Essentials of PCB Design

02: Project Design

pcb.wpi.edu

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about this class

schedule

C-Term

Mon, Feb. 16	Basics of PCBs **6-7PM; AK 116**
Fri, Feb. 20	Designing your Project **6-7PM; AK 116**
Mon, Feb. 23	Layout + Routing **6-7PM; AK 116**
Fri, Feb. 27	Working with KiCad **6-7PM; AK 116**
Mon, Mar. 2 Optional	Advanced Topics **6-7PM; AK 116**

D-Term

Week of Mar. 16	Office Hours **Time TBD**
Sat, Mar. 21	Boards Due **Midnight**
Week of Mar. 30	Assembly Sessions **Times TBD**

course tracks

choose one!

Track 1

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

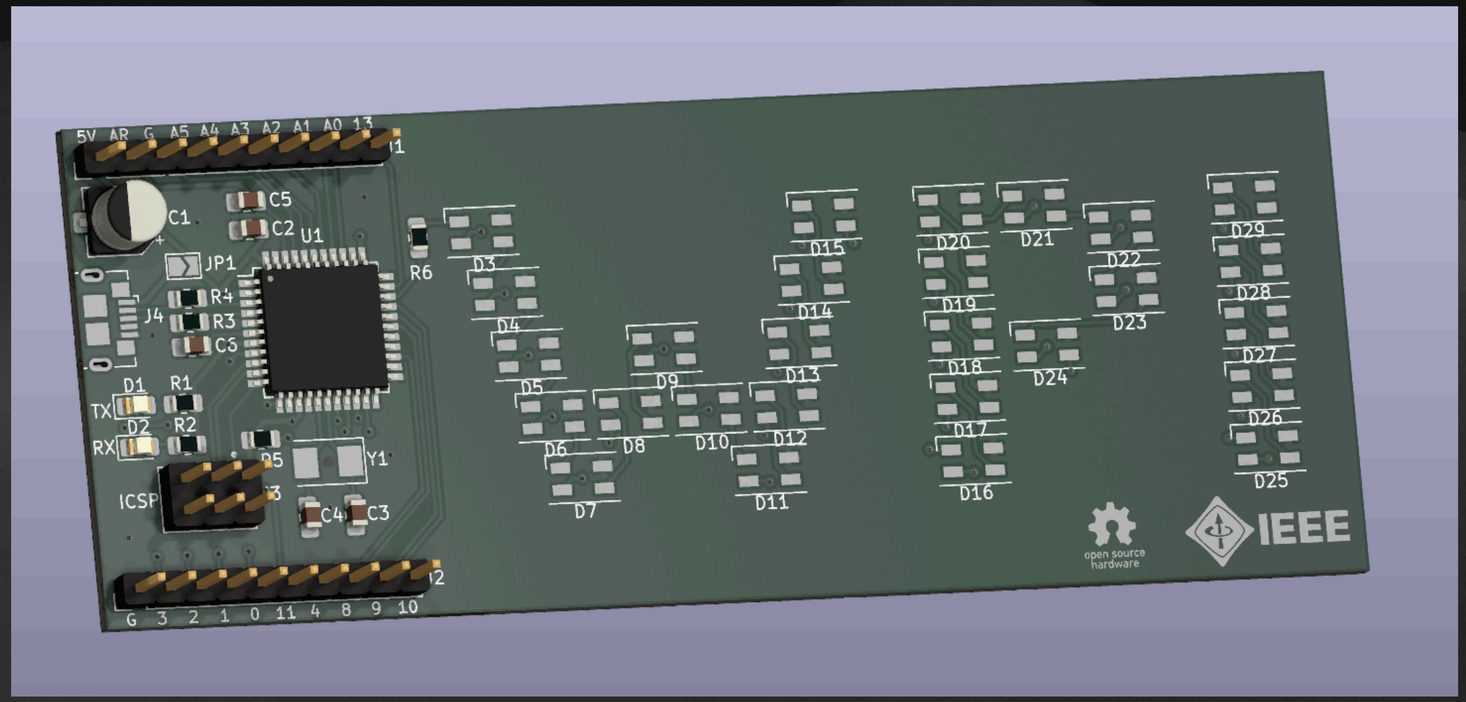
Design your own schematic and board, up to 102x102mm, and we'll fund it + up to $10 in components.

