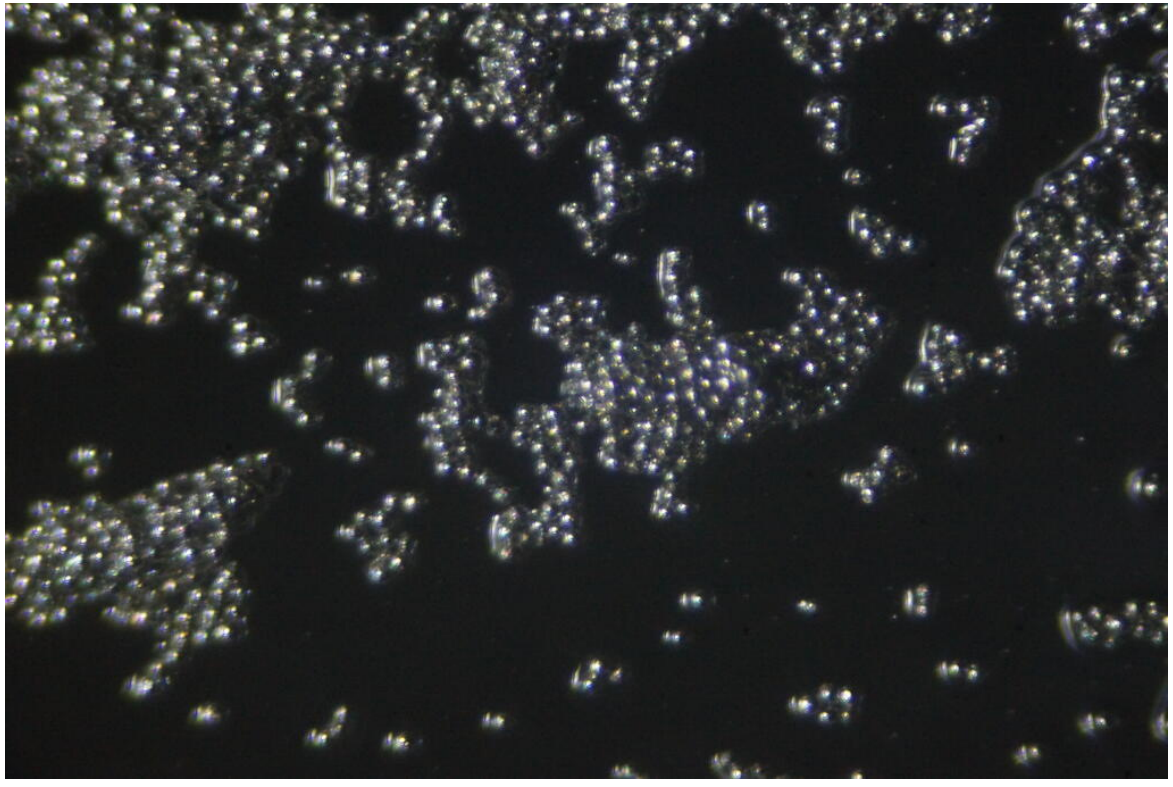


Figure 14: Solder paste under the microscope

Solder paste

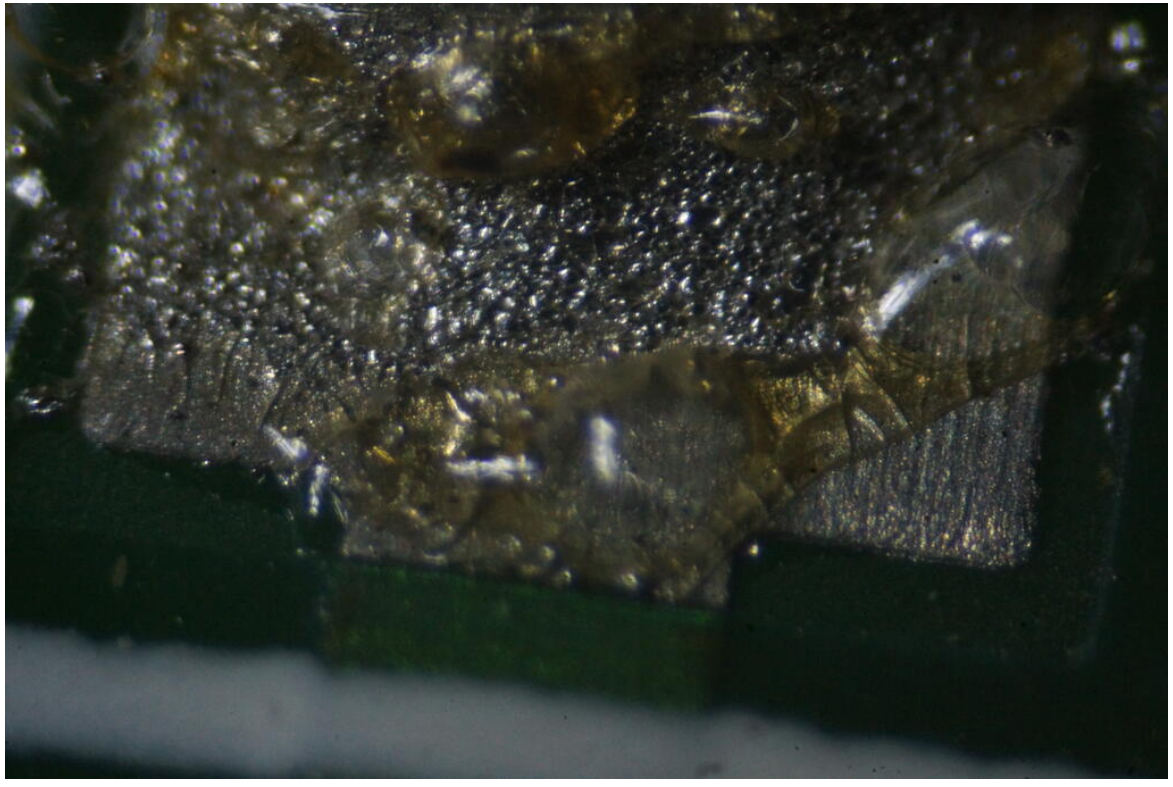


Figure 15: solder paste joint: OK

Solder paste

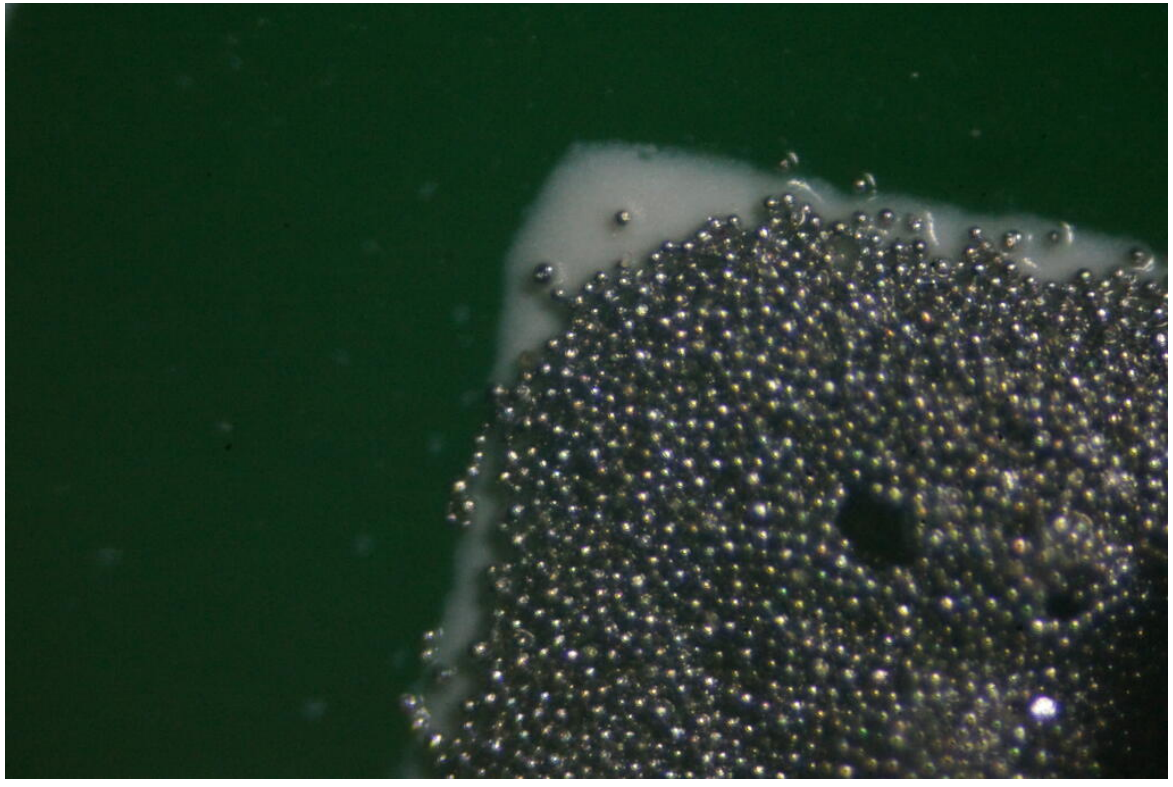


Figure 16: solder paste joint: cold solder

Soldering using a dissection scope

Figure 17: using a microscope for soldering

Hand-soldering surface mount

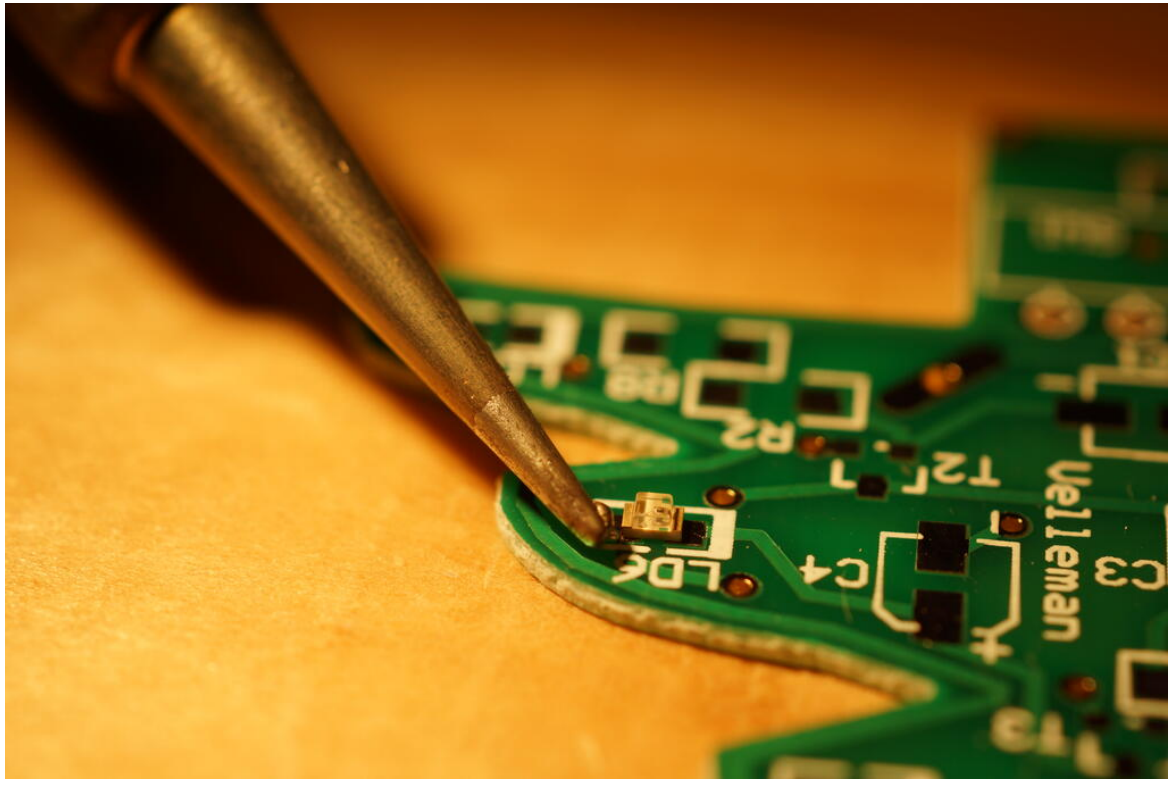


