Essentials of PCB Design

02: Project Design

WPI A25 | Daniel Gorbunov, William Sobral

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about this class

schedule

A-Term

Tue, Sep. 23	Basics of PCBs **6-7PM; AK 233**
Thur, Sep. 25	Designing your Project **6-7:30PM; AK 233**
Tue, Sep. 30	Layout + Routing **6-7:30PM; AK 233**
Thur, Oct. 2	Working with KiCad **6-7:30PM; AK 233**

B-Term

Mon, Oct. 20 - Fri, Oct. 24	Office Hours **TBD**
Fri, Oct. 24	Boards Due **By 11:59PM**
Tue, Nov. 4 (tentative)	Assembly **TBD**

course tracks

choose one!

Track 1

Recommended if you've never designed a PCB.

Use the class LED board schematic. Lay out the PCB with your own design, and we'll help you add any extra peripherals/features.

Track 2

You've designed a PCB before, and have extensive circuit design experience.

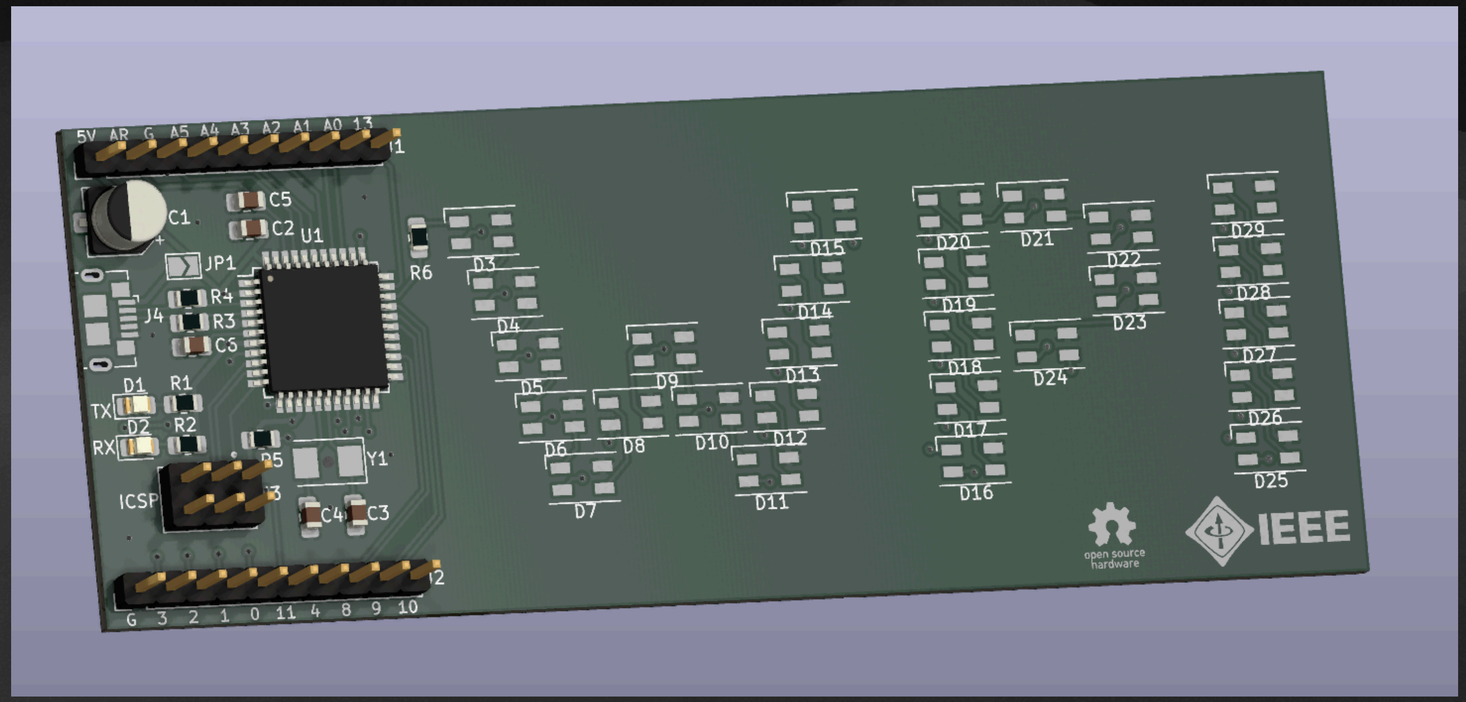
Design your own schematic and board, up to 102x102mm, and we'll fund it + up to $10 in components.

track 1 board

A simple embedded system.

You'll layout the entire board, including a custom LED pattern, and peripherals of your choosing.

You'll program an LED pattern in C++ (we'll provide starter code).



We will do our best to help you!

lecture 1 recap

the basics

- Lecture 1 covered basics of PCBs
- Today we'll cover the first two steps of PCB design:

  1. Research and Design

  2. Schematic Capture

lecture 2

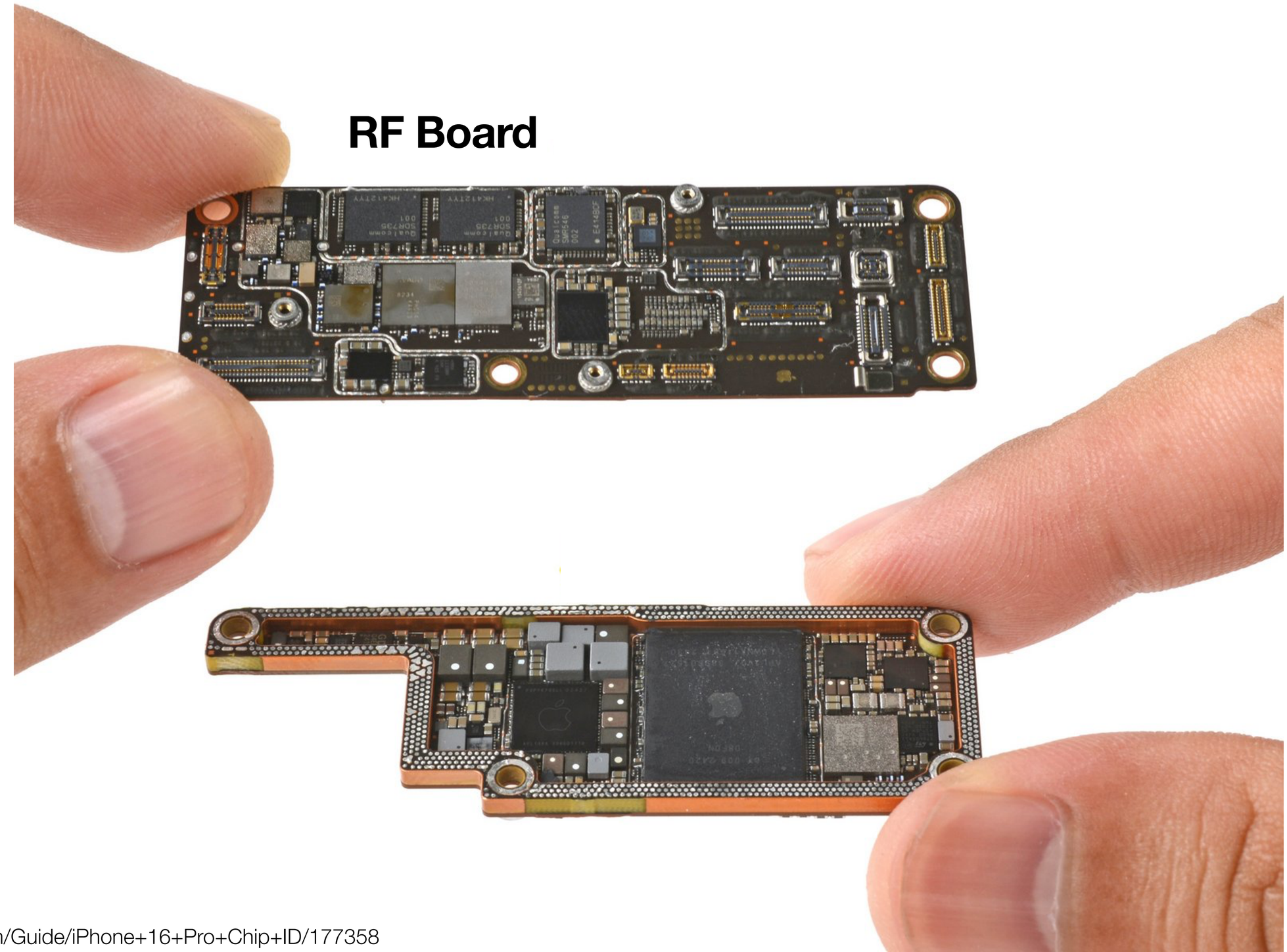
goals

- We’ll show you a variety of personal projects
- We want you to understand how to approach building custom hardware
- This is not a skill you learn in college or at a job

- **It requires ideation, research, and motivation.**

Some really cool PCBs…

RF Board



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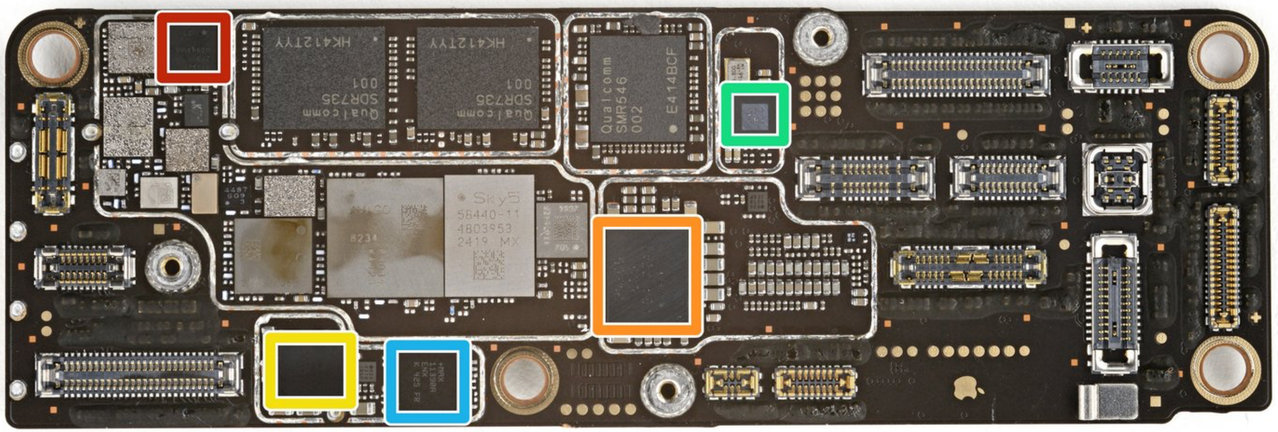
RF Board (Top)



- STMicroelectronics eSIM/secure element
- Qualcomm power management
- Cirrus Logic audio amplifier
- Qualcomm clock generator
- Analog Devices analog to digital converter
- Everything else: RF magic

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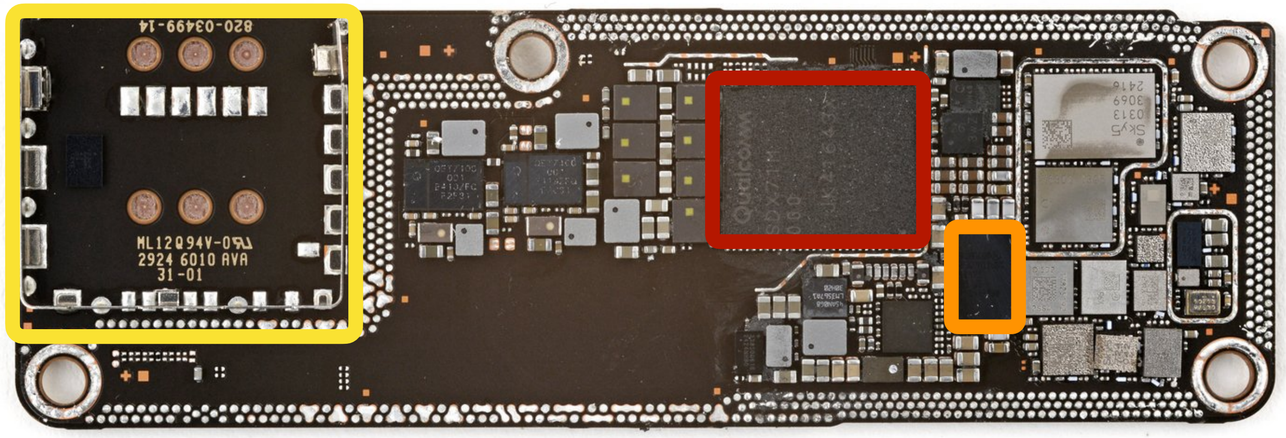
RF Board (Bottom)



- **Qualcomm modem**
- **Broadcom wireless charging controller**
- **Sim card tray (non-US)**

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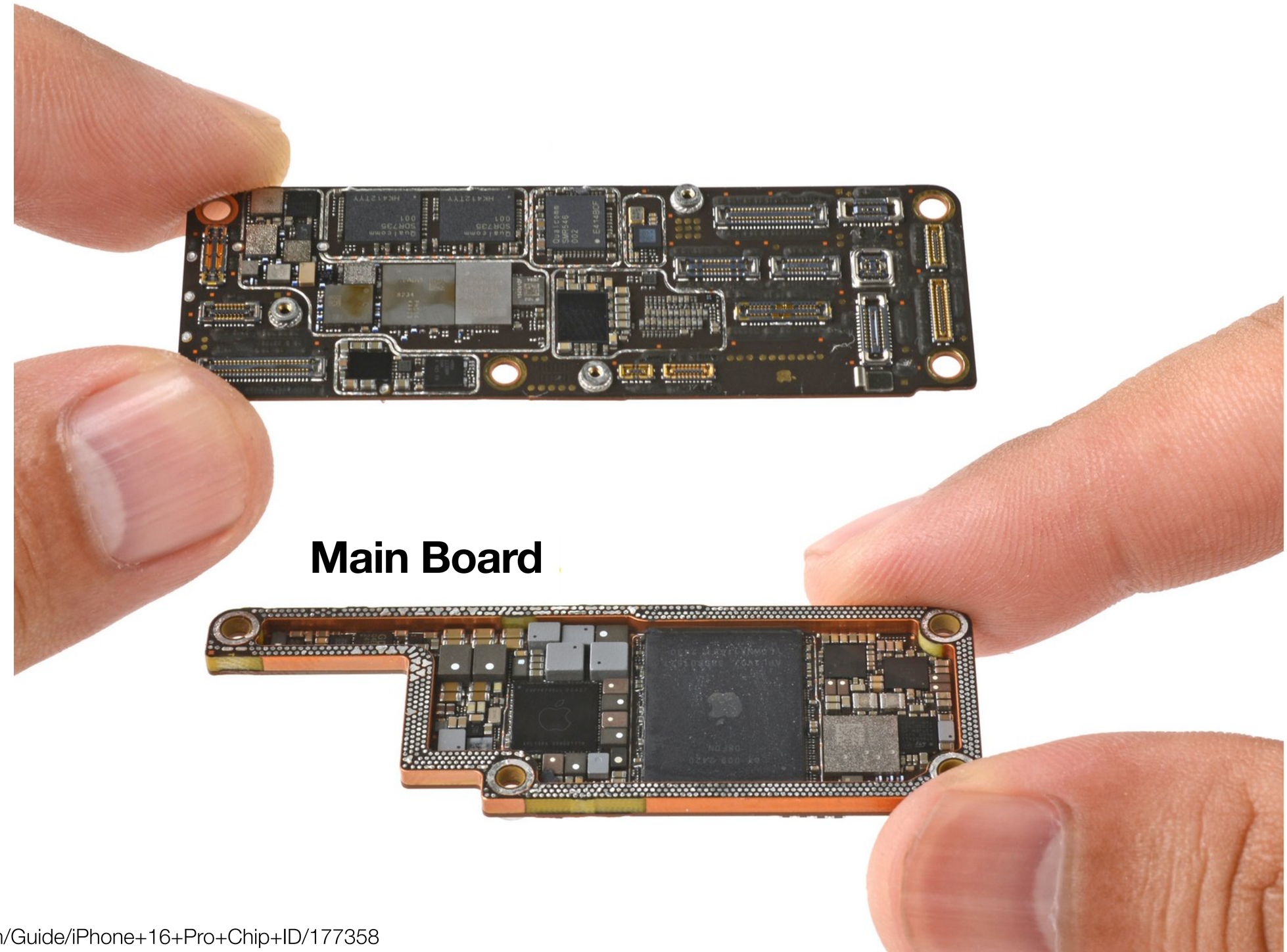