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

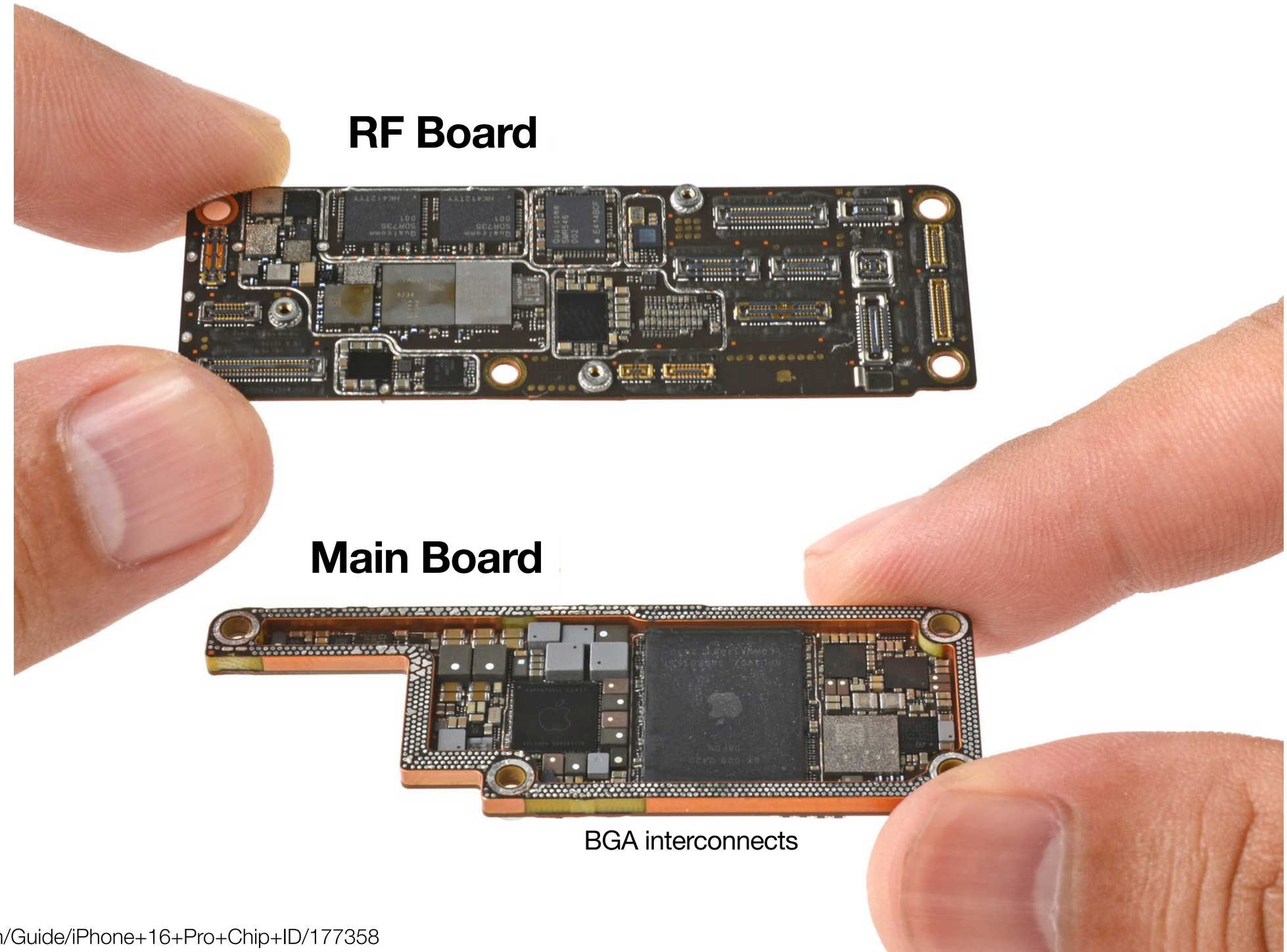
goals

- We’ll show you a variety of projects
- We want you to understand how to approach building custom hardware
- You learn these skills through designing your own hardware, end to end
- Not at college or a job