Figure 18: hand solder 01

Hand-soldering surface mount

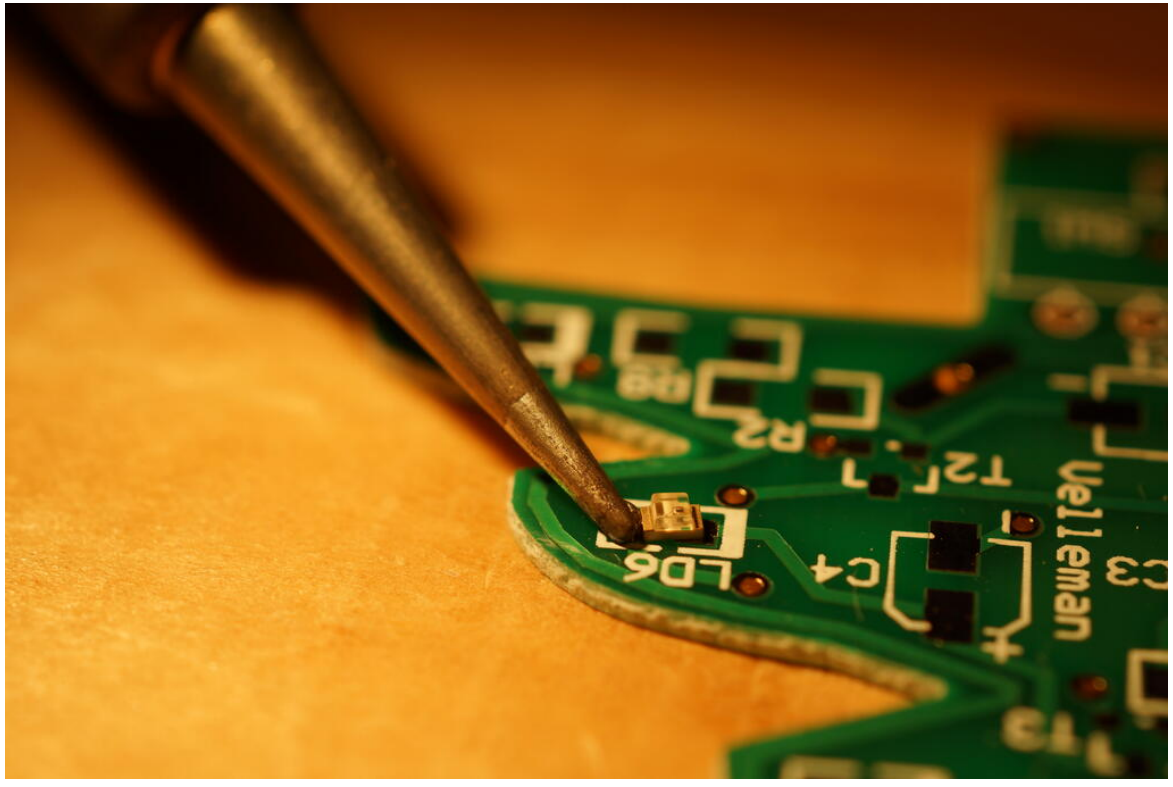


Figure 19: hand solder 02

Hand-soldering surface mount

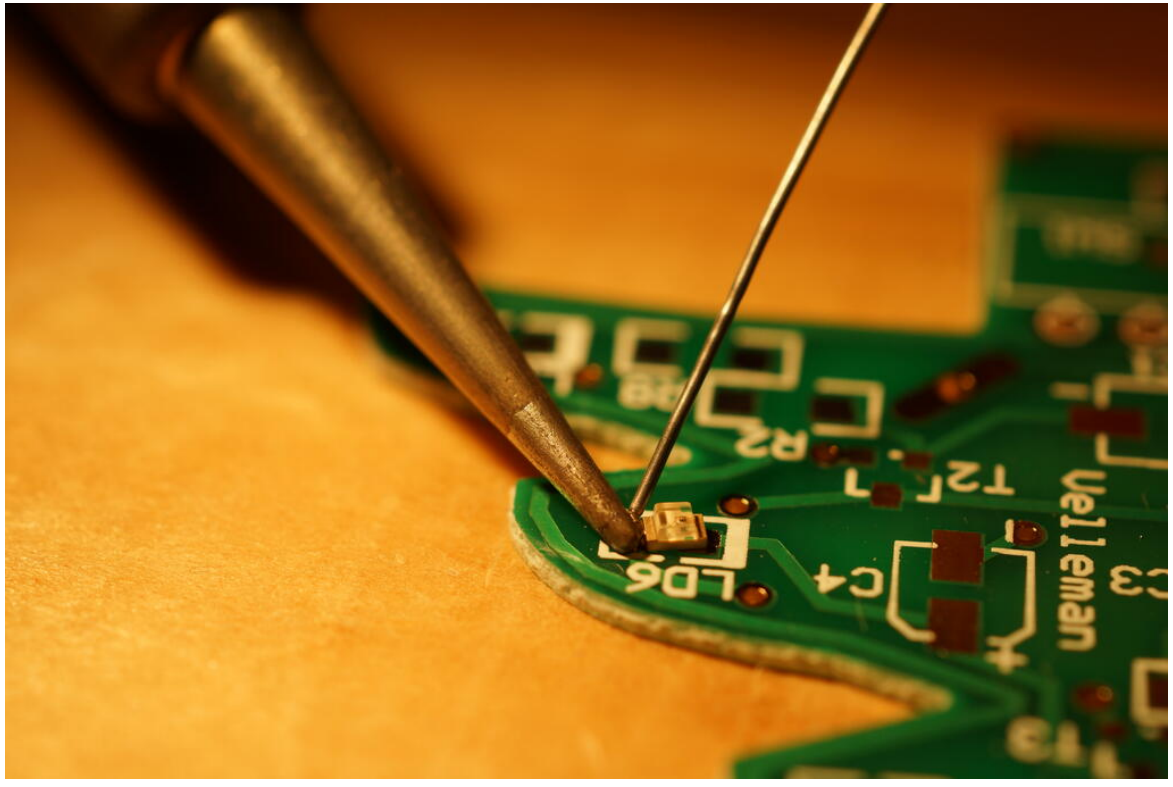


Figure 20: hand solder 03

Hand-soldering surface mount

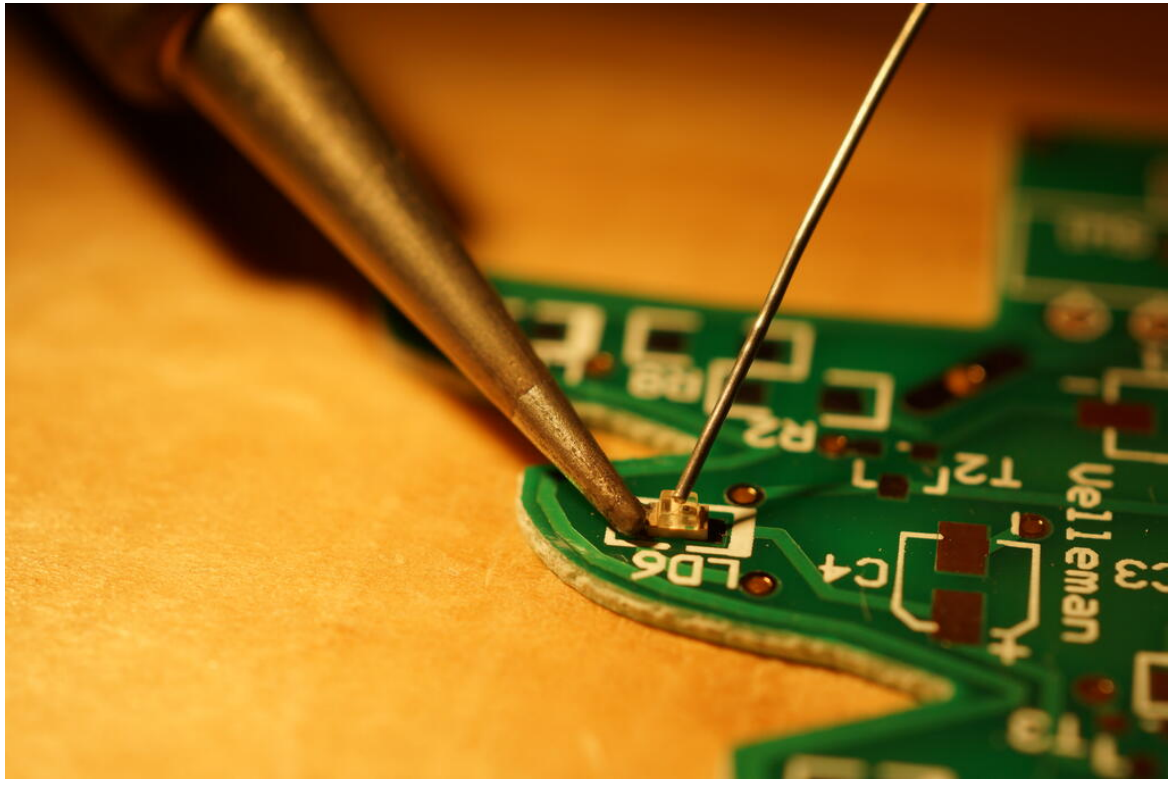


Figure 21: hand solder 04

Hand-soldering surface mount

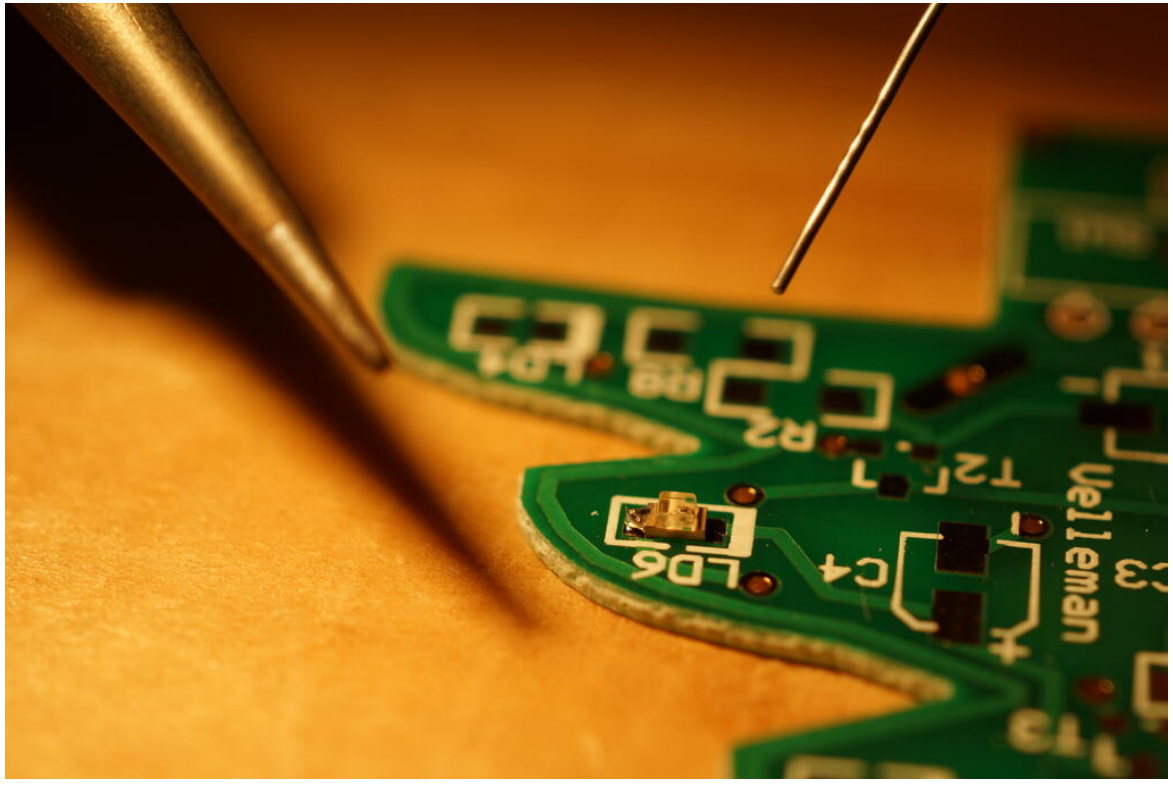


Figure 22: hand solder 05