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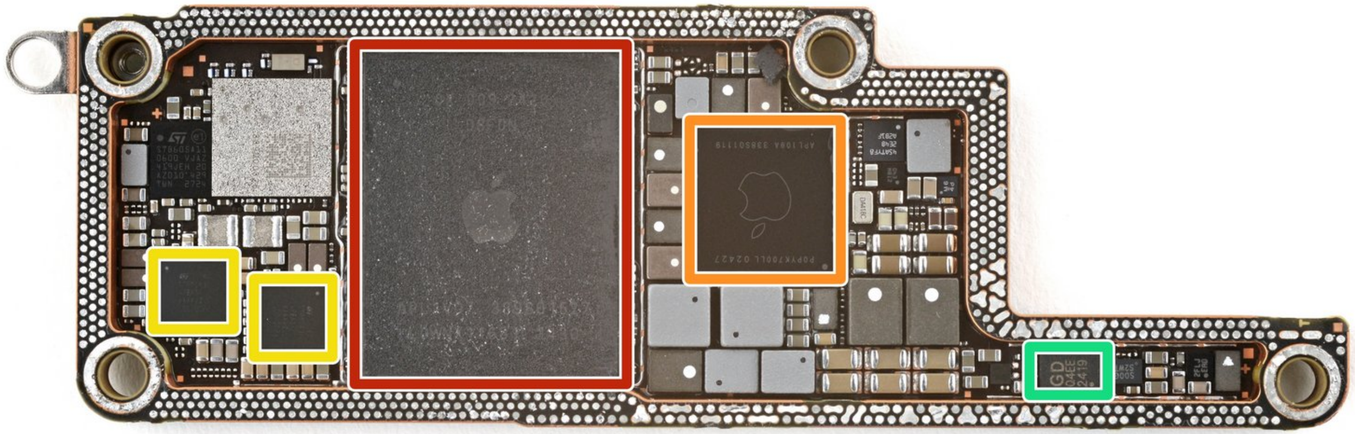
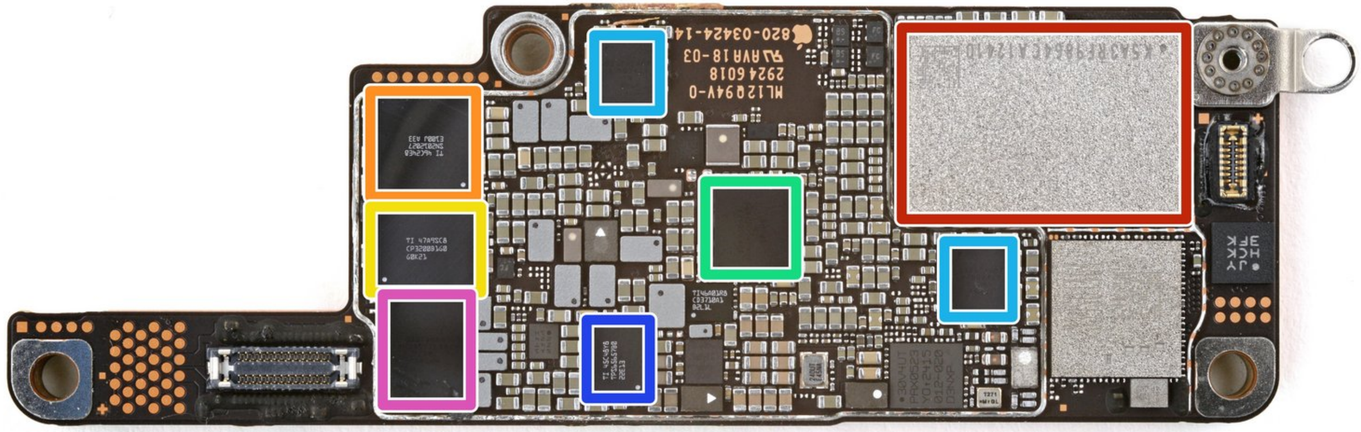
Main Board (Top)



- Apple A18 Pro SoC
- Apple power management
- STMicroelectronics power management
- GigaDevice 1MB flash memory

https://www.ifixit.com/Guide/iPhone+16+Pro+Chip+ID/177358

Main Board (Bottom)



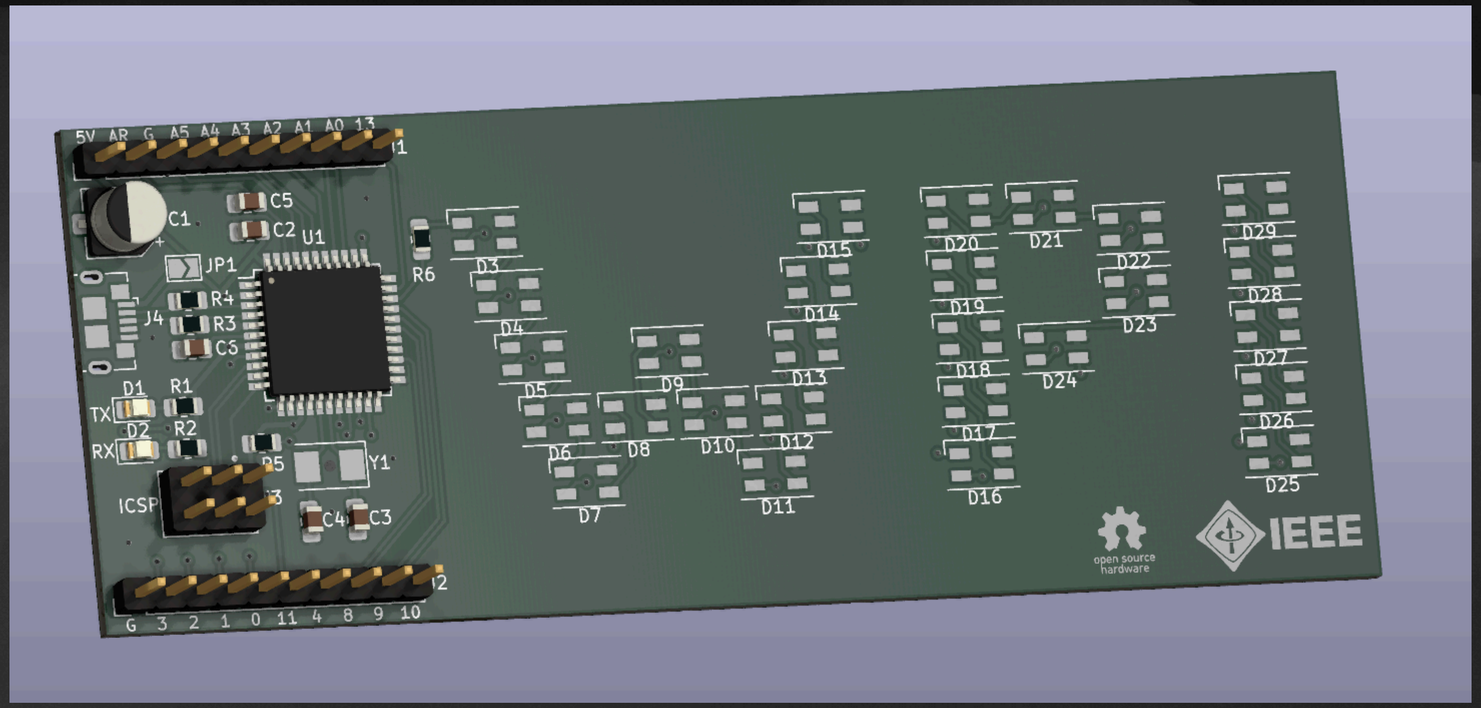
- Kioxia 128 GB NAND flash memory
- Texas Instruments USB-C controller
- Texas Instruments battery charger
- Cirrus Logic audio codec
- Cirrus Logic audio amplifier
- Texas Instruments display power supply
- Cirrus Logic power management

https://www.ifixit.com/Guide/iPhone+16+Pro+Chip+ID/177358

pcb design process

walkthrough

1. **Research and Design**
2. Schematic Capture
3. Layout
4. Routing
5. Order
6. Assembly



project ideation

i want to make something

- Start with a core idea and refine it as you research
- Focus on high-level system design, worry about specifics later
- Any project idea is a good one if you can:
    1. **Come up with a novel concept.**
    2. **Research the concept and related work.**
    3. **Understand the high-level system design.**

project ideation

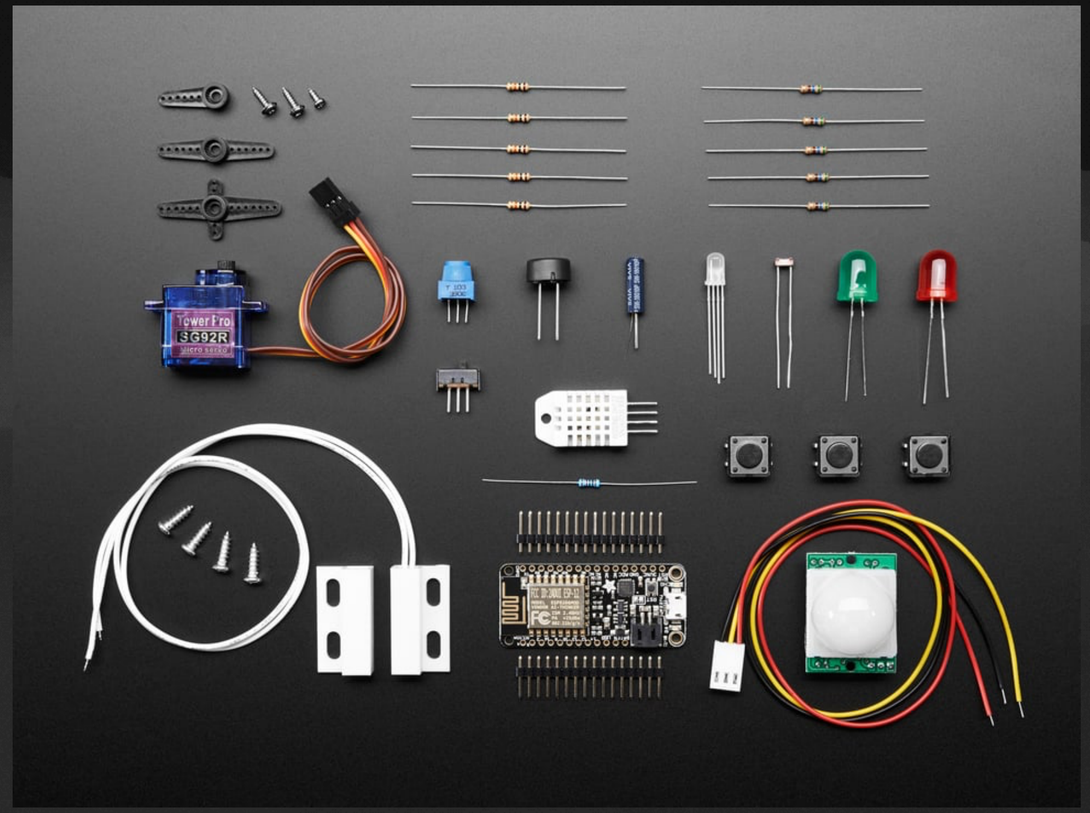
i want to make something

- **We’re teaching a top-down design-driven methodology.**
    1. Idea & Requirements
    2. System Design
    3. Detailed Design
    4. Implementation
    5. Testing

research and design

process

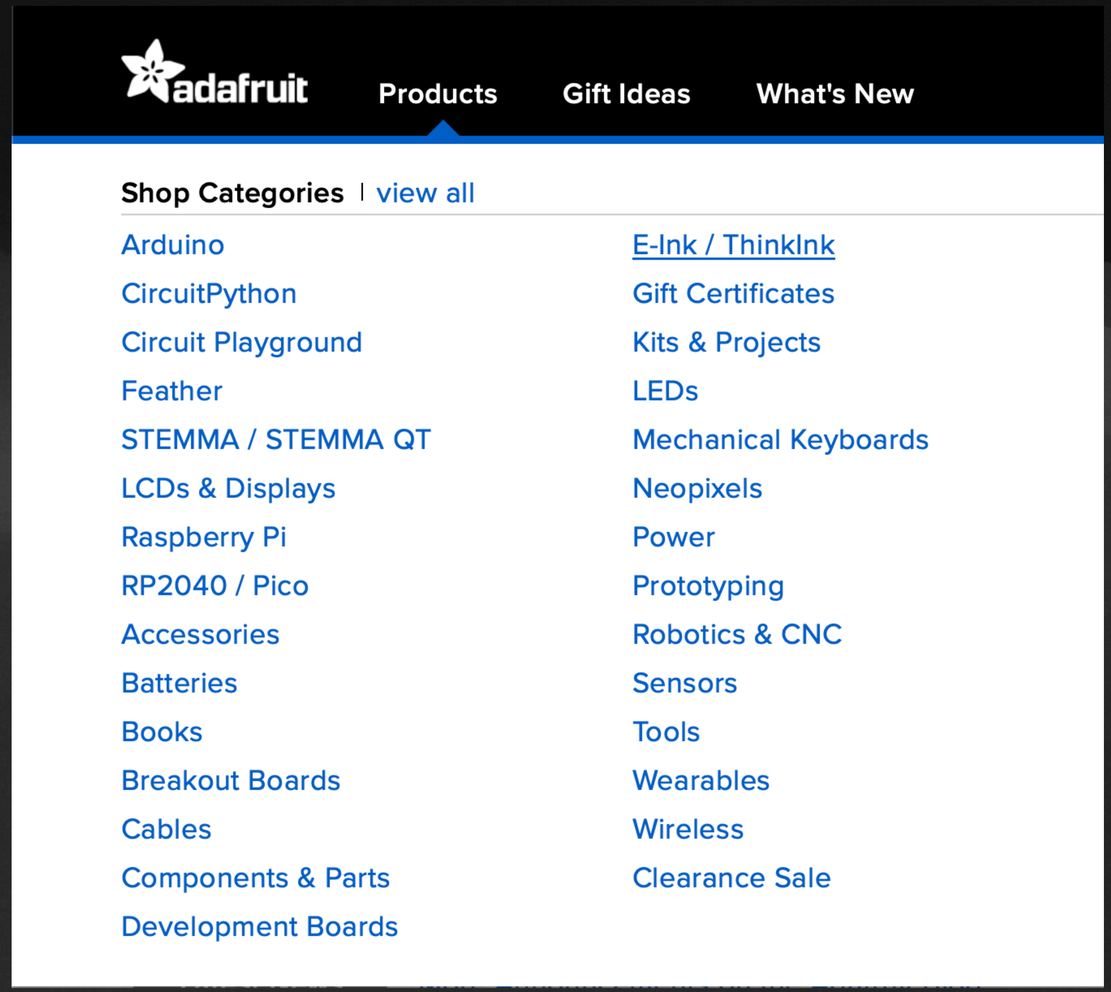
- Start with a project idea
  - Often fun to start with **peripherals** and what you want them to do
- Break down design into **major components**
- Research possible components and how to connect them to your peripherals
- Worry about details (passives) later