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

Some really cool PCBs…

iPhone 16 Pro Logic Board



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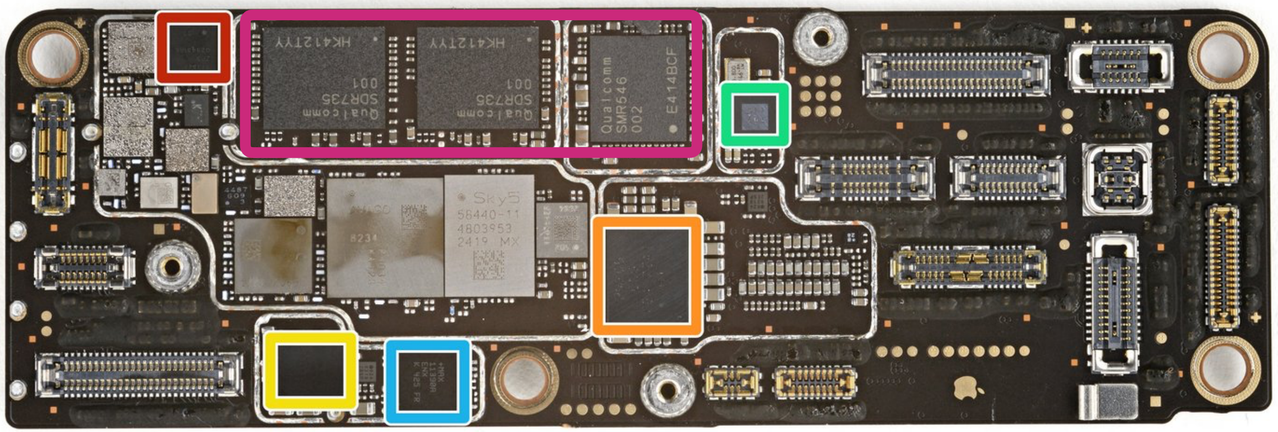
RF Board (Top)



EMI shielding has been removed

- STMicroelectronics eSIM/secure element
- Qualcomm power management
- Cirrus Logic audio amplifier
- Qualcomm clock generator
- Analog Devices ADC
- Qualcomm RF front end

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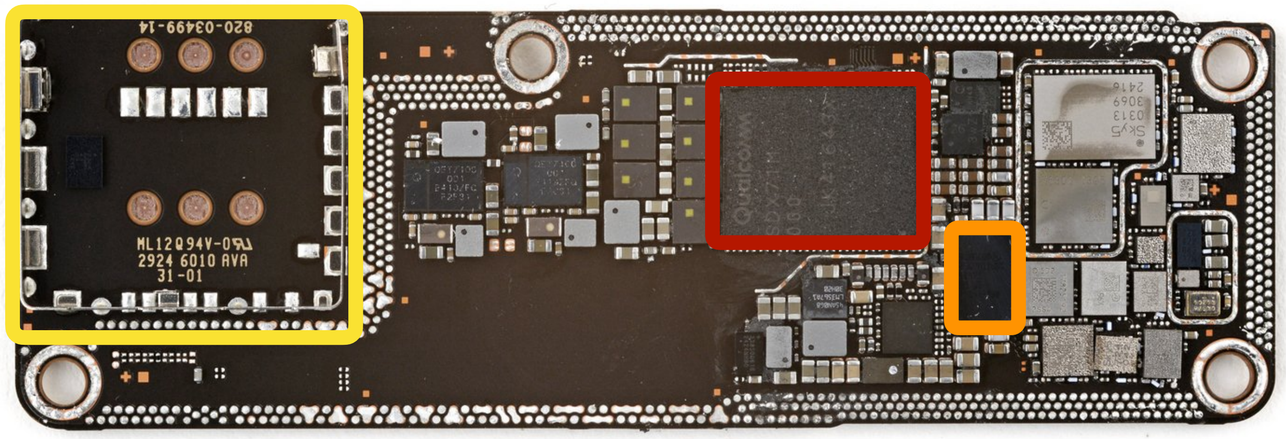
RF Board (Bottom)