Hand-soldering surface mount

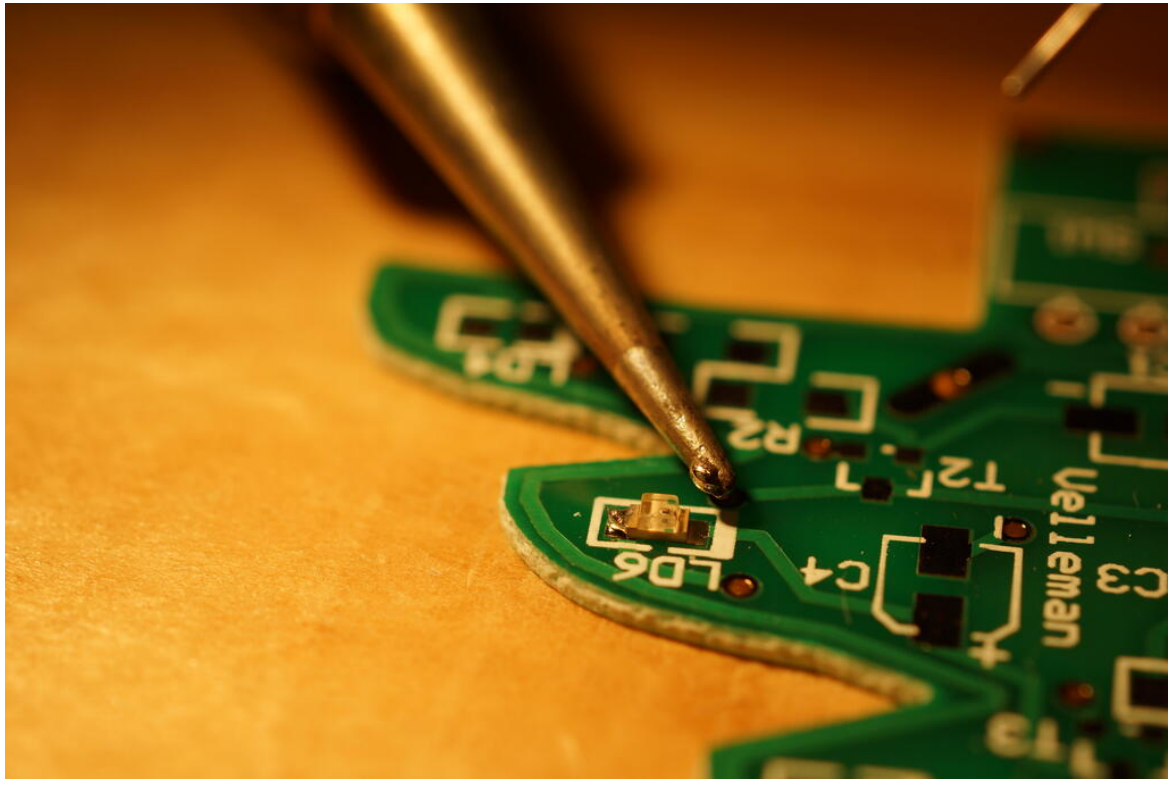


Figure 23: hand solder 06

Hand-soldering surface mount

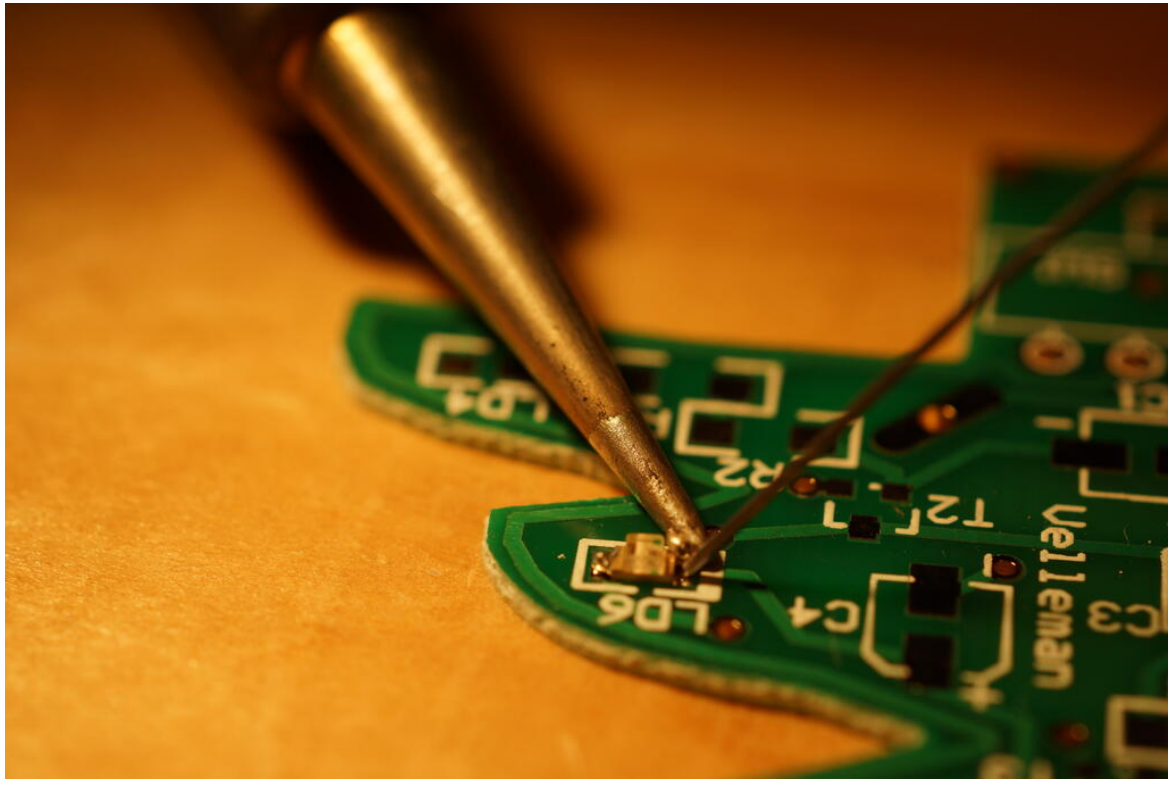


Figure 24: hand solder 07

Hand-soldering surface mount

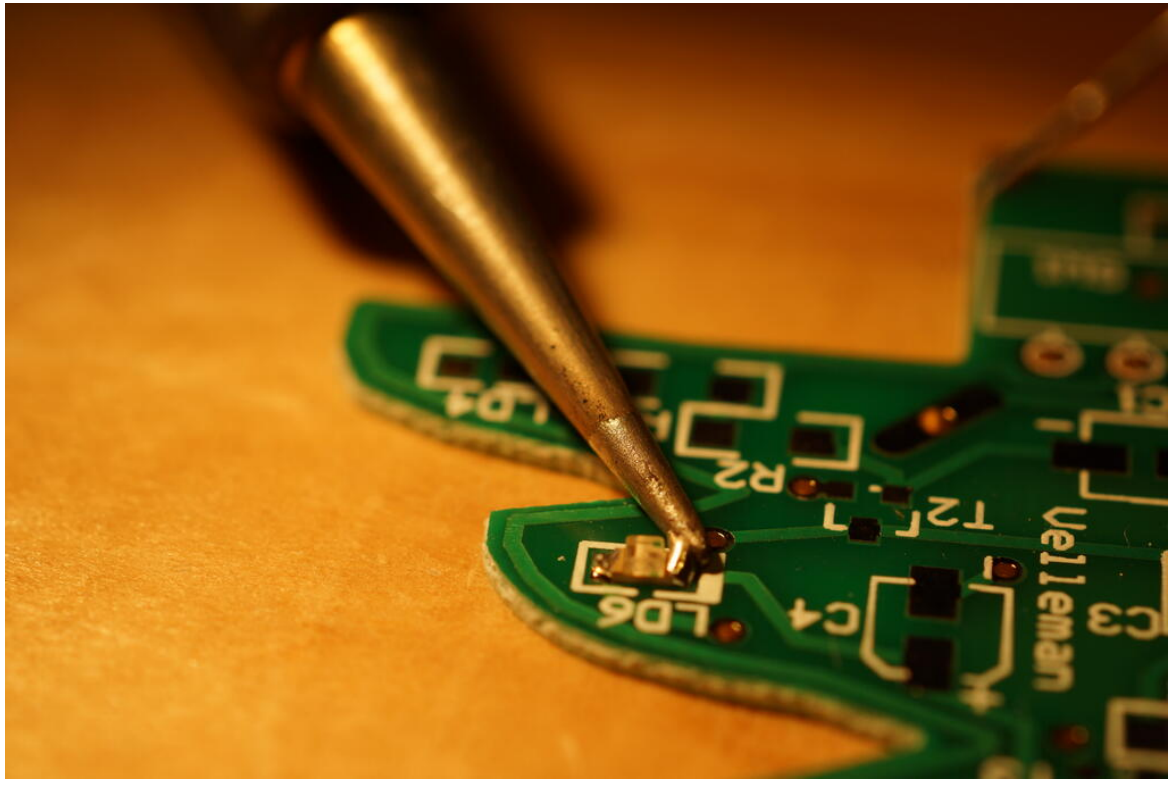


Figure 25: hand solder 08

Hand-soldering surface mount

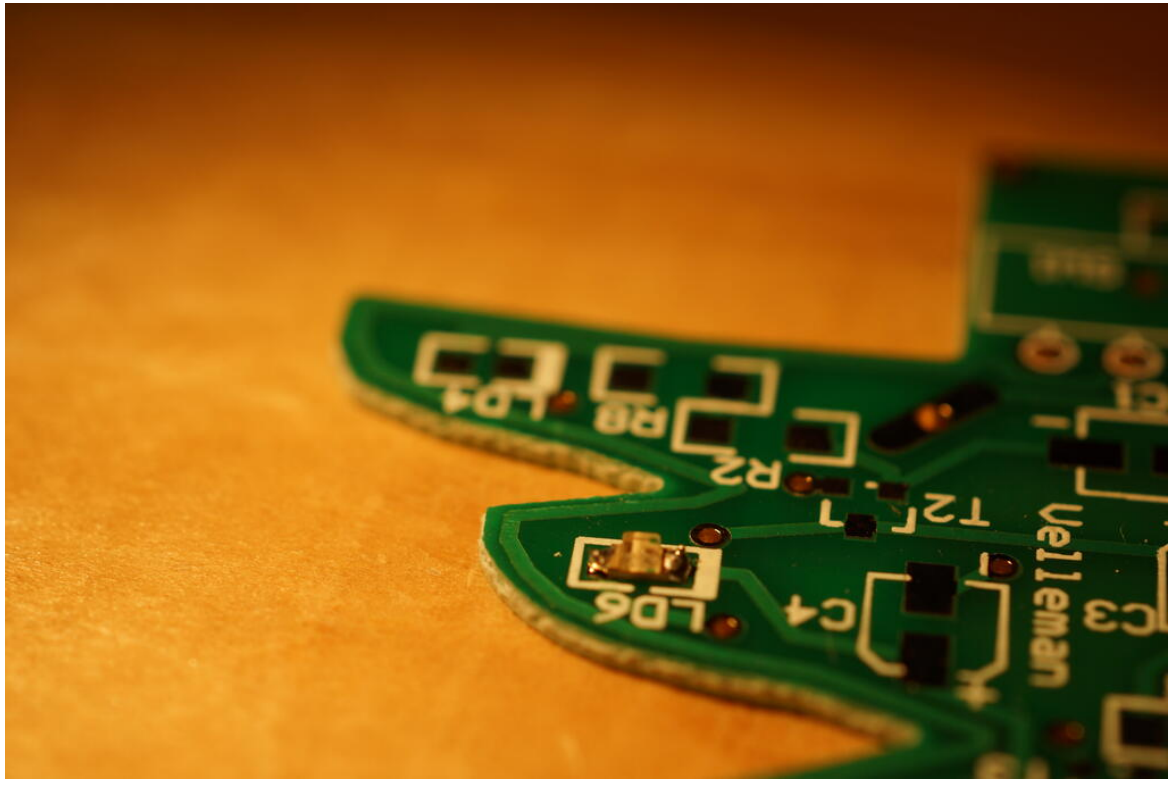


Figure 26: hand solder 09

Hand-soldering surface mount