research and design

research

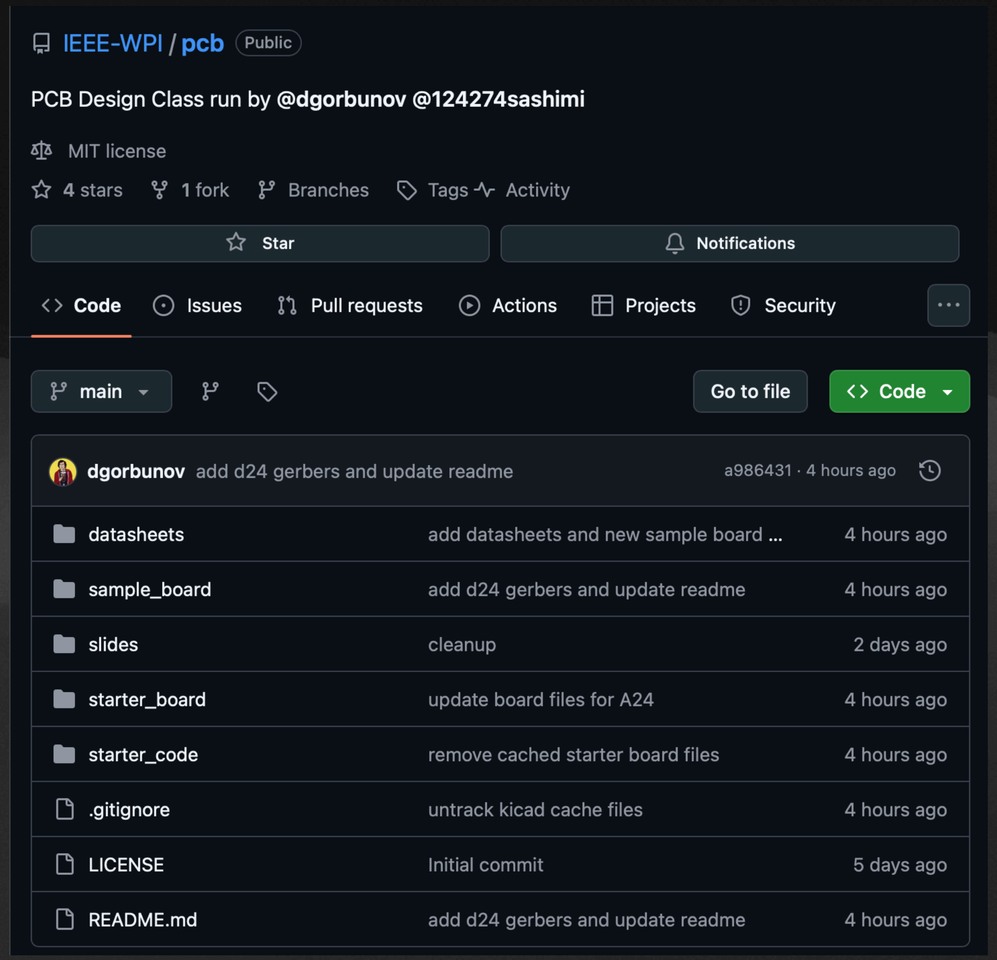
- **Cool parts, inspiration, docs:**
  - Adafruit
  - SparkFun
- **Major parts distributors:**
  - DigiKey
  - Mouser



research and design

open source

- **Research, research, research!**
- You will learn a lot from researching existing open-source projects
- Use these projects as a starting point
- Companies like Adafruit and SparkFun open source all of their schematics
- When you're done, open source your project to inspire others and showcase your technical skills



This class itself is open-source!

Some project examples…

project examples
to get you excited!

1. LED music visualizer
2. Interactive LED art
3. Wireless battery-powered haptics

TeensyVisualizer

teensy visualizer

requirements

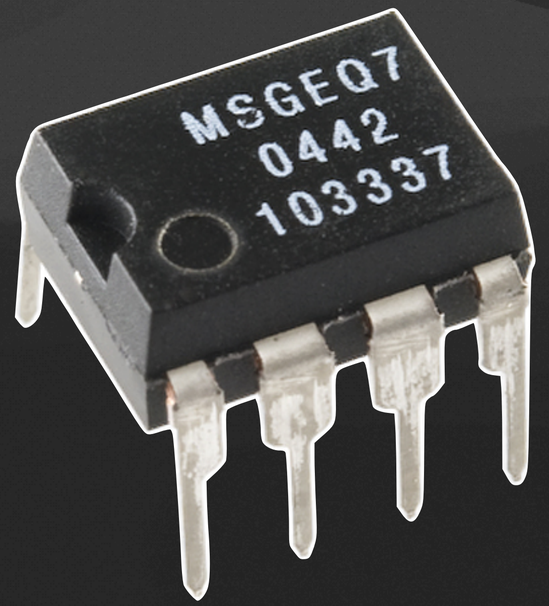
- Visualize music on LEDs real-time
- Use either microphone/line-in
- Must be portable; fit on a desk

github.com/dgorbunov/TeensyVisualizer

teensy visualizer

components

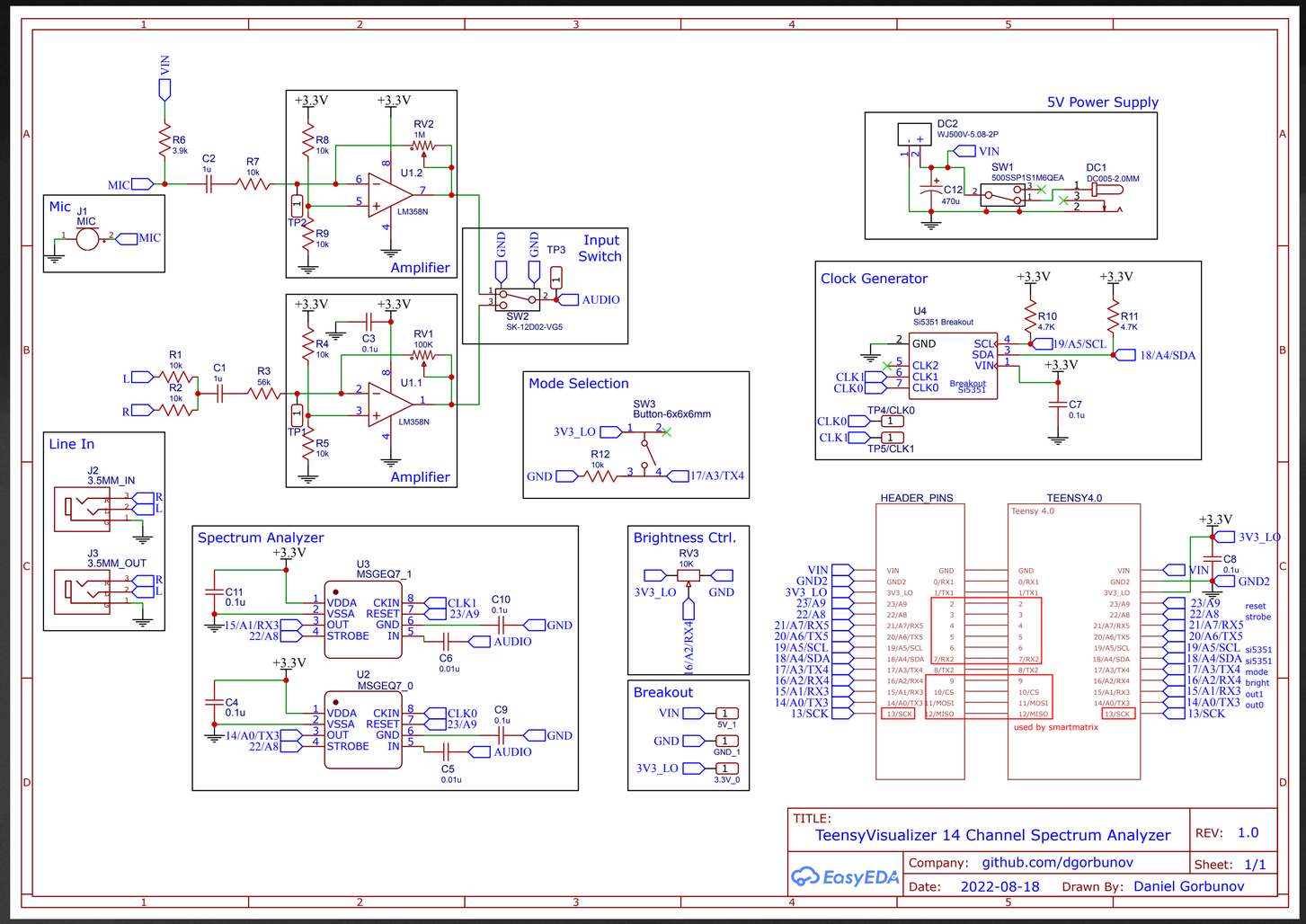
- Microcontroller (Teensy 4.0)
- LED matrix
- SmartLED driver board
- Line-in jack
- Microphone + Amplifier (LM358)
- Variable clock generator
- Graphic EQ chip (MSGEQ7)