BGA interconnects



EMI shielding has been removed

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

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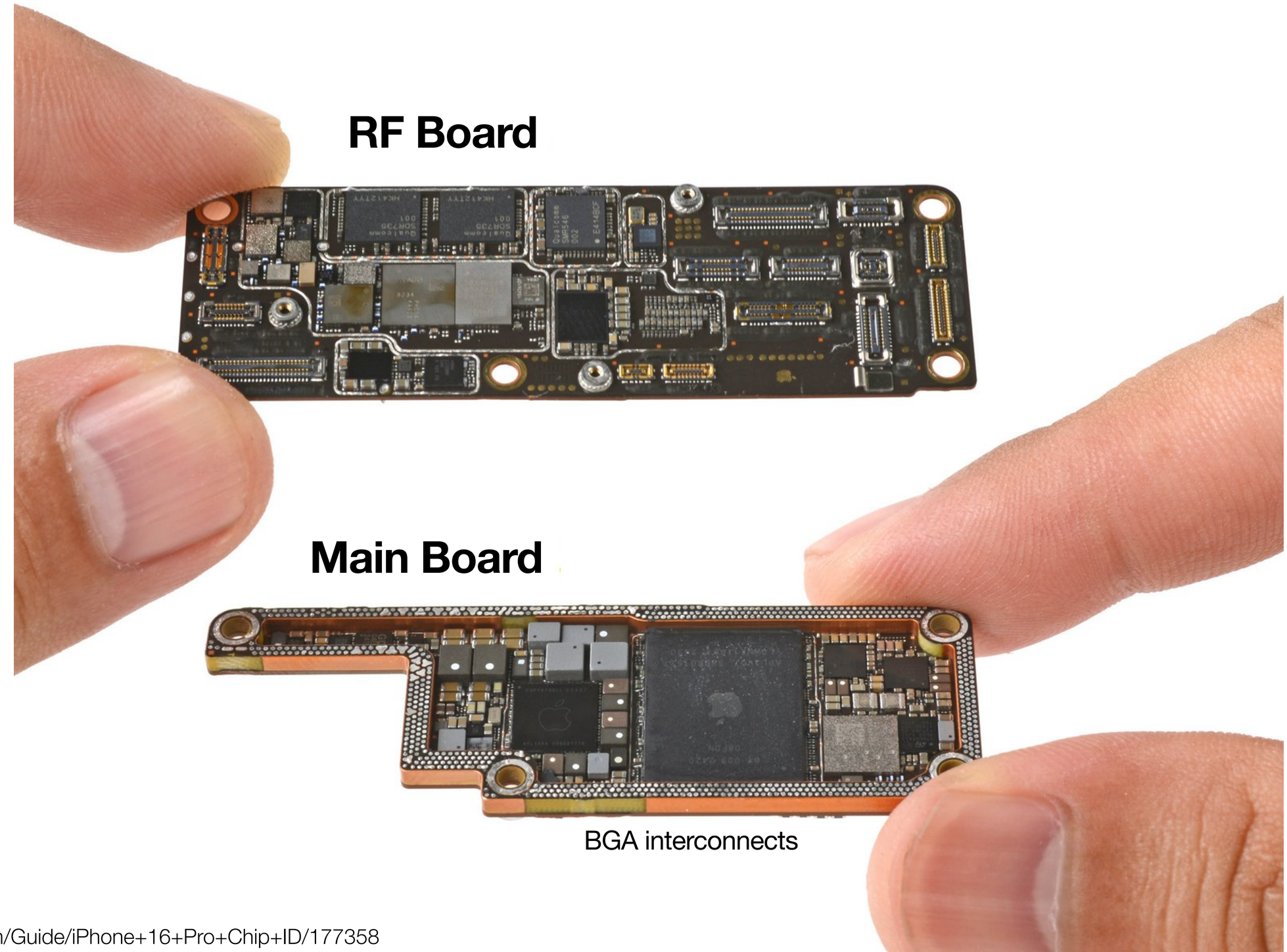