- The job of a solder joint is to conduct electricity, not to look pretty

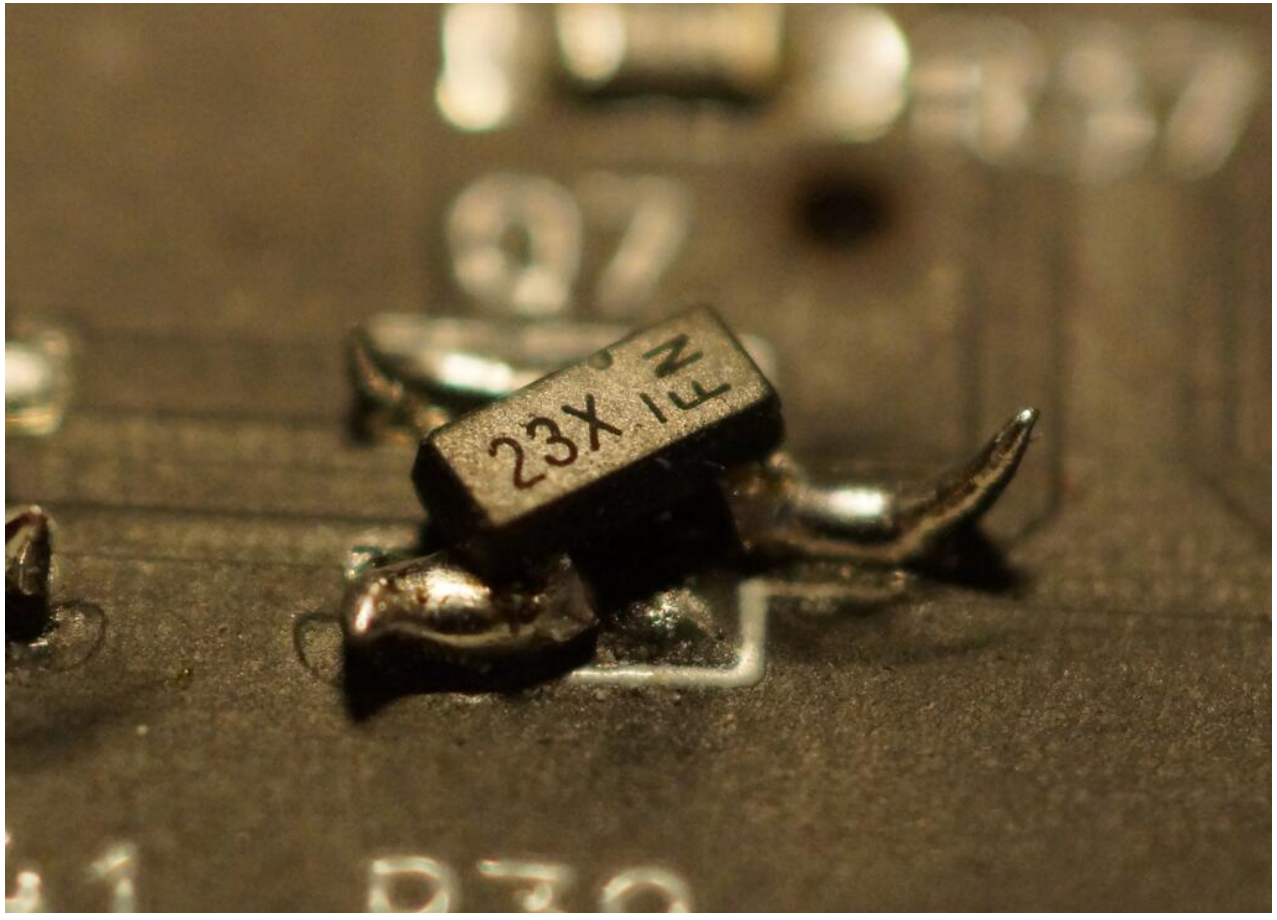


Figure 27: ugly, but works

Hand-soldering surface mount

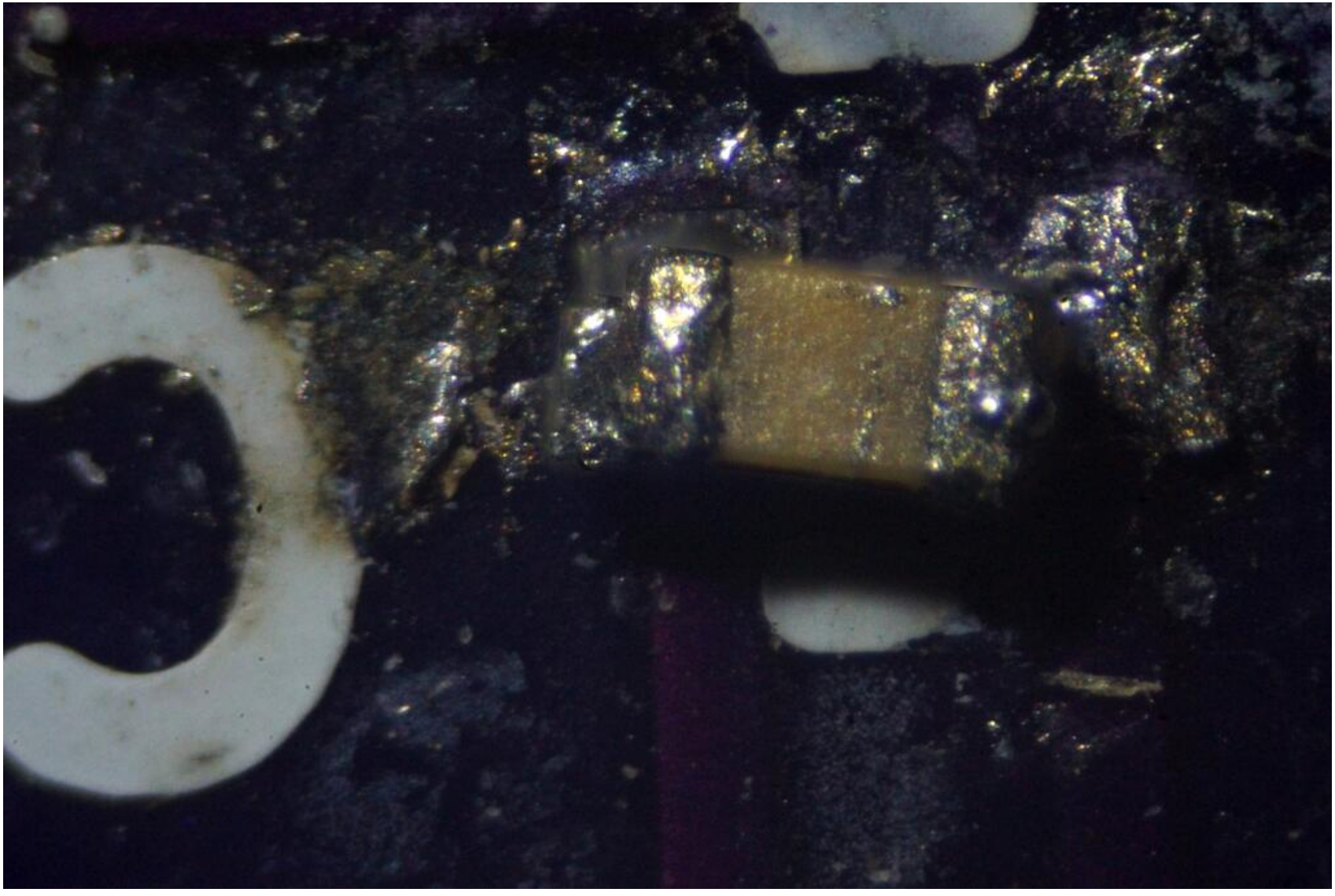
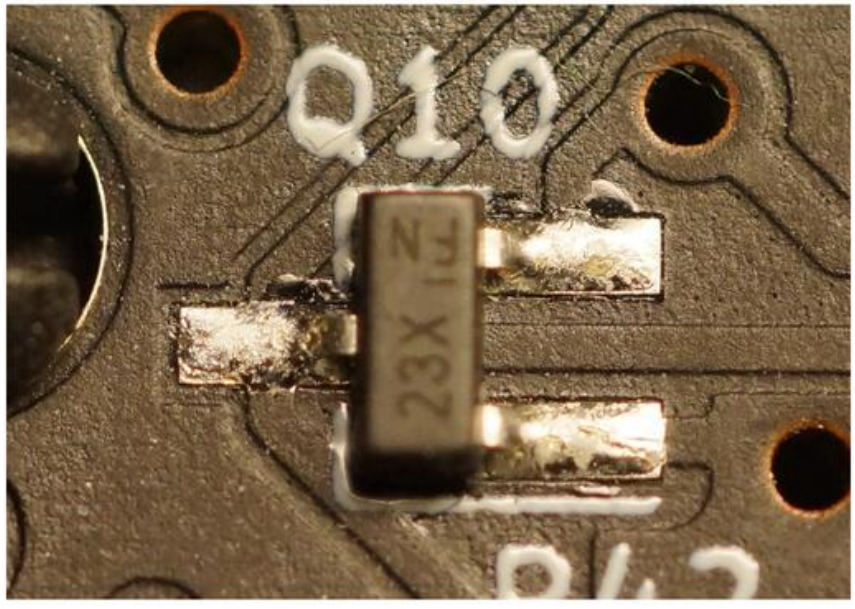
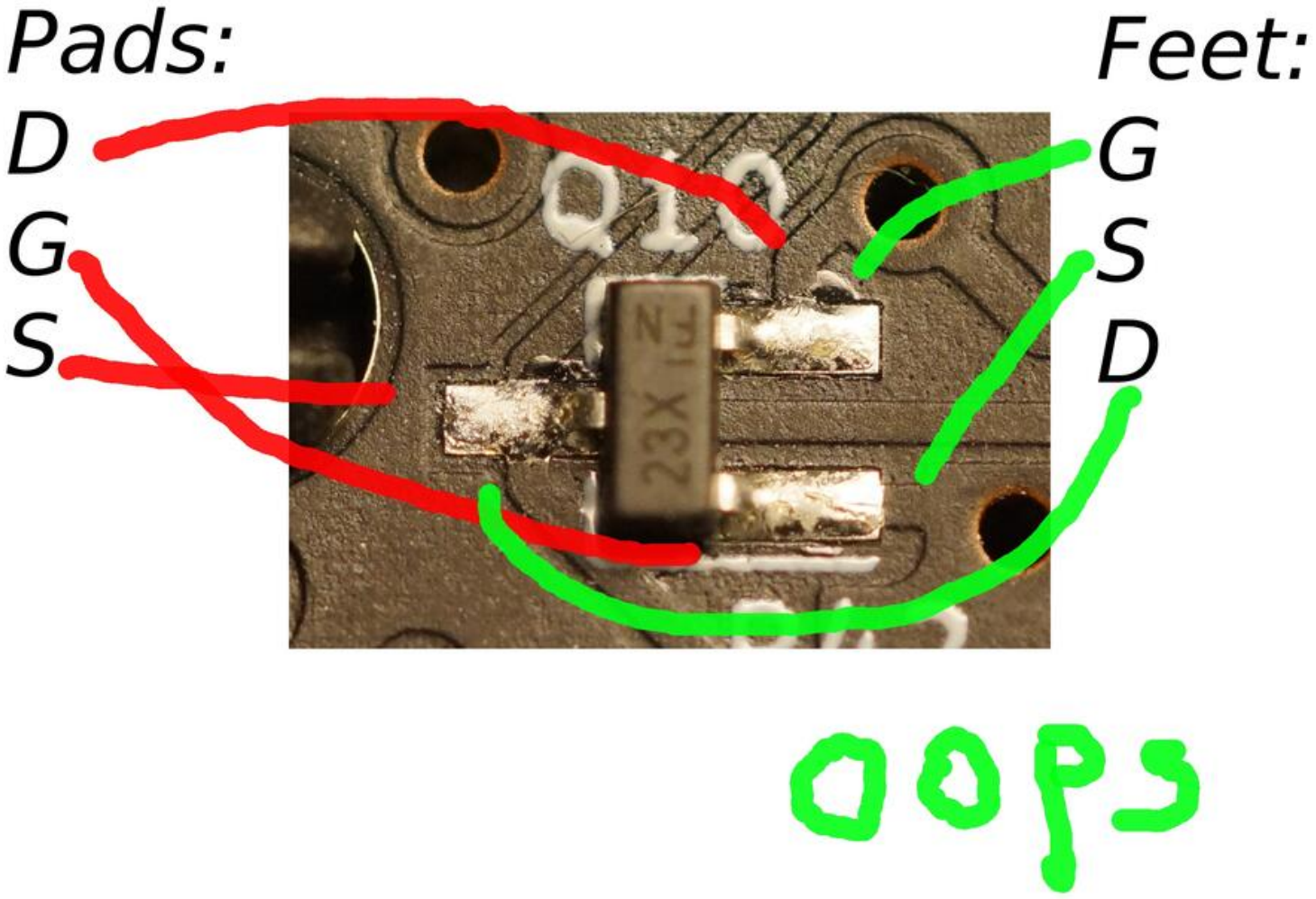


Figure 28: hand-soldered 0201 capacitor

Fixing misteaks



Fixing misteaks



Fixing mistakes

- You will make mistakes. You will be able to fix them.