github.com/dgorbunov/TeensyVisualizer

teensy visualizer

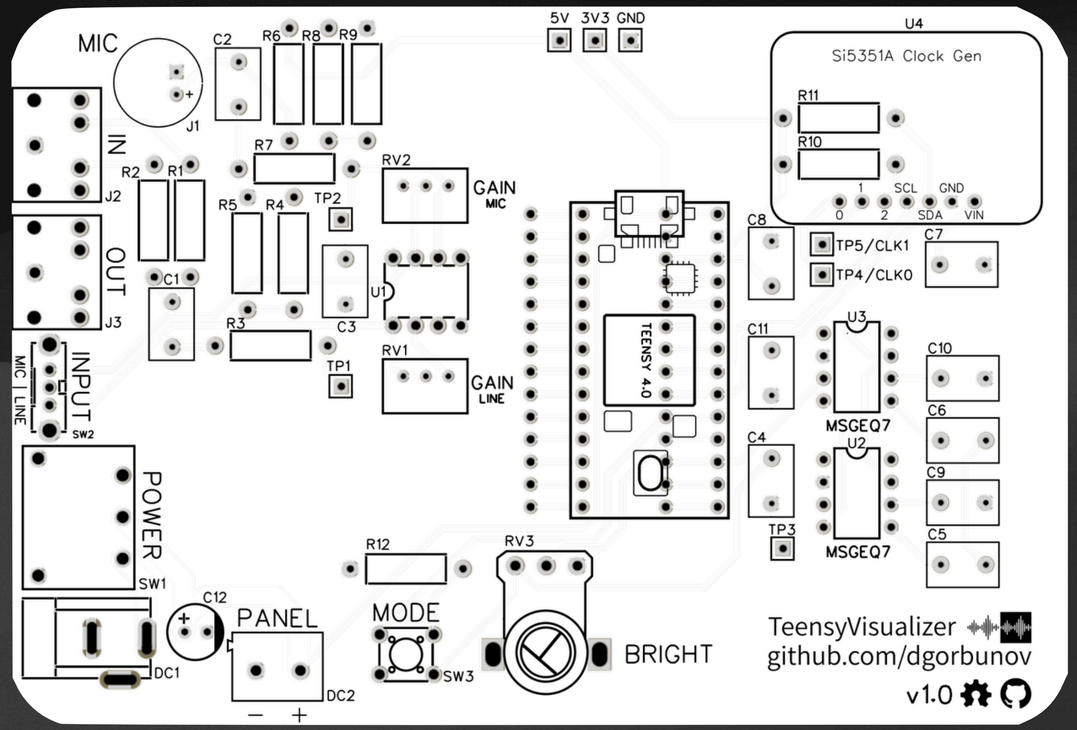
schematic

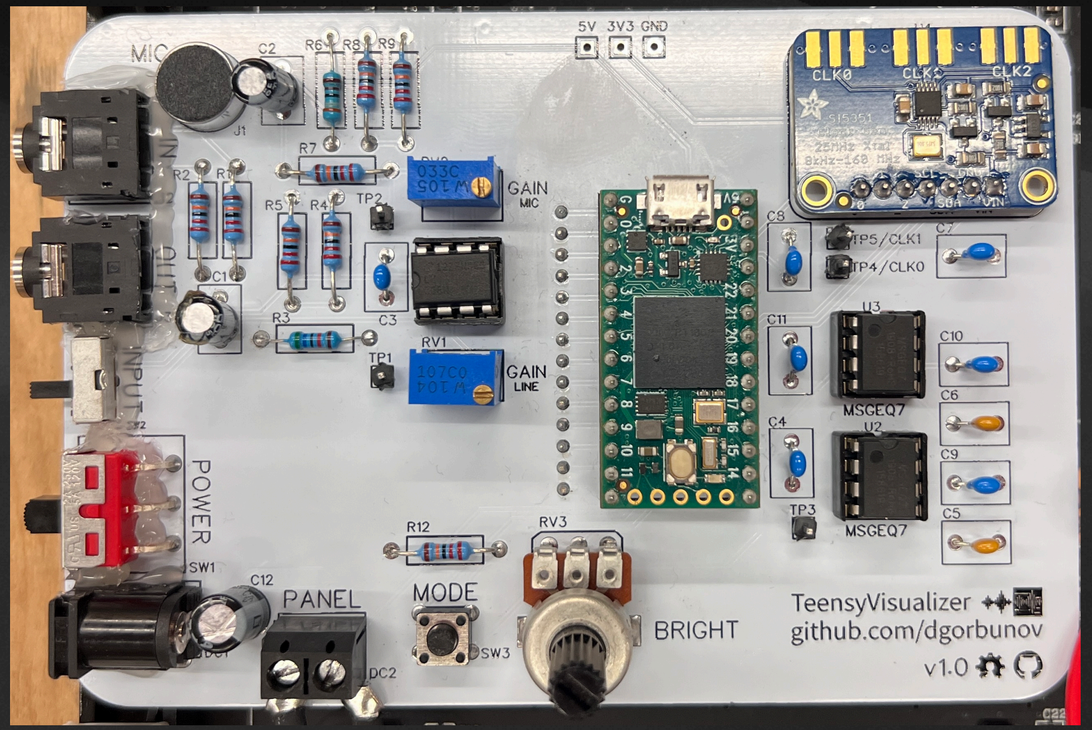


github.com/dgorbunov/TeensyVisualizer

teensy visualizer

board



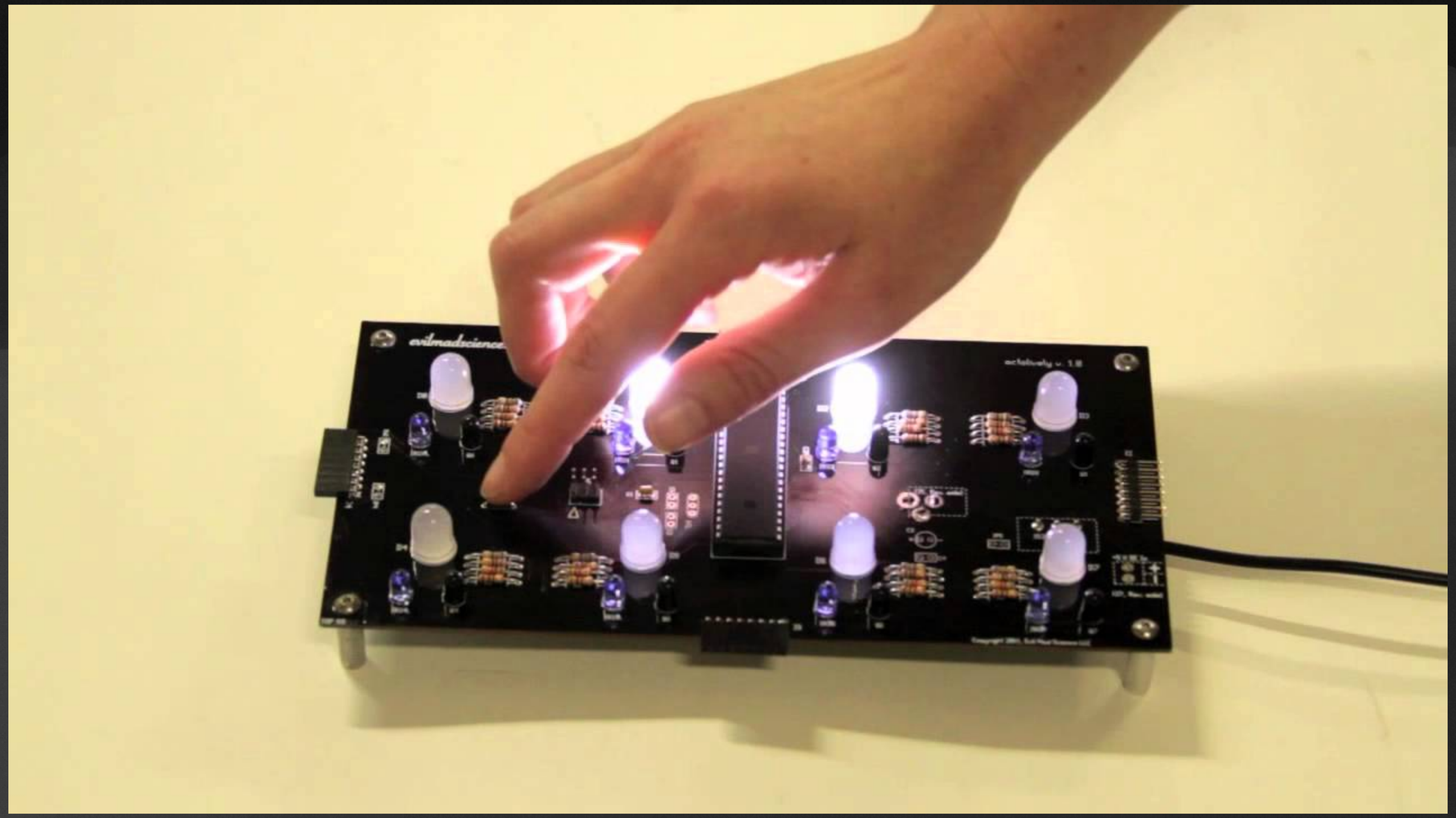


github.com/dgorbunov/TeensyVisualizer

Reactive LEDs

reactive LEDs

inspiration



reactive LEDs

requirements

- Must be interactive; respond in a fluid way to proximity
- Must have low unit price
- Must be infinitely tileable

github.com/dgorbunov/TeensyVisualizer

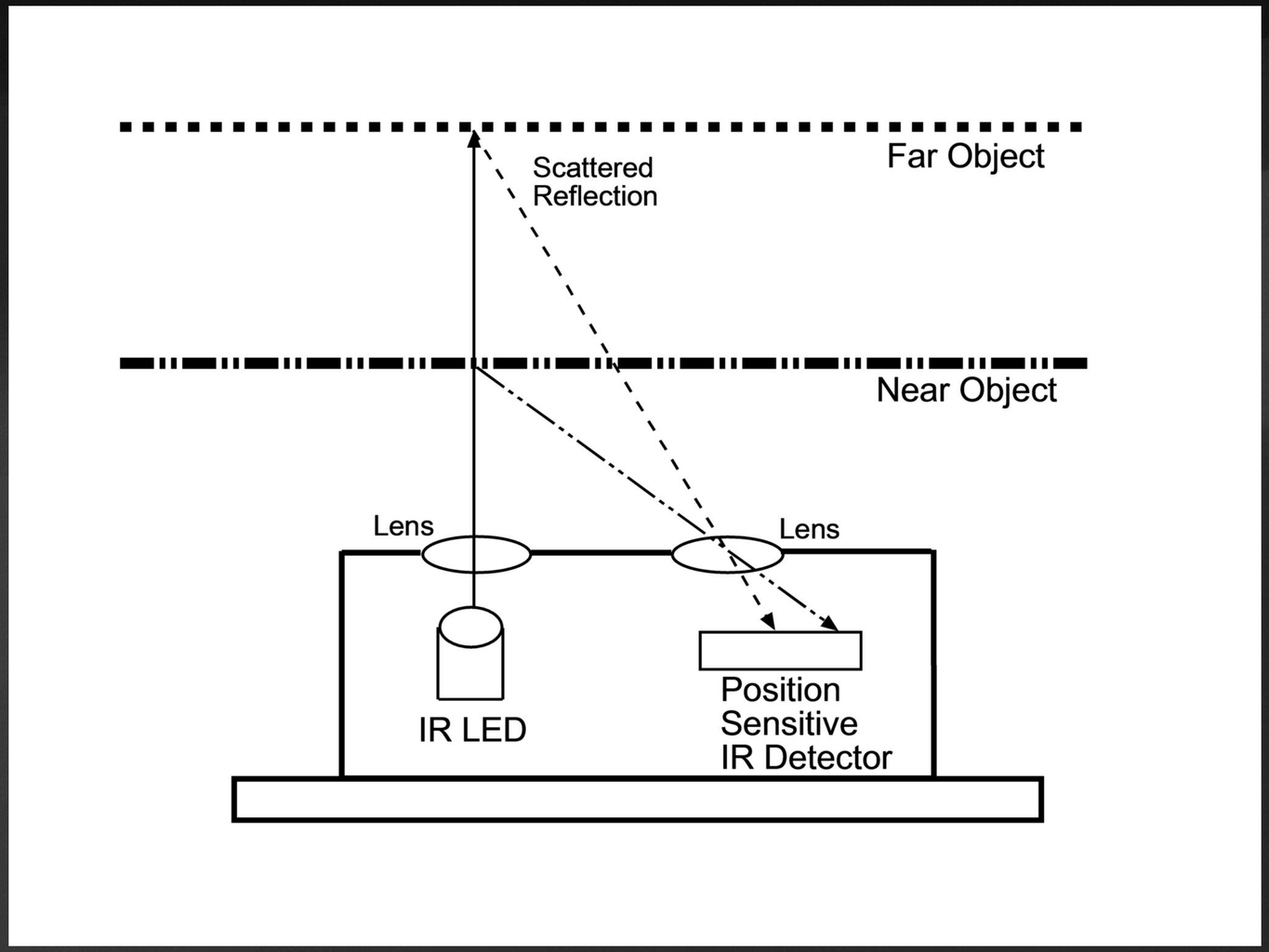
reactive LEDs

components

- Microcontroller (ATMega 32u4)
- RGB LEDs (Neopixels)
- Distance sensors?
  - Ultrasonic
  - Time-of-flight
  - **Infrared**

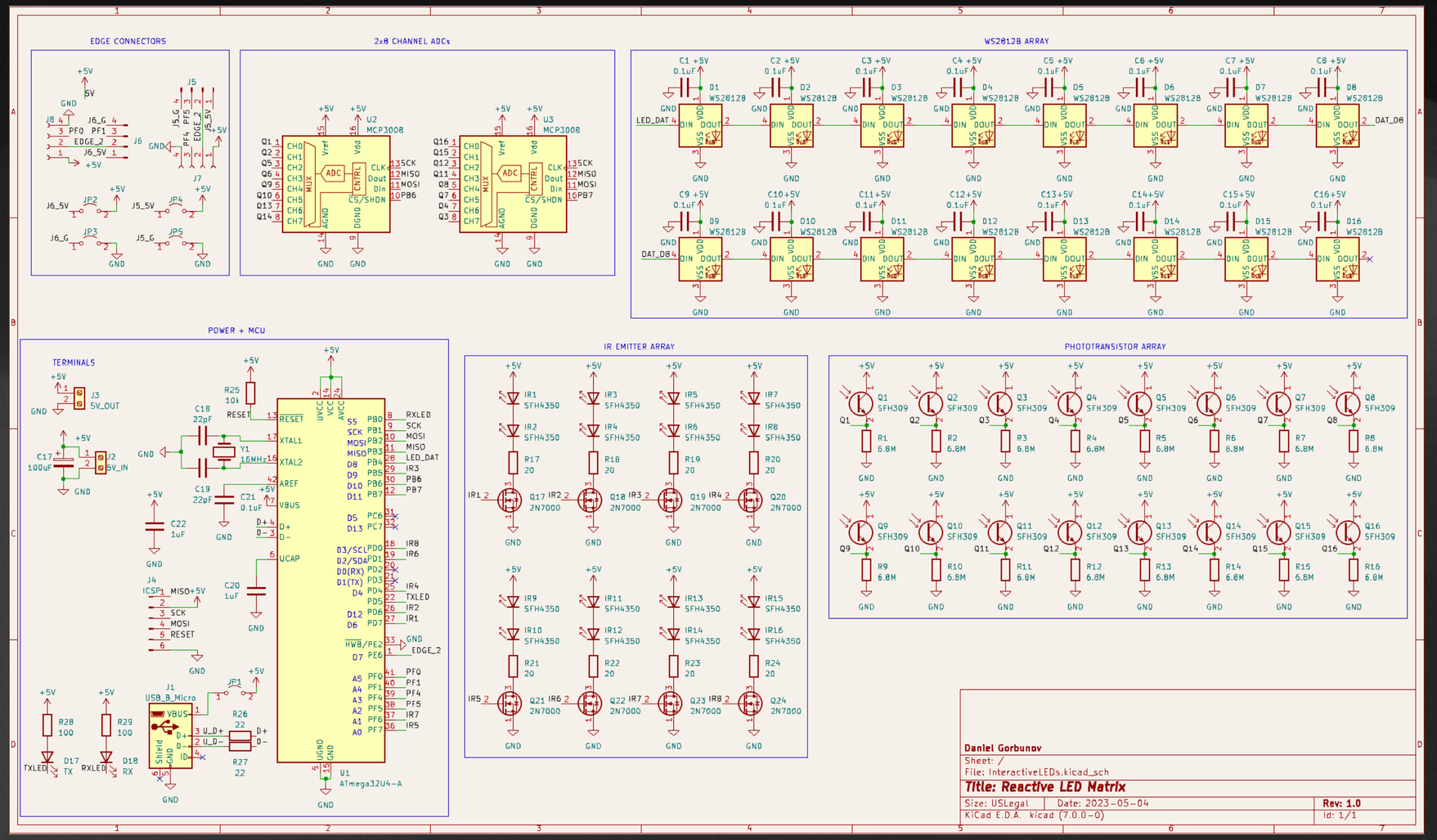
reactive LEDs

infrared sensing



reactive LEDs

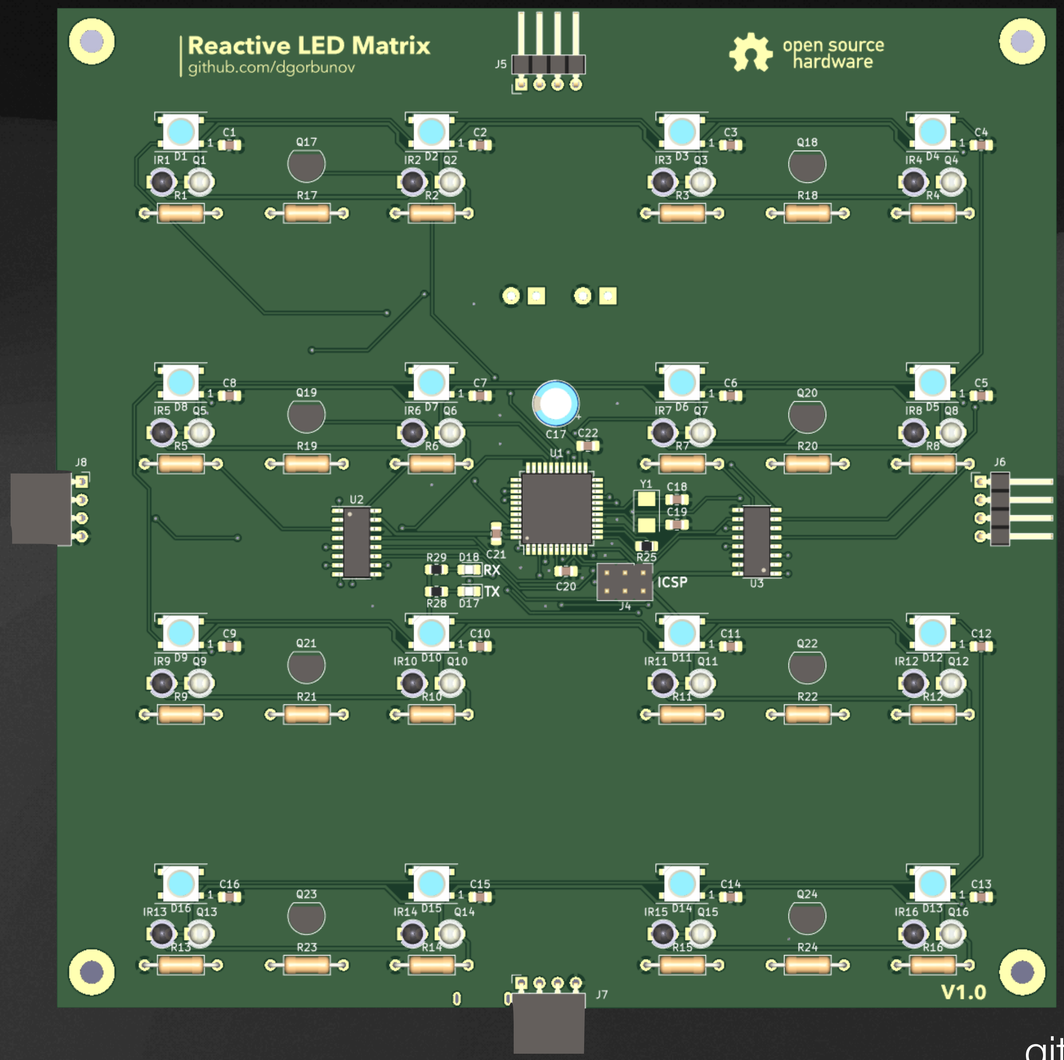
schematic



github.com/dgorbunov/ReactiveLEDMatrix

reactive LEDs

board



github.com/dgorbunov/ReactiveLEDMatrix

Wireless Haptics

SpatialSense

requirements

- Low-latency wireless haptic wearable
- Must be very small and attach to human body
- Must be battery powered
- Position/orientation should be trackable in 3D space