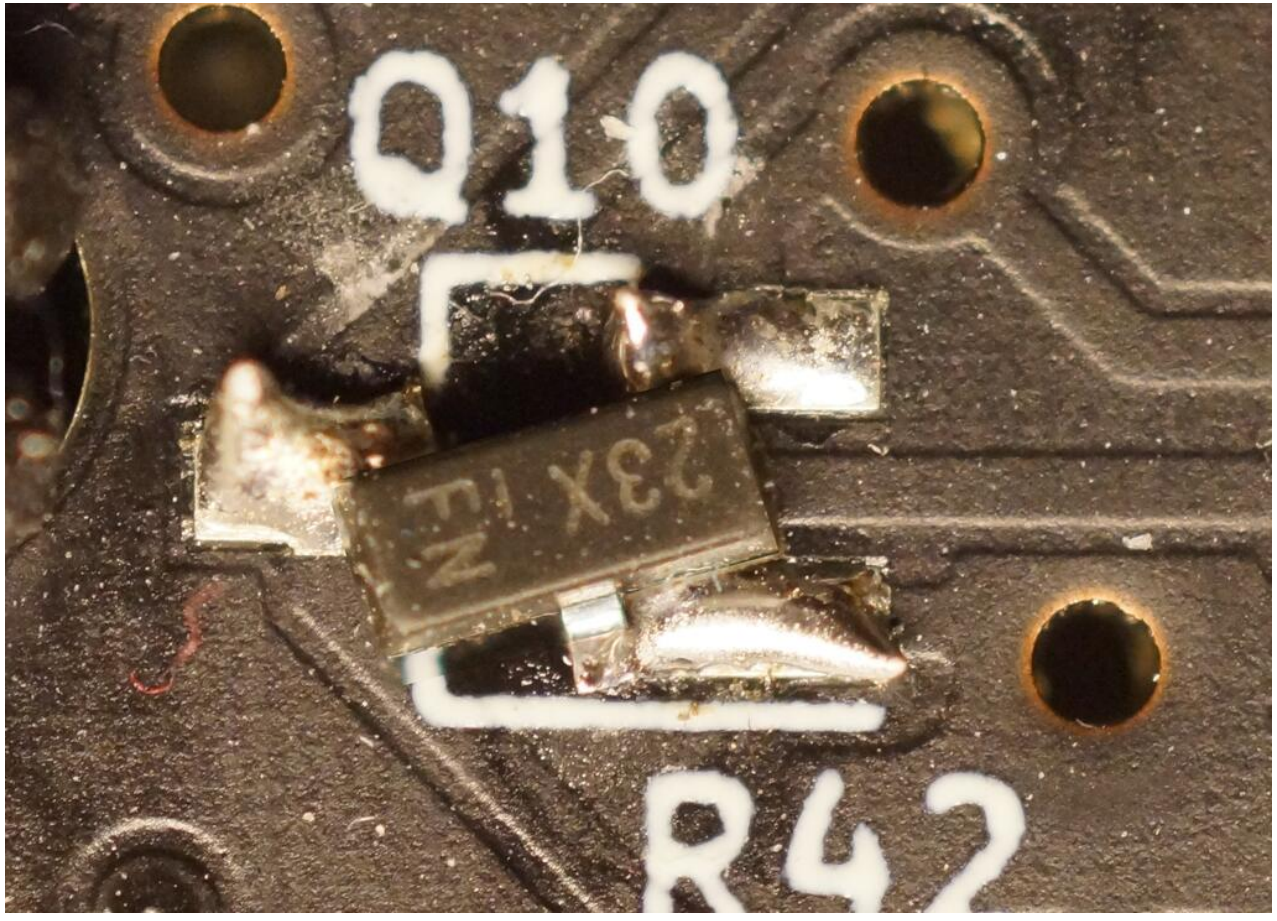


Figure 29: rotated Q10

Fixing mistakes

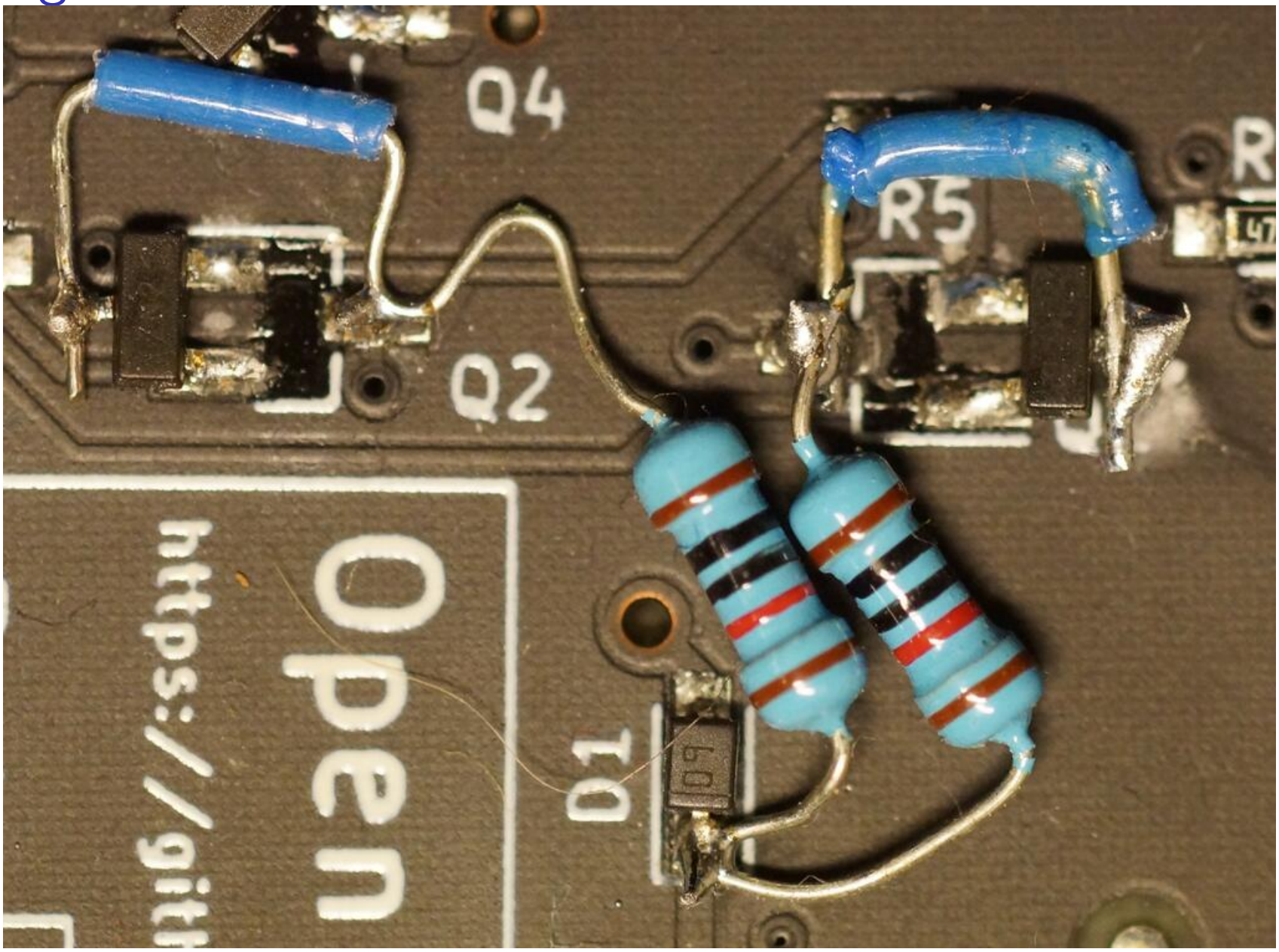


Figure 30: flipped Q1-Q2

Fixing mistakes

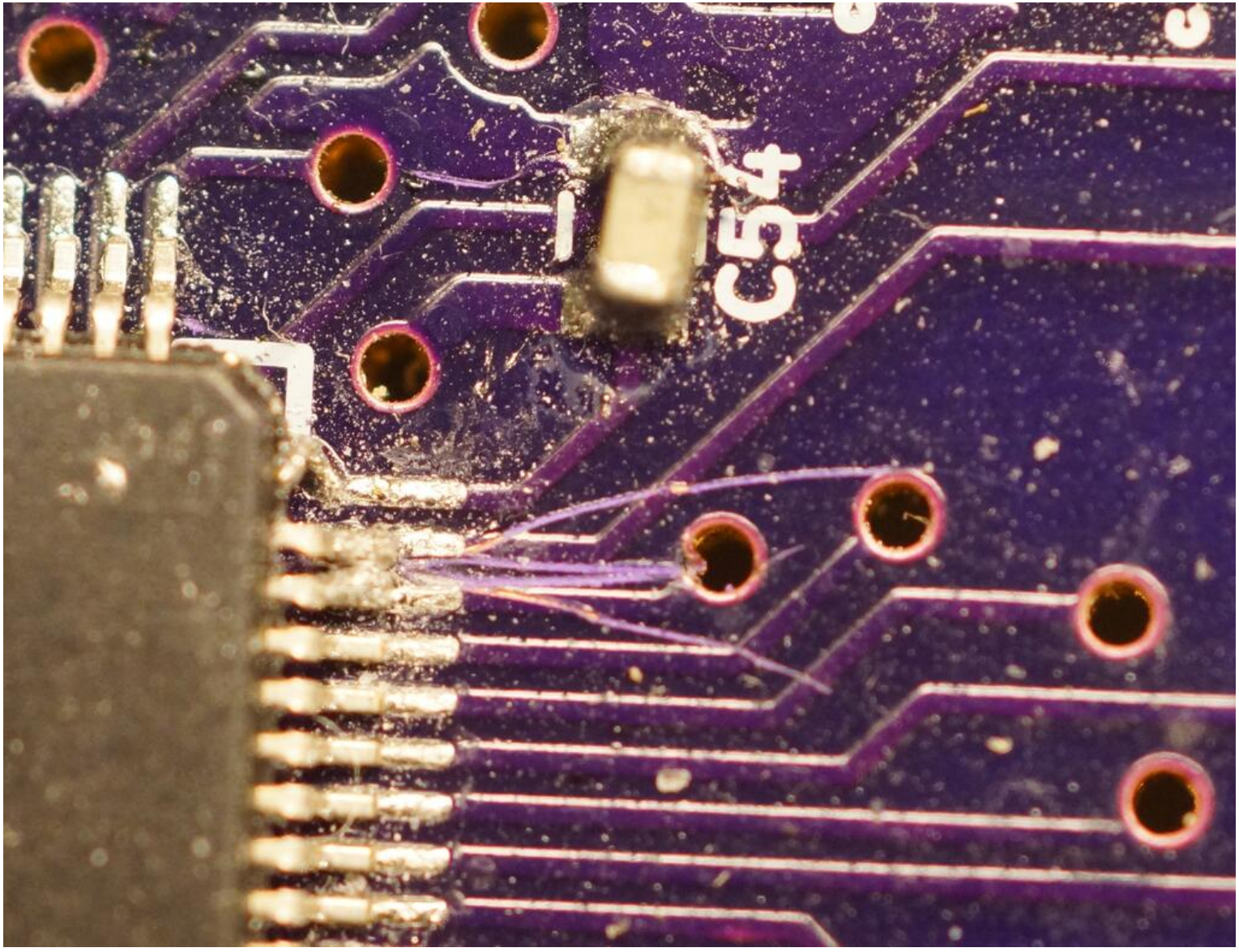


Figure 31: cut traces

Fixing mistakes

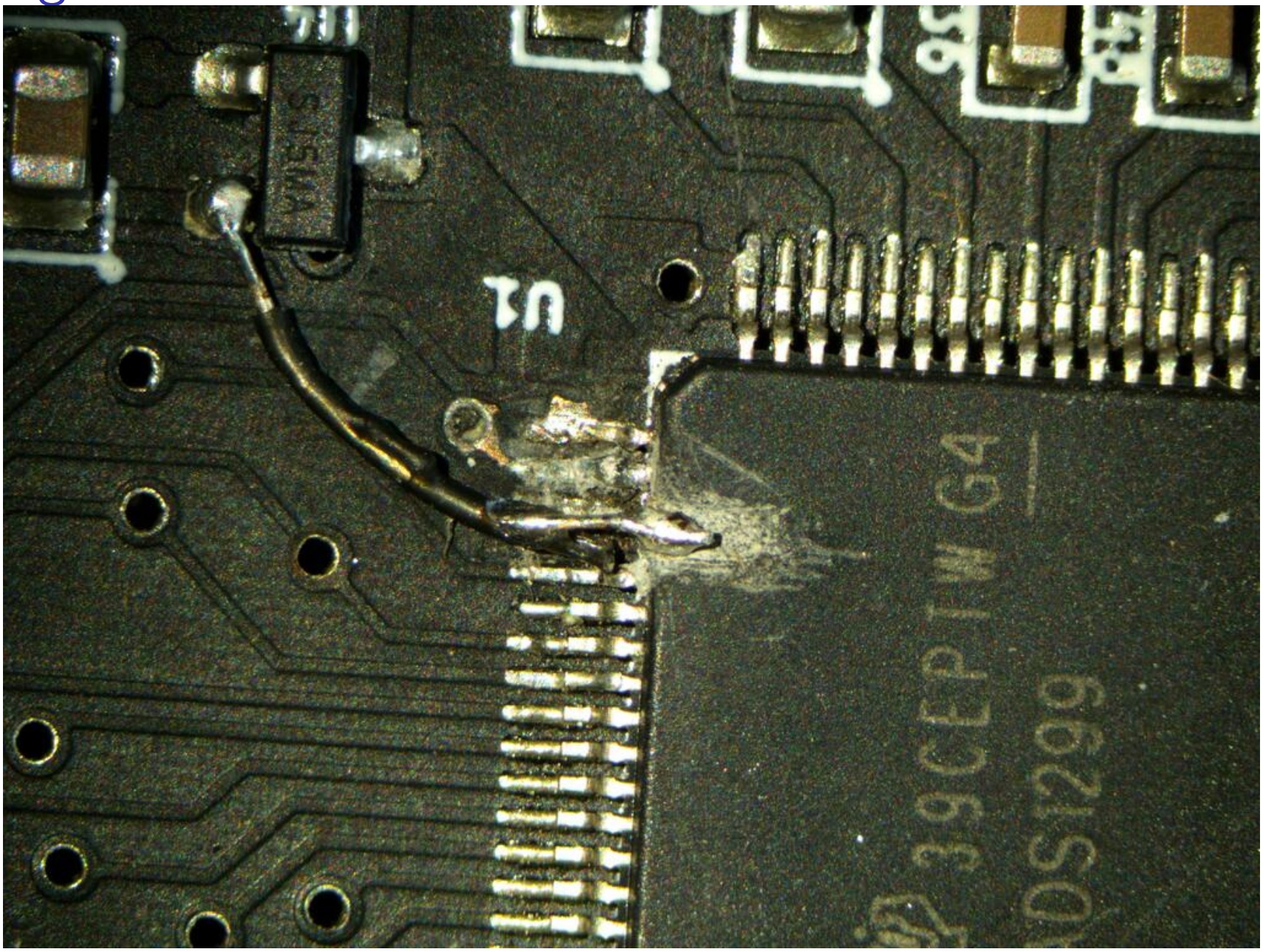


Figure 32: green wire into the chip

Safety is important, and often fairly simple

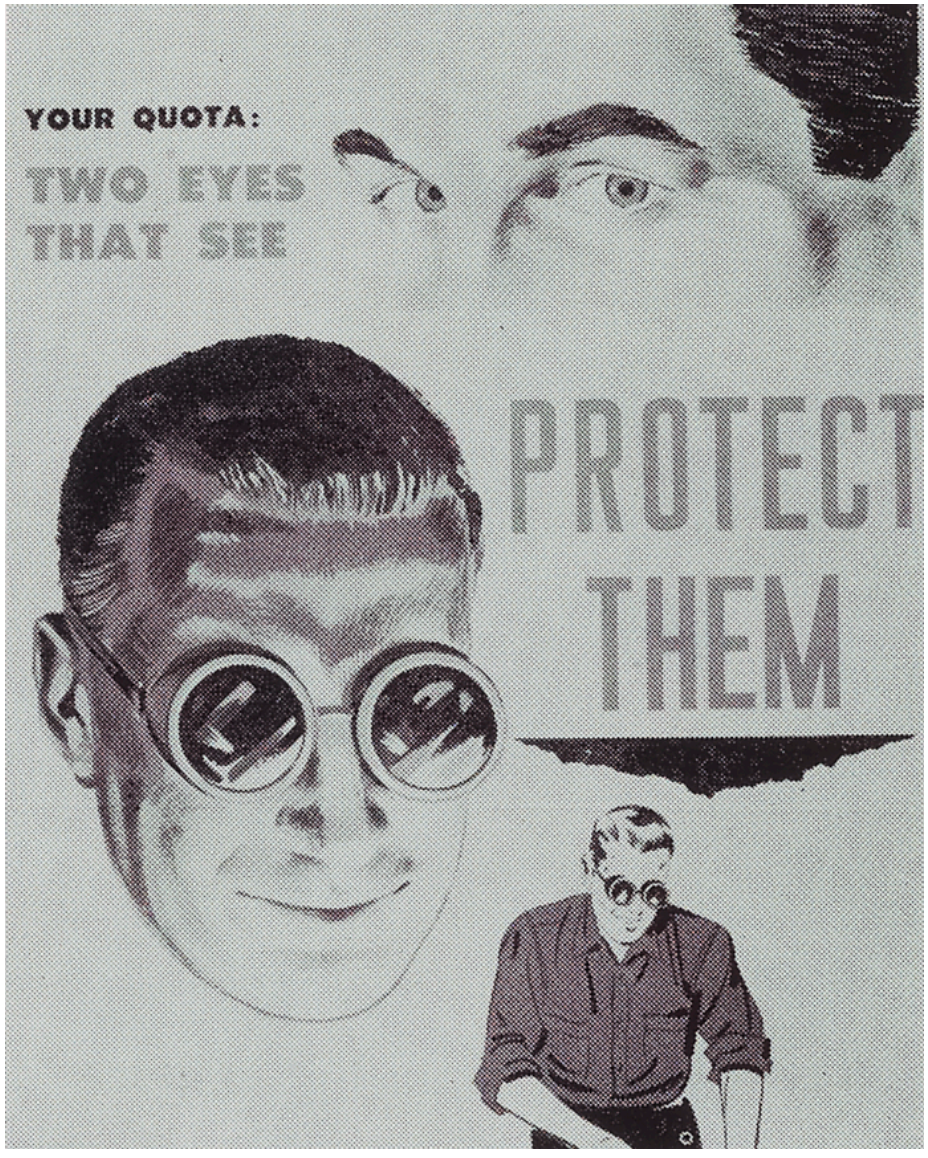


Figure 33: goggles

What could go wrong?