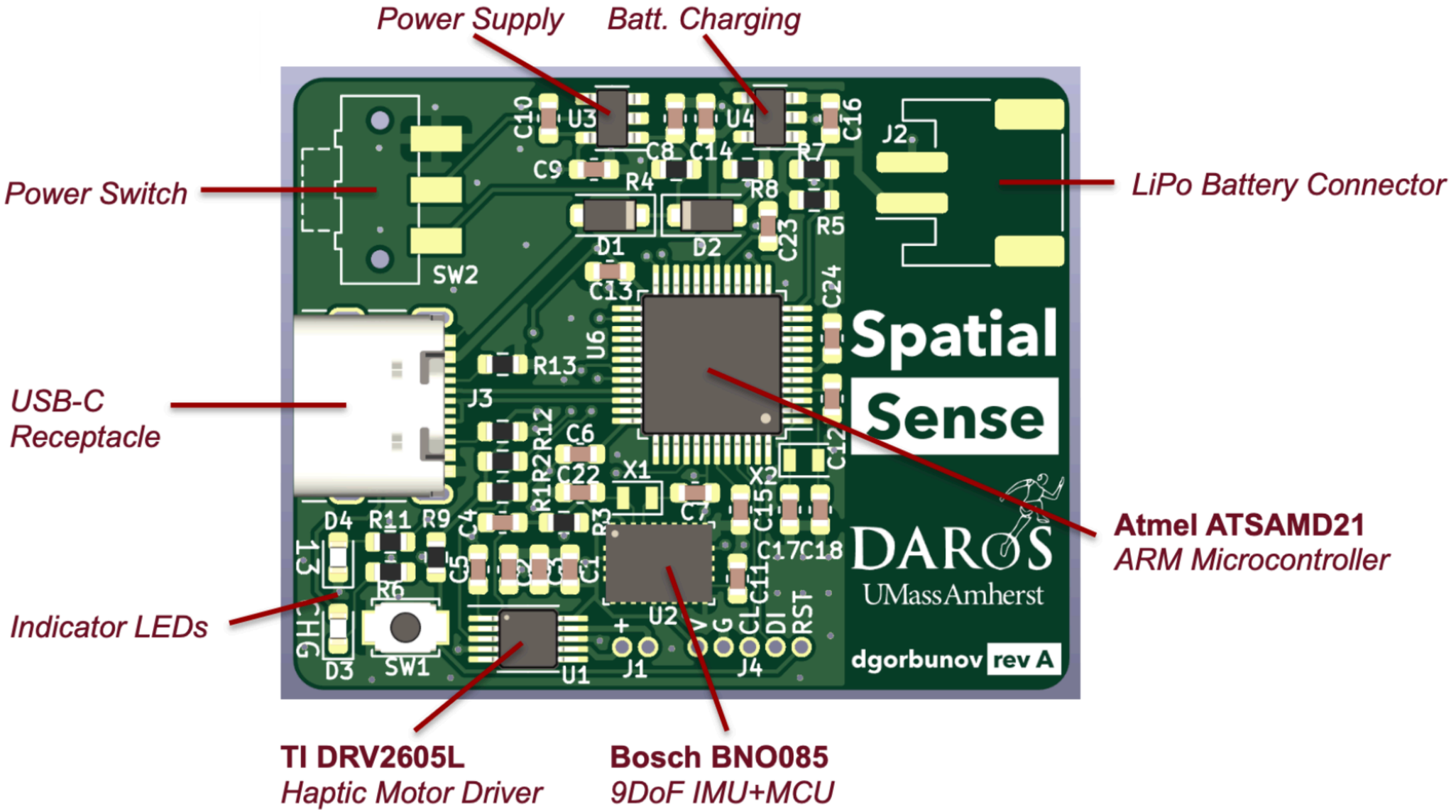
github.com/dgorbunov/SpatialSense

SpatialSense

components

- ARM Microcontroller (Atmel)
- Vibration motor (Vybronics)
- Haptic Motor Driver (Texas Instruments)
- 6 axis IMU (Bosch)
- Battery charging IC
- LiPo battery
- Voltage regulator
- Packet radio (915MHz)

github.com/dgorbunov/SpatialSense

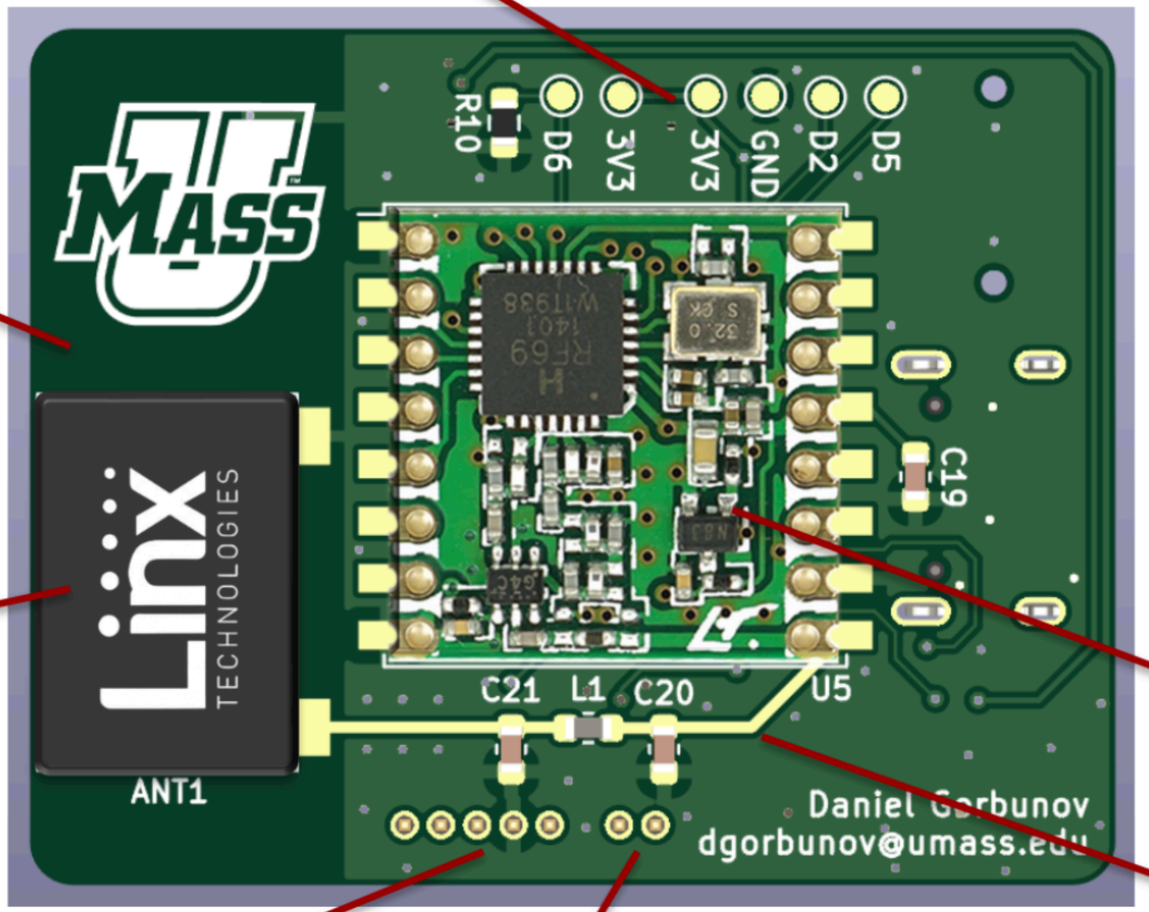


github.com/dgorbunov/SpatialSense

Breakouts (extra features)

RF Plane (no GND)