- User error
- Spills
- Power surges
- Hacking
- Drops/falls
- etc.

How serious is it

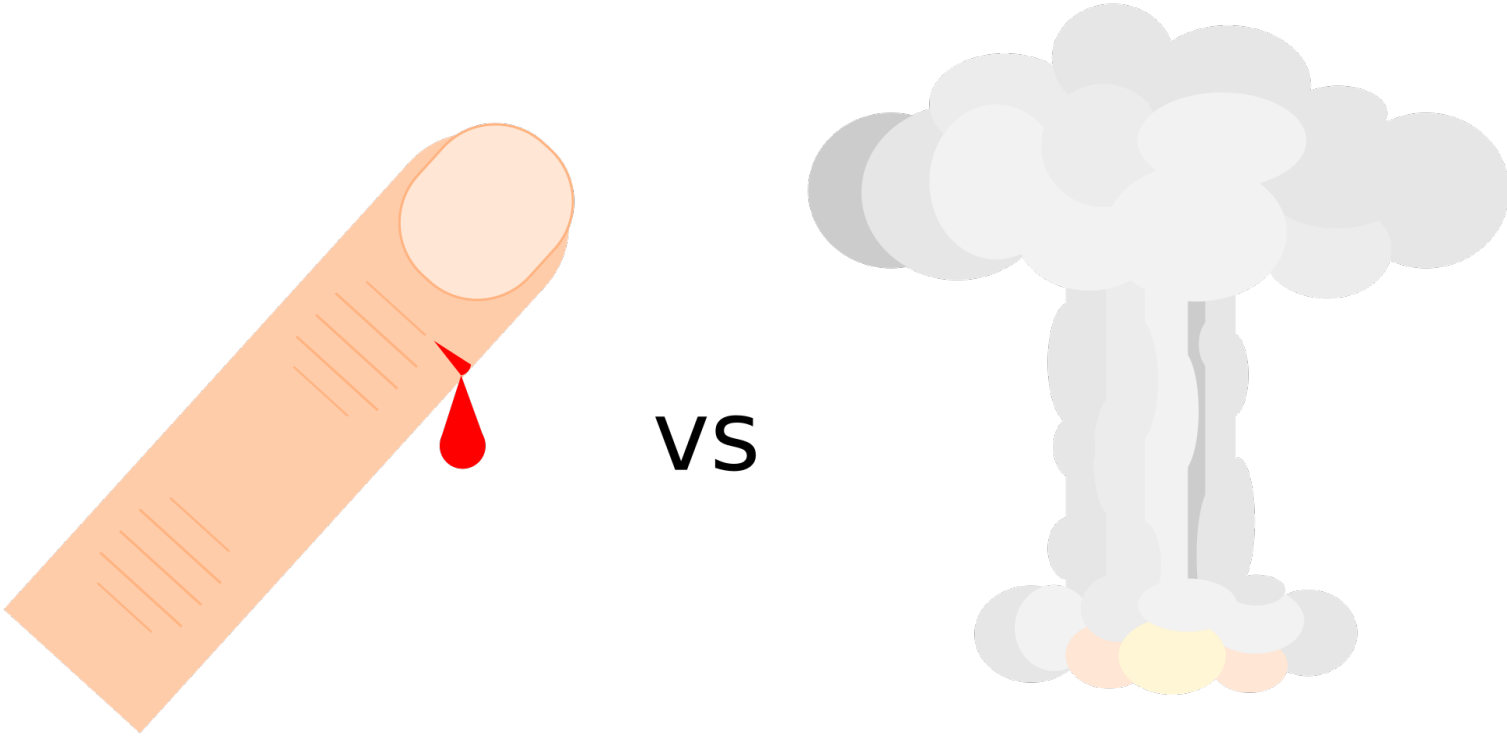


Figure 34: Paper cut vs nuclear explosion

How likely is it

Examples:

- Very likely:
  - user forgets to turn device off overnight
  - device dropped from 1 meter above ground
- Very unlikely:
  - user starves while using device because they forgot to eat
  - device dropped out of airplane

Risk

Risk = Severity of harm * Probability of harm

(e.g. ISO 14971)

Acceptable risk

Acceptable risk varies by circumstance

Figure 35: free climber [1]

[1] Image by Heinz Hummel from Pixabay, Pixabay license

Mitigation

Decrease the risk of the event

- example: remove internet connectivity from a device to make it less likely to be hacked

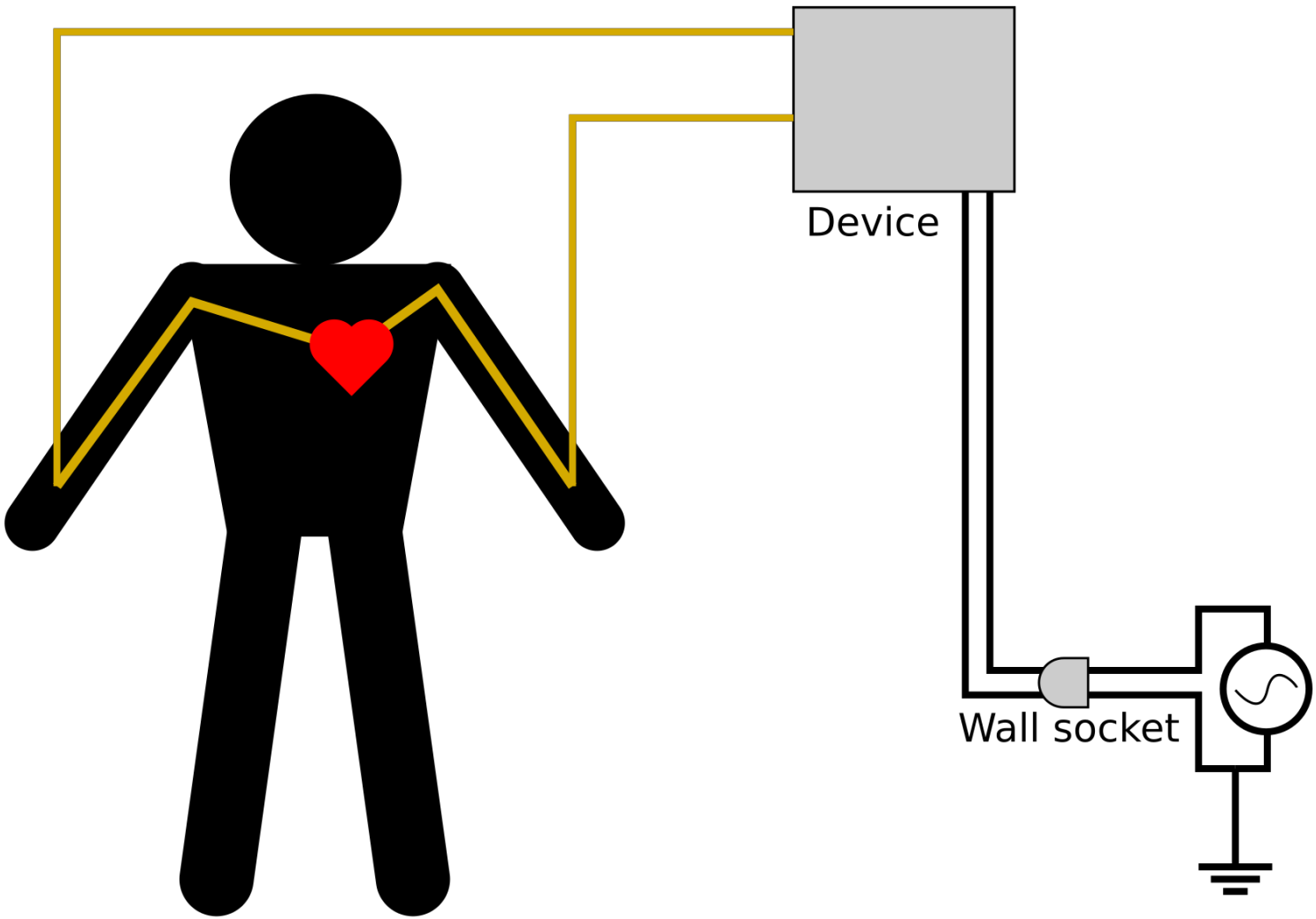
Decrease the severity of the event

- example: add a disconnection alarm to a ventilator so it fails loudly rather than quietly if it is accidentally disconnected from the patient

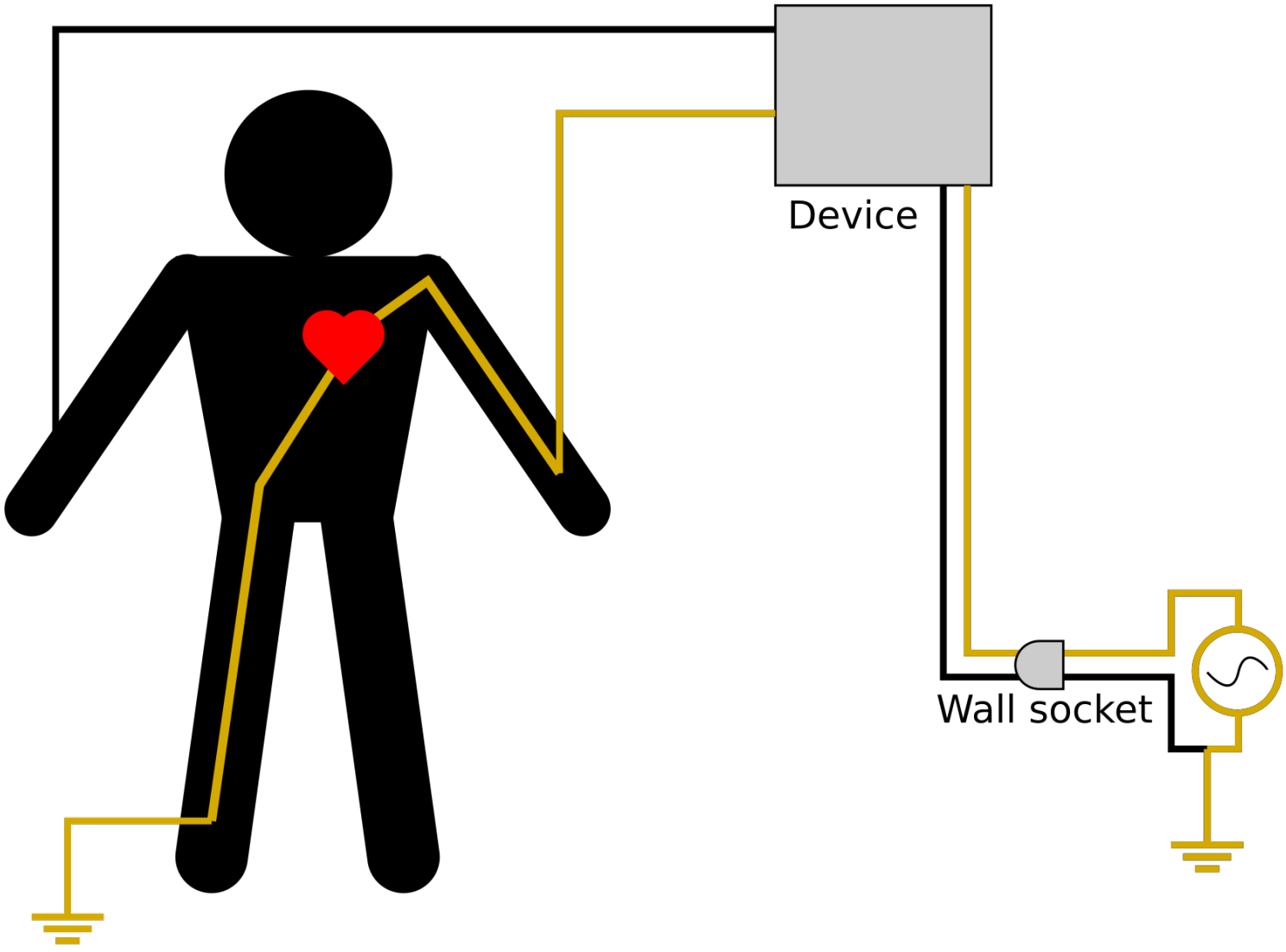
Example: Risk of electrical shock

- Small currents can be dangerous when crossing the heart
- Current rather than voltage
  - Pacemaker voltages (~2 volts)
  - Minimum fibrilation currents
    - 10s of milliamps through skin
    - 10s of microamps at the heart
  - Resistances can be very low in a medical context
    - central lines, surgery, etc.
- Probability may be low, but severity can be high

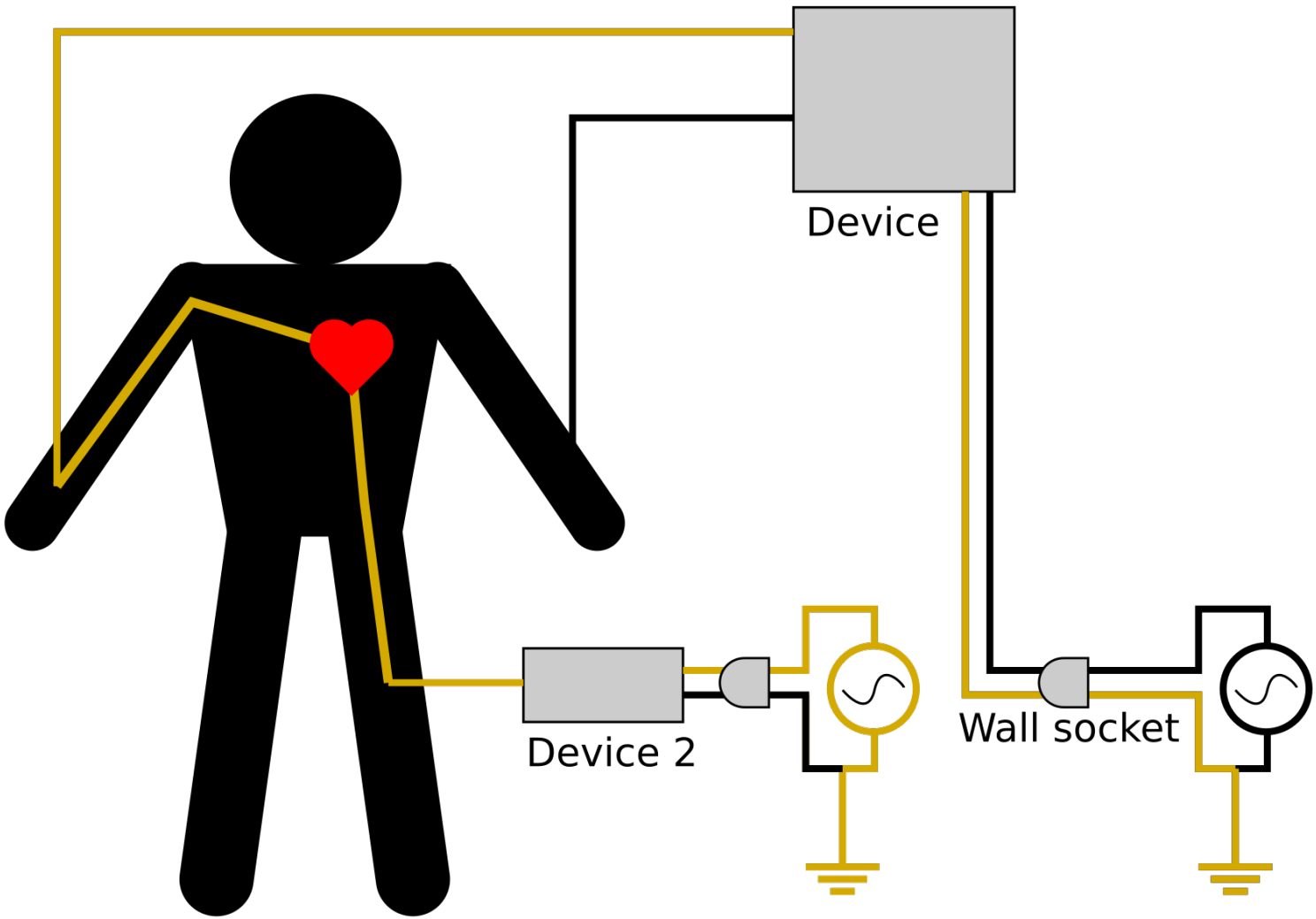
Risk of shock between electrodes



Risk of shock between device and ground

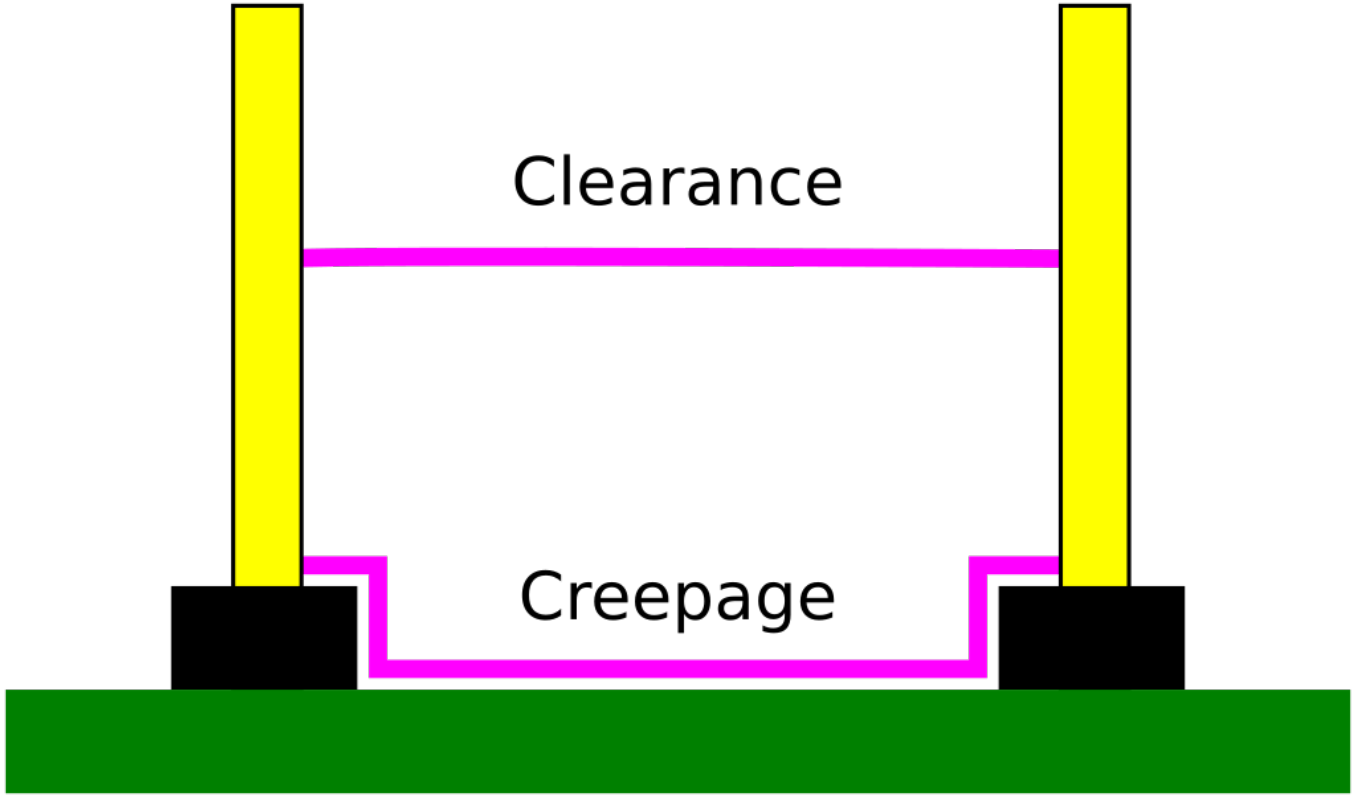


Risk of shock between devices



Example Mitigation: Isolation

- Batteries (Safety Extra Low Voltage, or SELV)
  - e.g.: unplugged laptop
- Creepage and clearance



- Power isolation
- Data isolation

Leakage current standards

Leakage Current	Body	Body Floating	Cardiac Floating
Earth	500 μA	500 μA	500 μA
Enclosure	100 μA	100 μA	100 μA
Patient	100 μA	100 μA	10 μA

- Note that these are very low currents
- Can only be 2-5 times larger even if component fails

Designing for failures

- Safe if any one component fails
- 2 means of patient protection
  - two layers of basic isolation vs. reinforced isolation
- Current limiting resistors on patient connections

Take home message

- a little thought about safety goes a long way
- great tools and resources to support you
- don't be too intimidated
  - try
  - repeat
  - you'll improve as you go
- happy hardware hacking!

References and Contacts

- Tools
  - https://www.arduino.cc/
  - https://kicad-pcb.org/
  - https://www.openscad.org/
- Books
  - The Art of Electronics, Horowitz and Hill
  - Medical Instrumentation Aplication and Design, Webster
- SMD Soldering technique videos
  - https://www.youtube.com/watch?v=eg2hxpy–gg
  - https://www.youtube.com/watch?v=JKqgU2Hw3mY
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  - ace.medlock@gmail.com
  - kms15@case.edu