Linx Antenna
915MHz, Tuned 50Ω Impedance



RFM69HCW
915MHz Packet Radio Transceiver

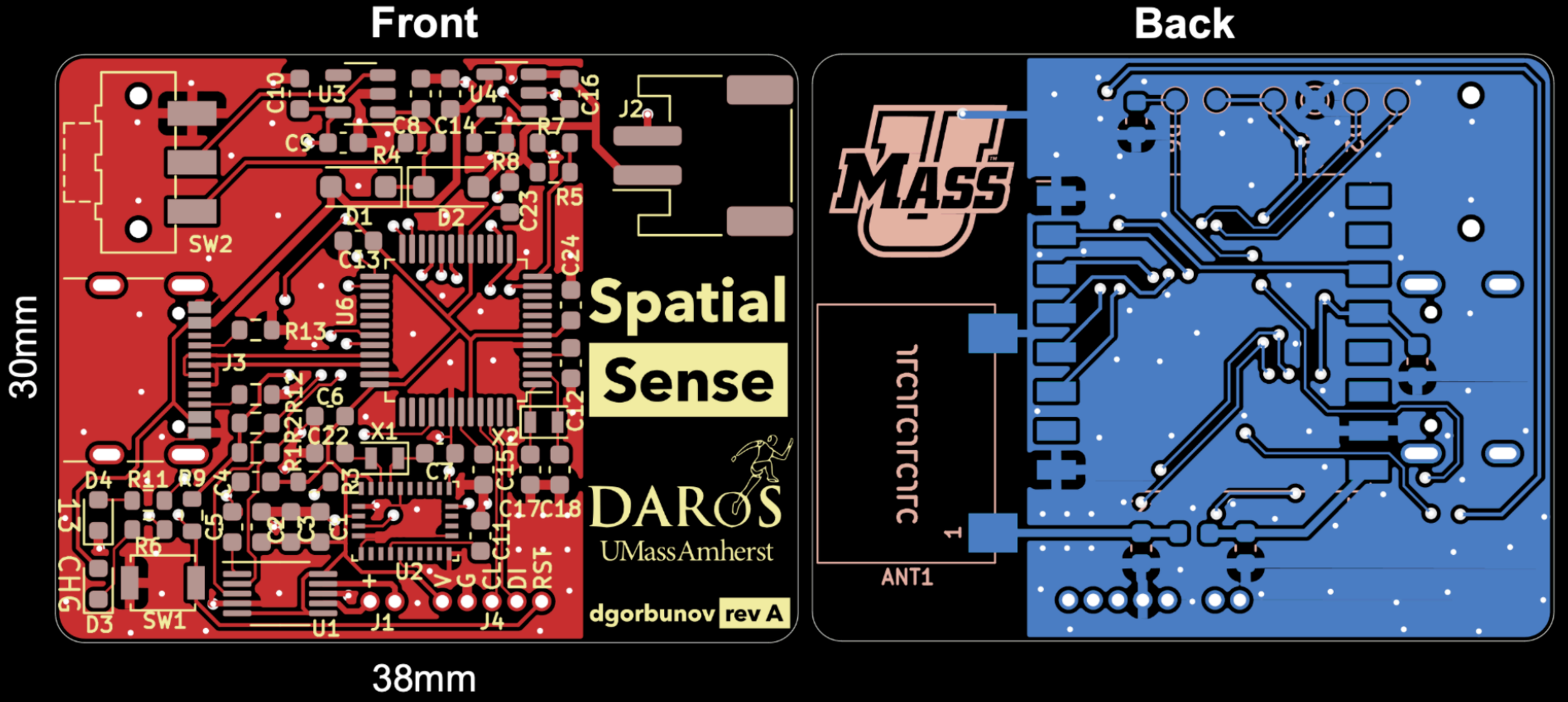
SWD Programming Interface

Vibration Motor Pins

RF Microstrip + Impedance Matching Network

github.com/dgorbunov/SpatialSense

PCB Layout

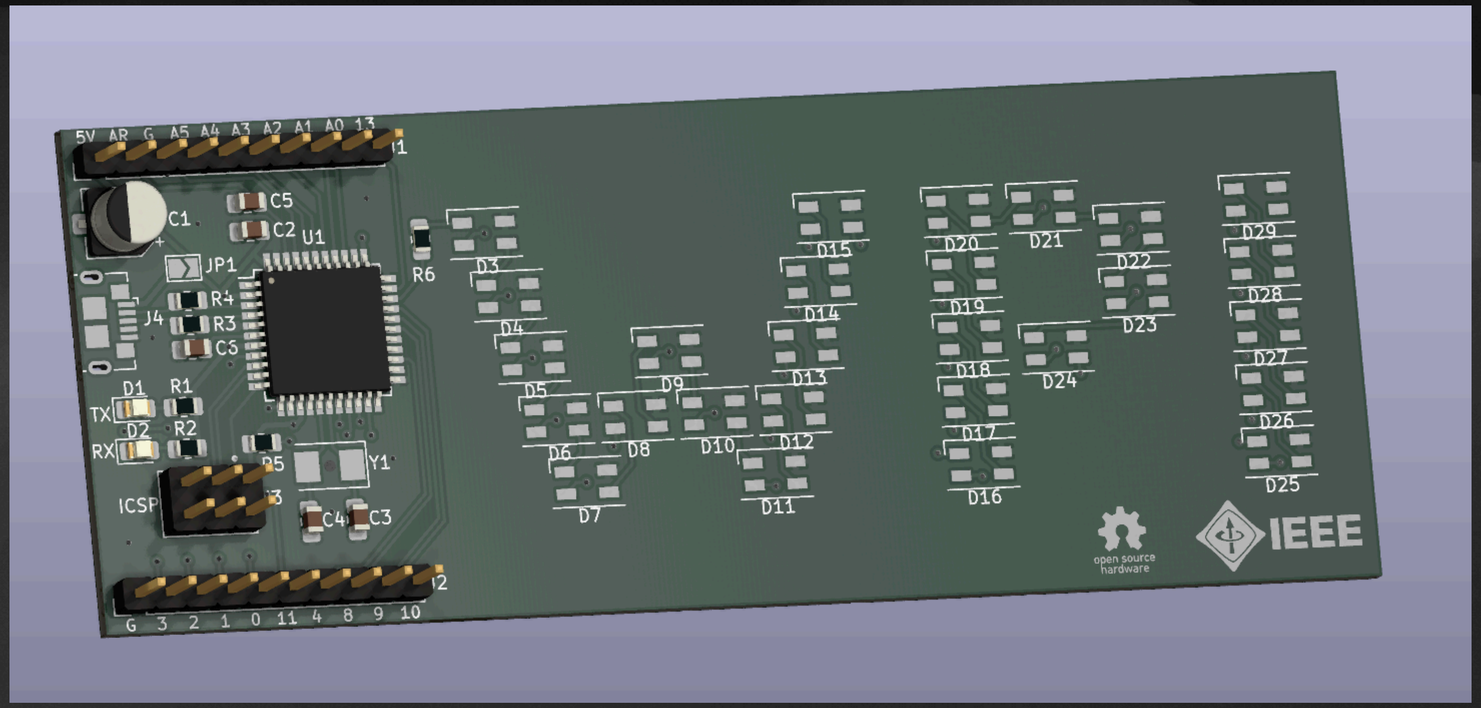


github.com/dgorbunov/SpatialSense

pcb design process

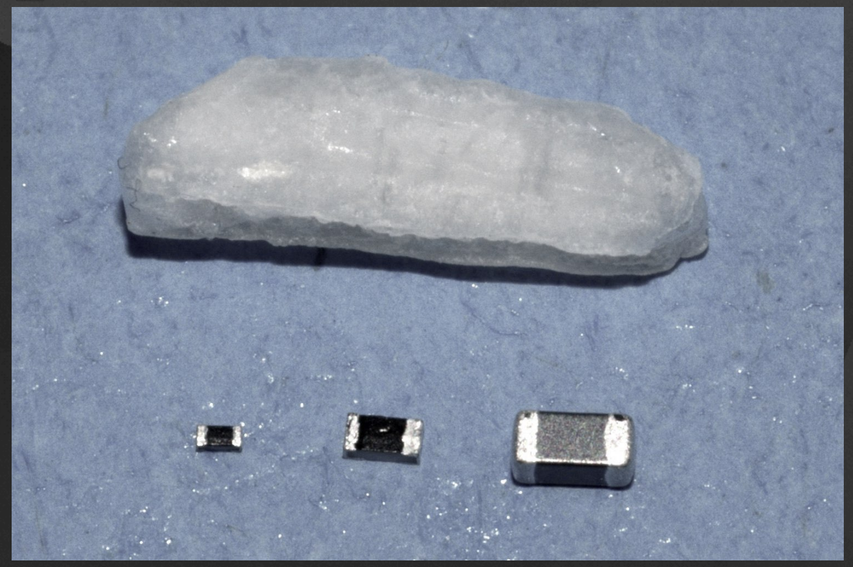
walkthrough

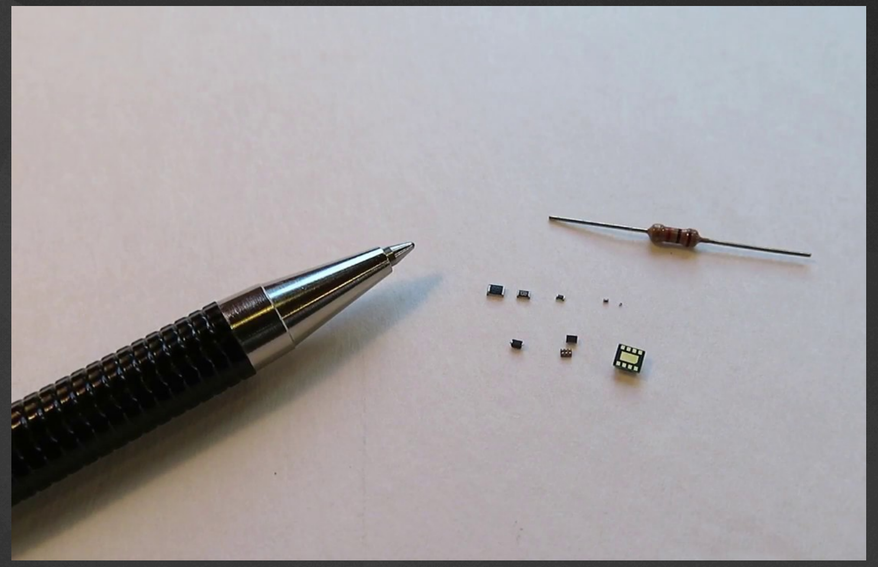
1. Research and Design
2. **Schematic Capture**
3. Layout
4. Routing
5. Order
6. Assembly

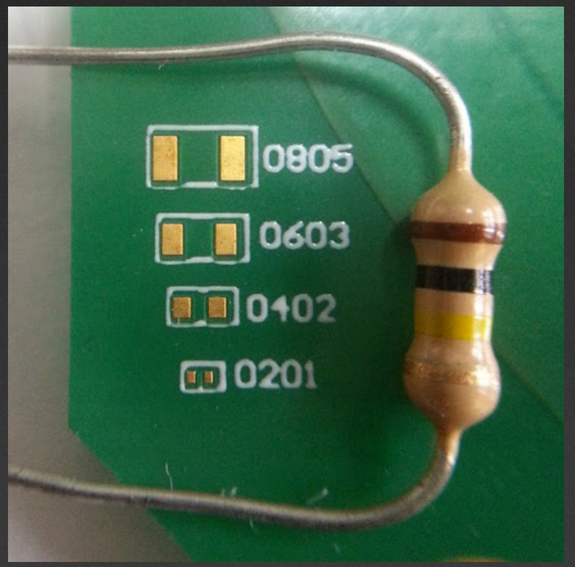


packages
an aside

- **Size matters -- don't make your life miserable**

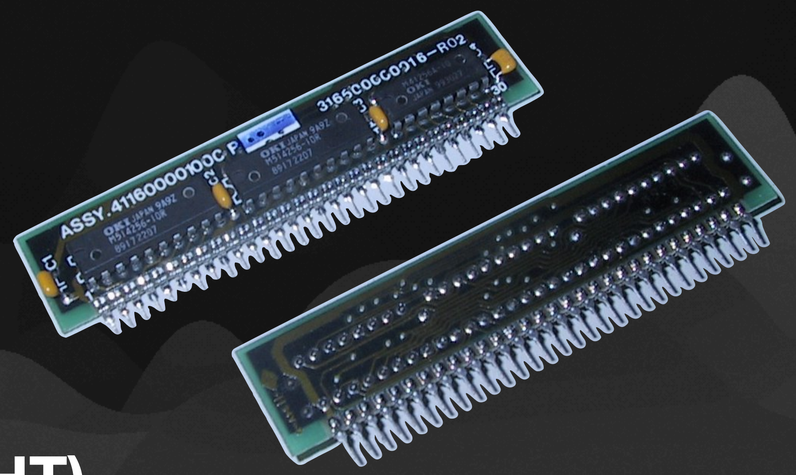


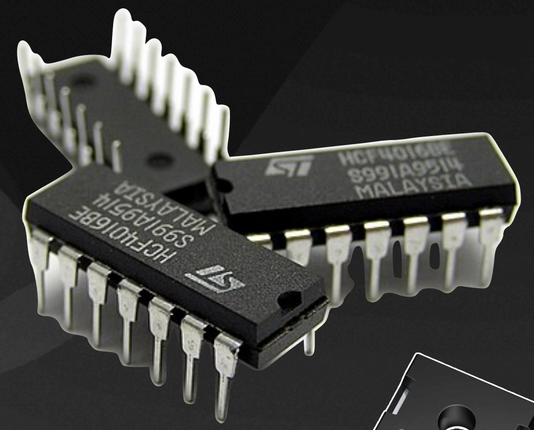




packages

simple components

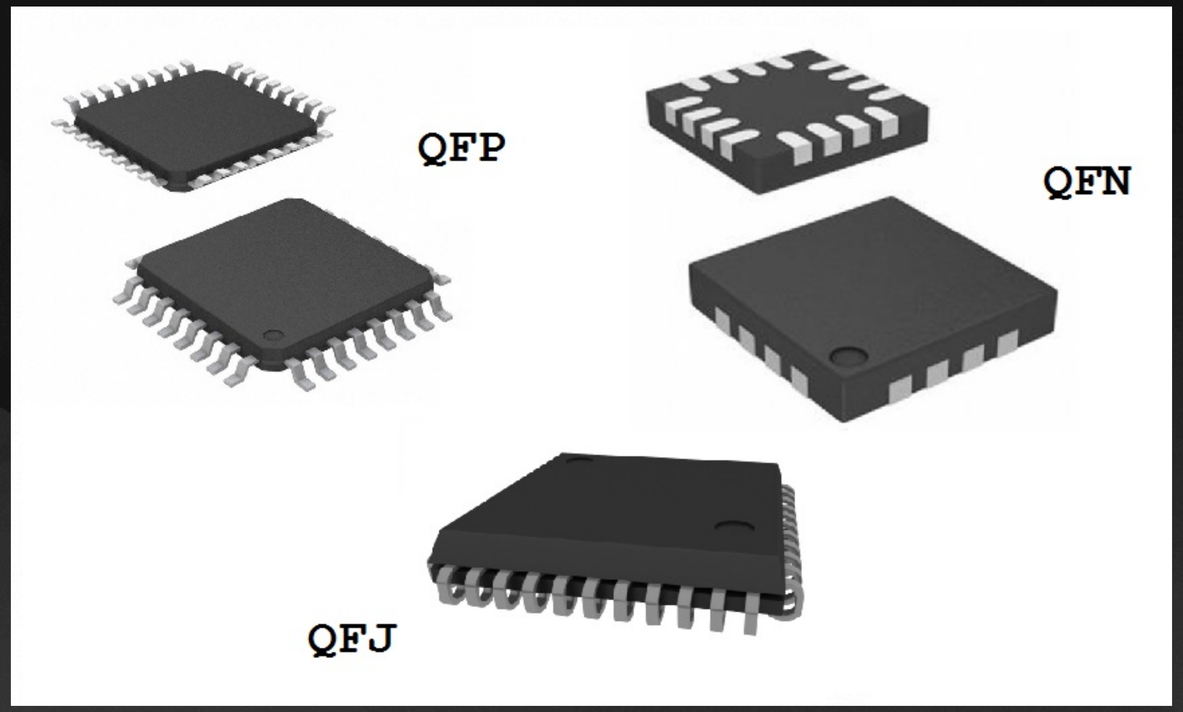


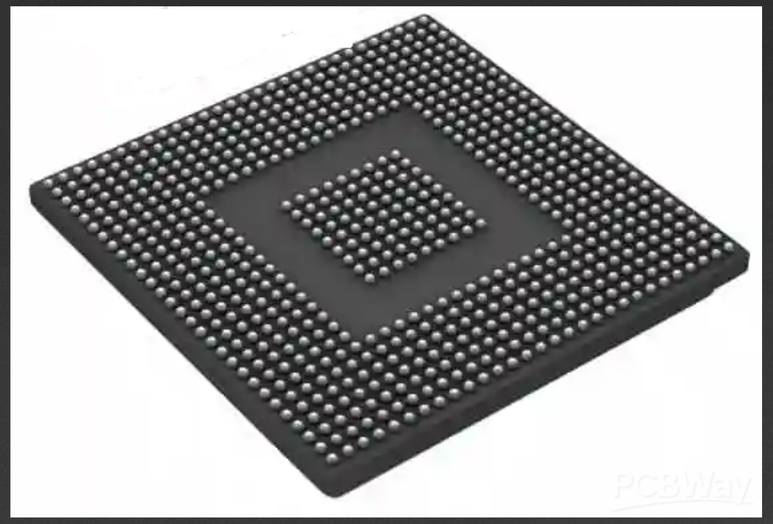


- **Shape matters too!**
- **Though Hole Technology (THT)**
  - Single in-line package (SIP)
  - Dual in-line package (DIP)
- **Surface Mount Technology (SMT)**
  - Small outline package (SOP)
  - Small outline transistor (SOT)

packages
complicated components

- **IC Packages**
  - Quad flat pack (QFP, TQFP)
  - Quad flat J (QFJ)
  - Quad flat pack no-lead (QFN, TQFN)
  - Ball Grid Array (BGA, FBGA)





packages
an aside

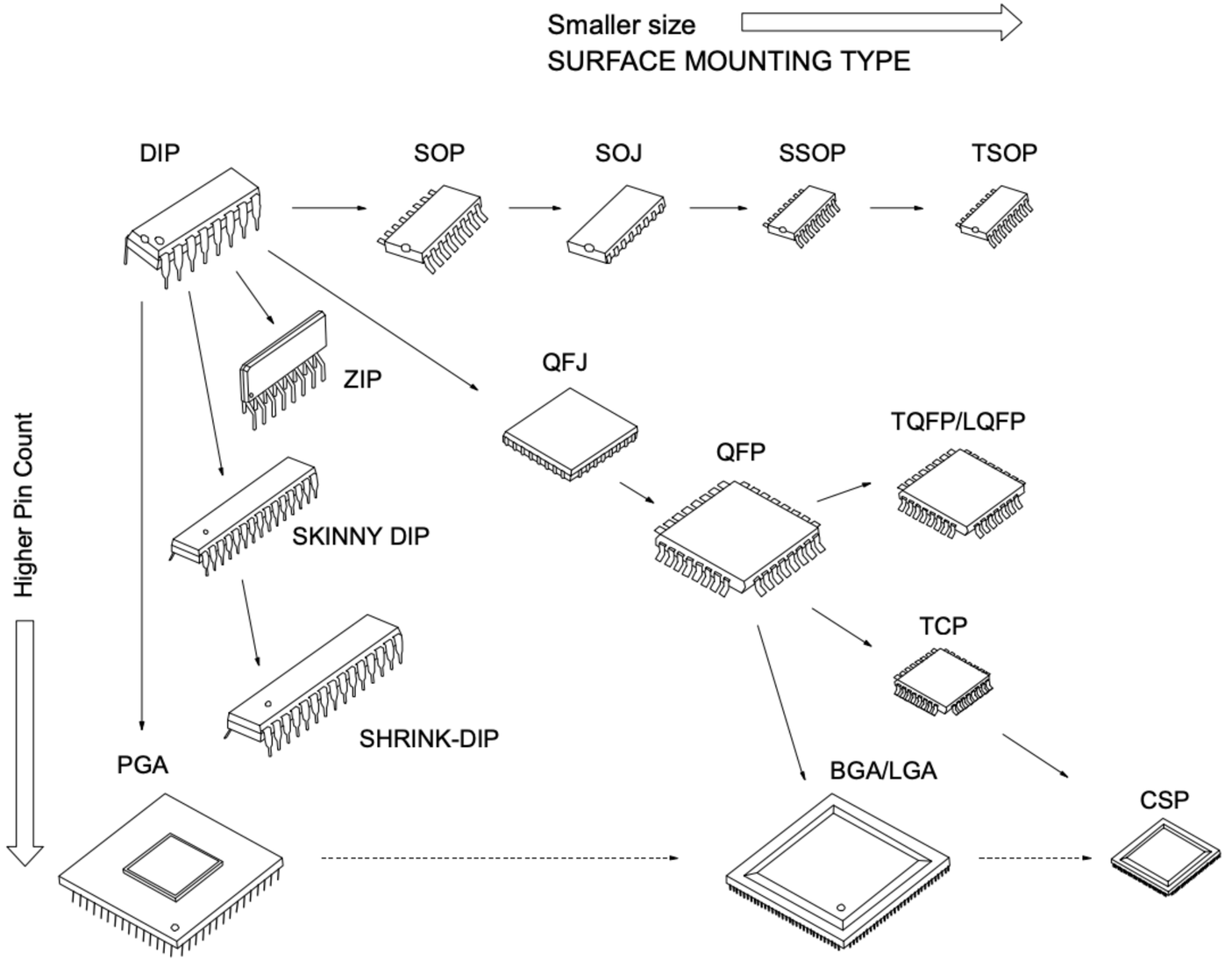


Figure 1.1.1 Packaging Trend

schematic capture
process

- Use parts distributors (DigiKey, Mouser) to find specific components
- Read datasheets to find what the exact product number you need
- Footprints matter here!
  - Consider board size, and desired manufacturing + assembly process!
- Start with key components first!

Mfr Part #	Quantity Available	Price	Series	Package	Product Status
ATMEGA32U4-MU IC MCU 8BIT 32KB FLASH 44VQFN *Microchip Technology*	14,742 In Stock	1 : **$5.26000** Tray	AVR® ATmega	Tray	Active
ATMEGA32U4RC-MU IC MCU 8BIT 32KB FLASH 44VQFN *Microchip Technology*	10,393 In Stock	1 : **$5.26000** Tray	AVR® ATmega	Tray	Active
ATMEGA32U4-AU IC MCU 8BIT 32KB FLASH 44TQFP *Microchip Technology*	17,825 In Stock	1 : **$5.29000** Tray	AVR® ATmega	Tray	Active
ATMEGA32U4-AUR IC MCU 8BIT 32KB FLASH 44TQFP *Microchip Technology*	43,172 In Stock	1 : **$5.39000** Cut Tape (CT) 1,500 : **$4.48003** Tape & Reel (TR)	AVR® ATmega	Tape & Reel (TR) Cut Tape (CT) Digi-Reel®	Active
ATMEGA32U4-MUR IC MCU 8BIT 32KB FLASH 44VQFN *Microchip Technology*	23,528 In Stock	1 : **$5.40000** Cut Tape (CT) 4,000 : **$4.49000** Tape & Reel (TR)	AVR® ATmega	Tape & Reel (TR) Cut Tape (CT) Digi-Reel®	Active
ATMEGA32U4RC-AU IC MCU 8BIT 32KB FLASH 44TQFP *Microchip Technology*	3,336 In Stock	1 : **$5.26000** Tray	AVR® ATmega	Tray	Active
ATMEGA32U4RC-MUR IC MCU 8BIT 32KB FLASH 44VQFN *Microchip Technology*	77,872 In Stock	1 : **$5.40000** Cut Tape (CT) 4,000 : **$4.49000** Tape & Reel (TR)	AVR® ATmega	Tape & Reel (TR) Cut Tape (CT) Digi-Reel®	Active

schematic capture

microcontroller

The microcontroller we will be using

Mfr Part #	Quantity Available	Price	Series	Package	Product Status
ATMEGA32U4-MU IC MCU 8BIT 32KB FLASH 44VQFN *Microchip Technology*	**14,742** In Stock	1 : **$5.26000** Tray	AVR® ATmega	Tray	Active
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Arduino IDE comes pre-installed with a compiler for this microcontroller, as they use it on some of their boards. Convenient for us!

schematic capture

microcontroller

External crystal, larger package

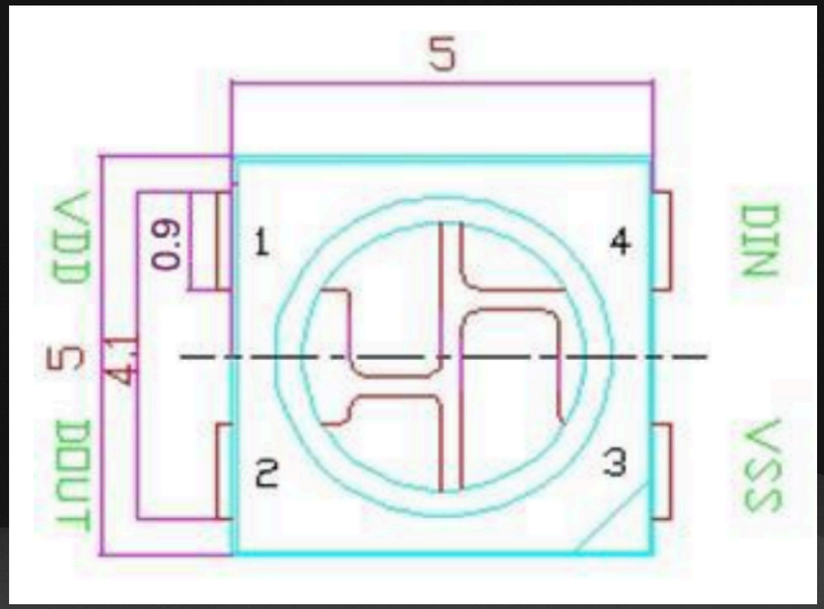
6.2 ATmega32U4

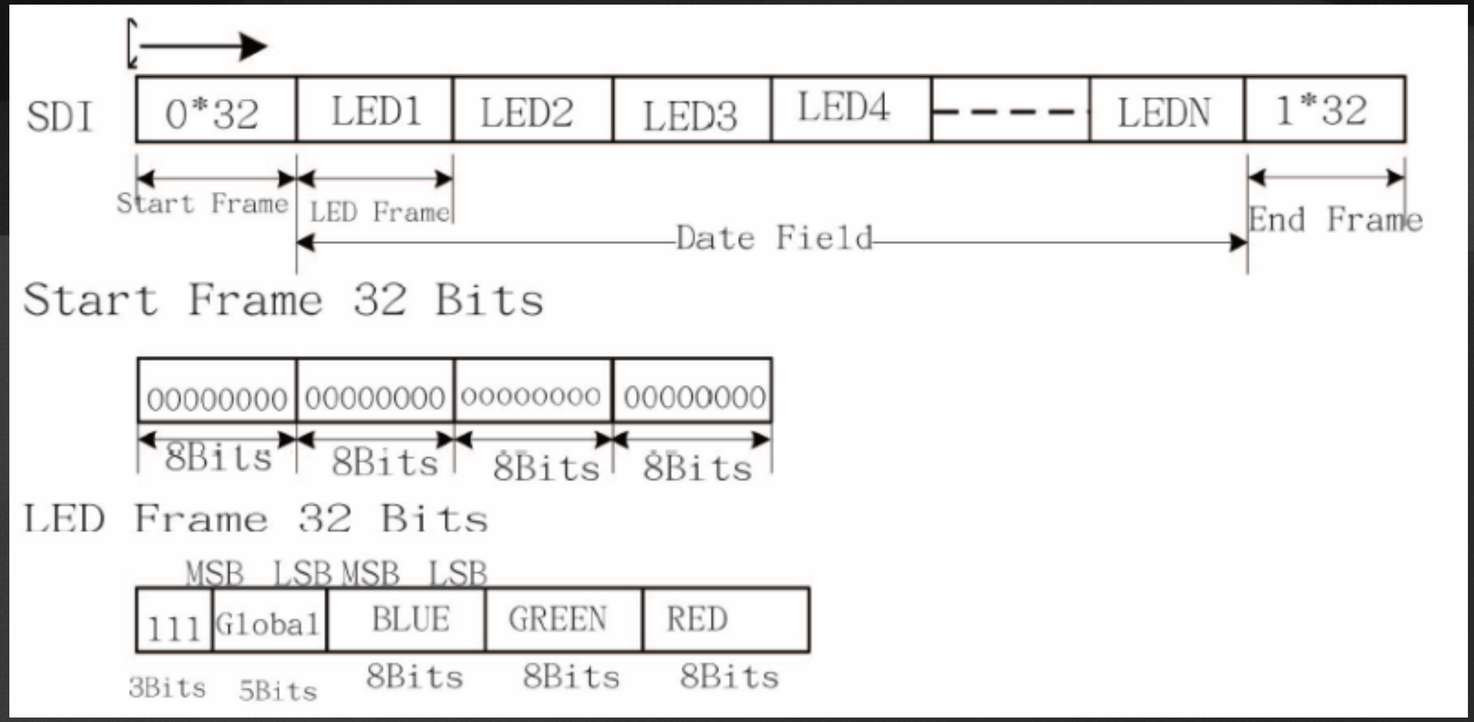
Speed [MHz]	Power Supply	Ordering Code	Default Oscillator	Package	Operation Range
16	2.7 - 5.5V	ATmega32U4-AU	External XTAL	44ML	Industrial (-40° to +85°C)
		ATmega32U4RC-AU	Internal Calib. RC		
		ATmega32U4-MU(1)(2)(3)	External XTAL	44PW	
		ATmega32U4RC-MU(1) (2) (3)	Internal Calib. RC		

Notes:
1. For more information on running the USB from internal RC oscillator consult application note AVR291: 8MHz Internal Oscillator Calibration for USB Low Speed on Atmel ATmega32U4RC.
2. USB operation from internal RC oscillator is only guaranteed for 0°C to 40°C.
3. These parts are shipped with no USB bootloader pre-programmed.

schematic capture

LEDs

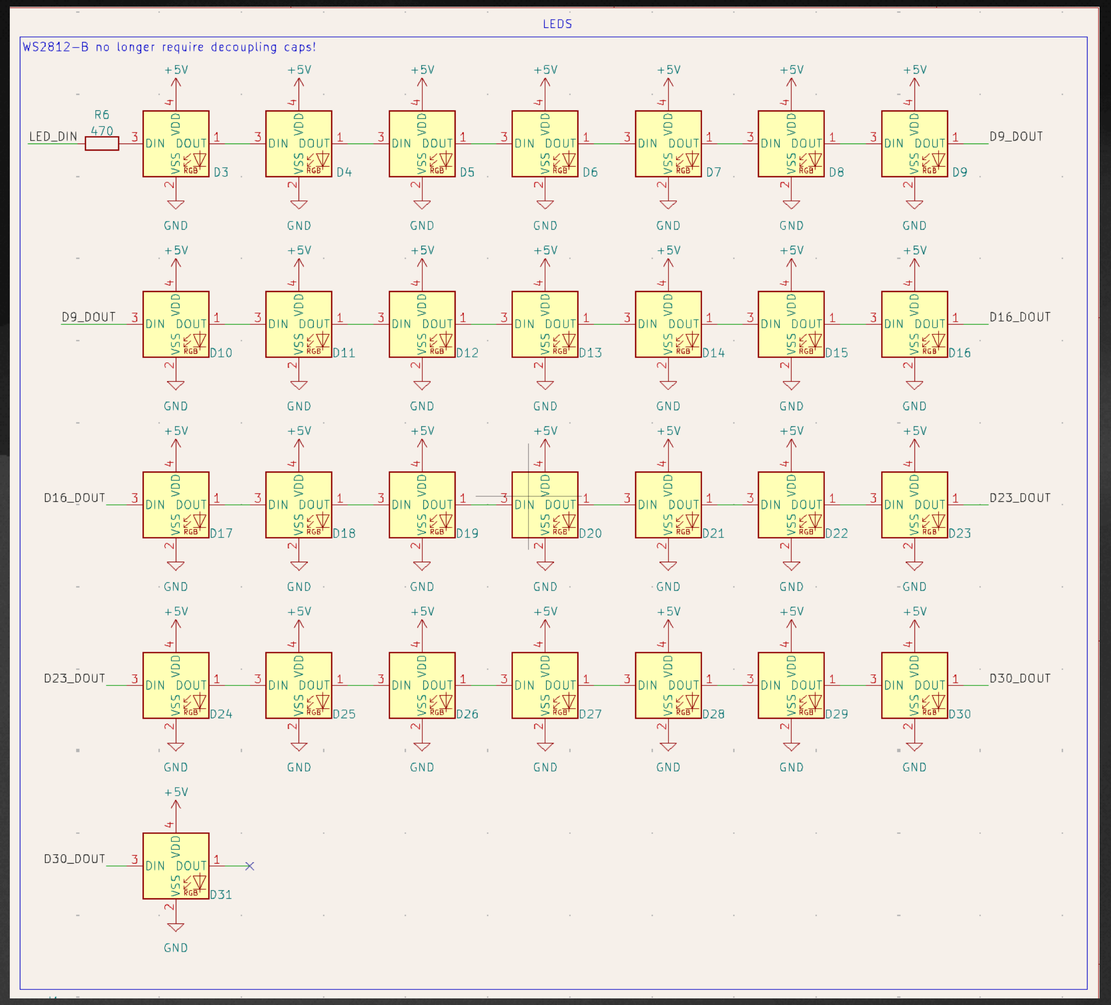


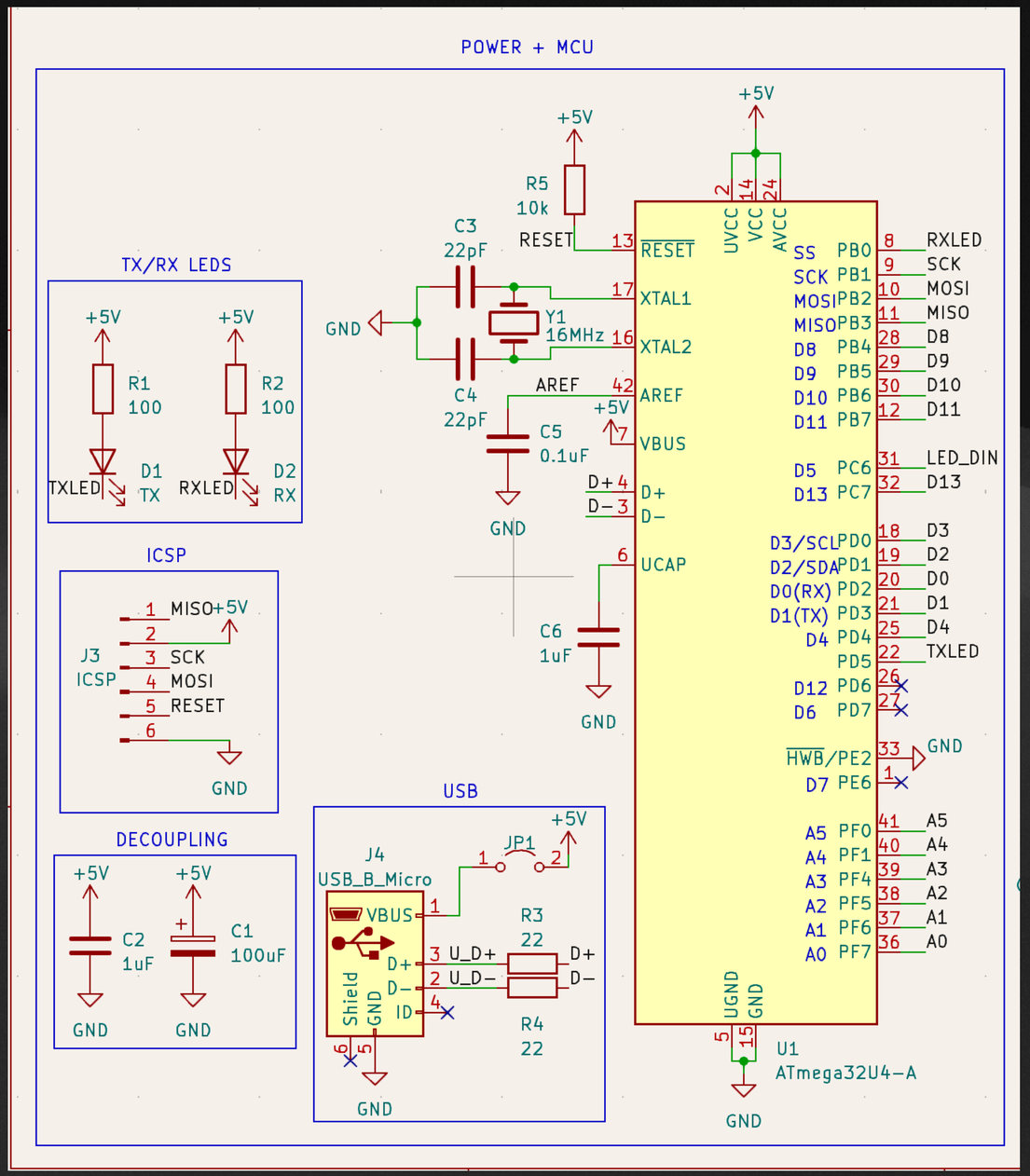


Each LED has 4 bytes of data

about the board

specifics

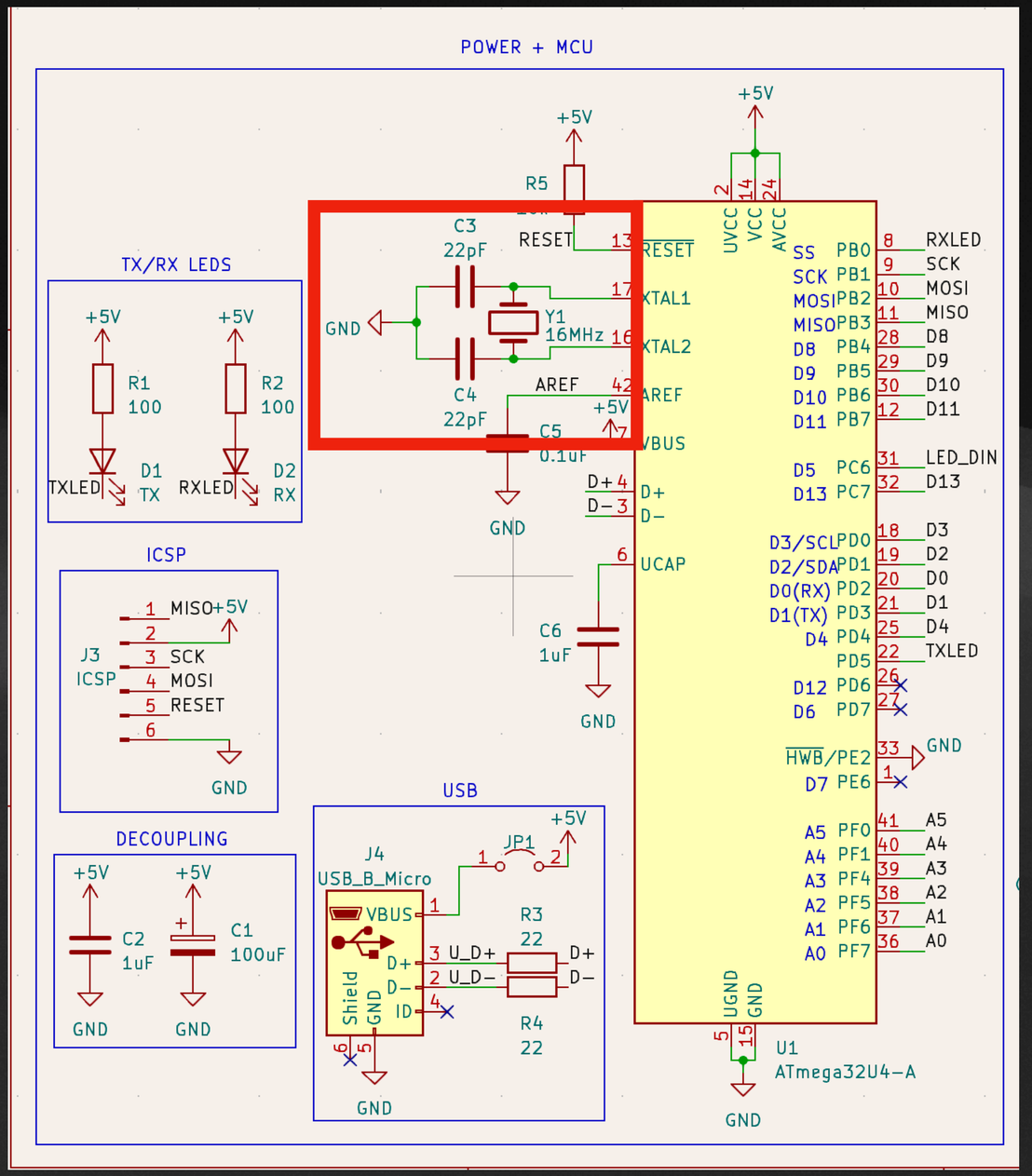




about the board

crystal oscillator

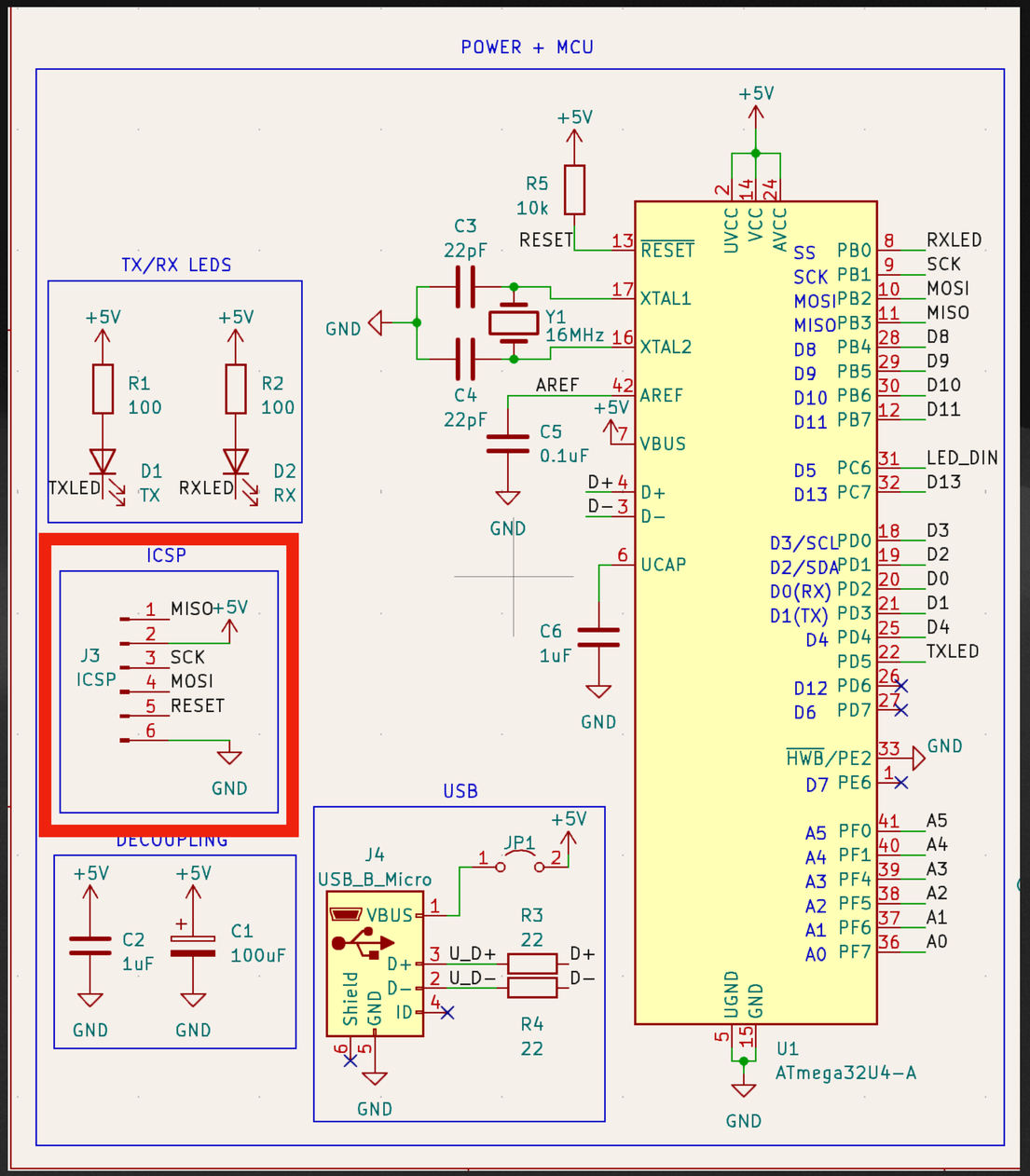
- An applied voltage to the crystal distorts the crystal causing mechanical vibration at its resonant frequency
- This generates 16MHz clock signal



about the board

ICSP

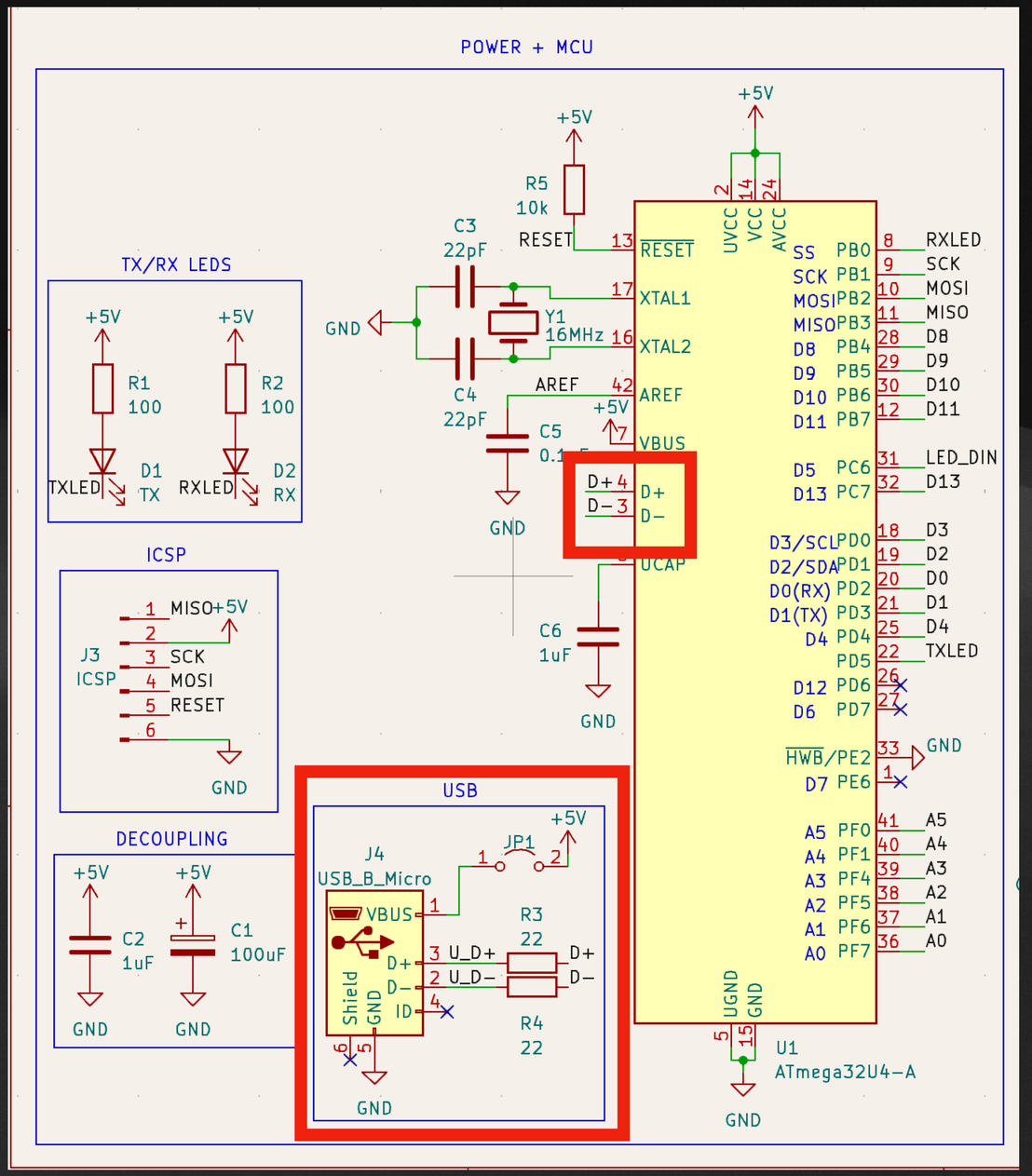
- ICSP = In-Circuit Serial Programming
- Allows us to upload the microcontroller's bootloader (in our case Arduino bootloader) directly via SPI



about the board

USB

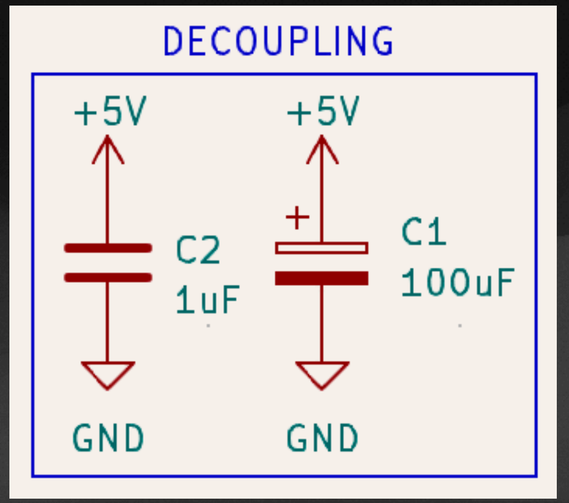
- Microcontrollers usually communicate via a serial protocol called UART
- Our microcontroller has an onboard USB to serial interface, and exposes two USB data pins
- This will allow us to program the microcontroller from the Arduino IDE once the bootloader is flashed.
- There is a 5V jumper should you power the board externally.



about the board

decoupling capacitors

- Stabilize power supply voltage in electronic circuits by filtering out noise and transient voltage spikes.
- Store charge and provide instantaneous current to maintain steady voltage.
- Usually placed near power pads.



$$C = \frac{I}{2\Pi f V_{IC}}$$

Where

- f is the frequency
- V_{IC} is the IC's voltage
- I is the drawn current