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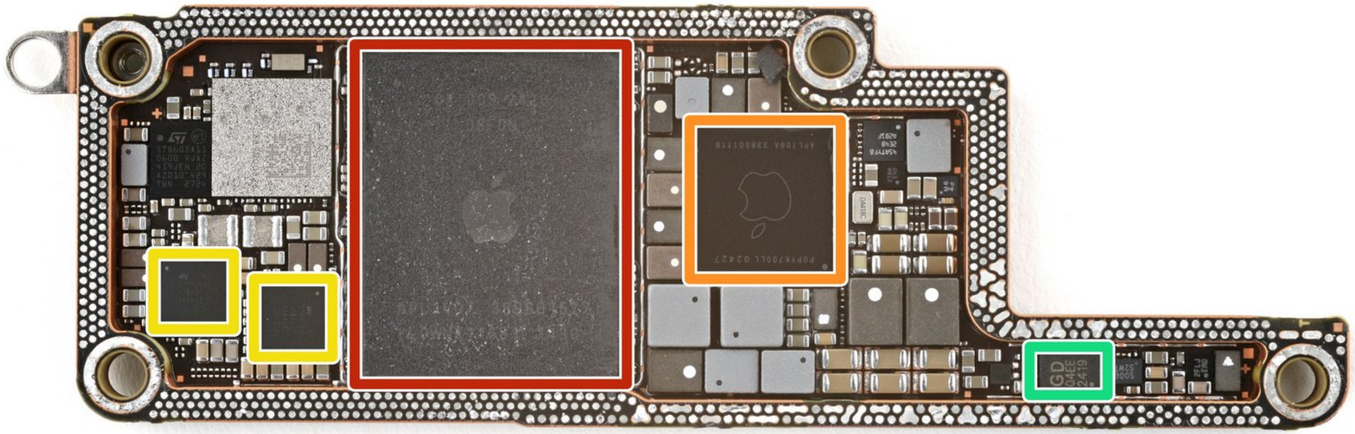
Main Board (Top)



BGA interconnects

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

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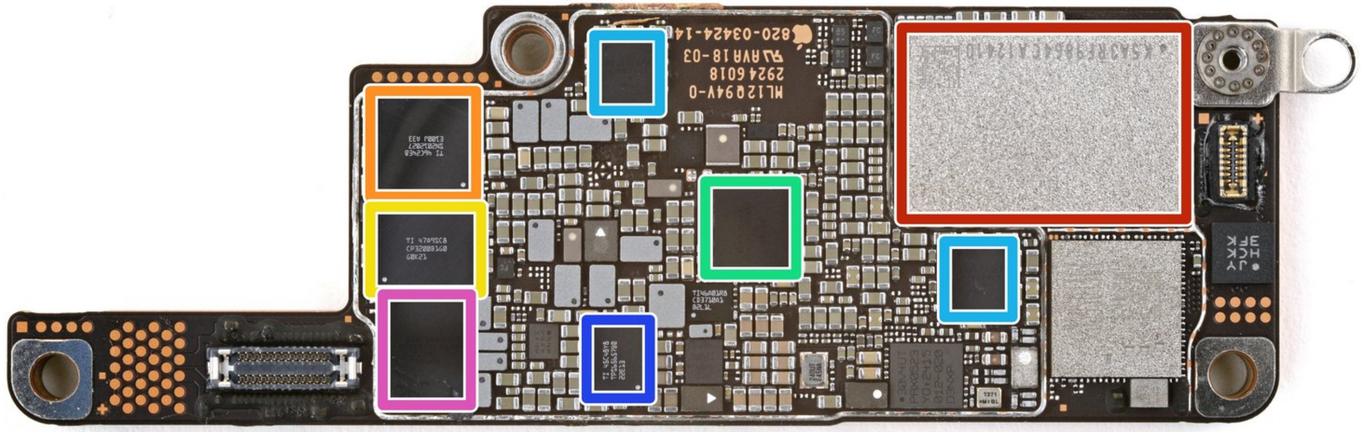
Main Board (Bottom)



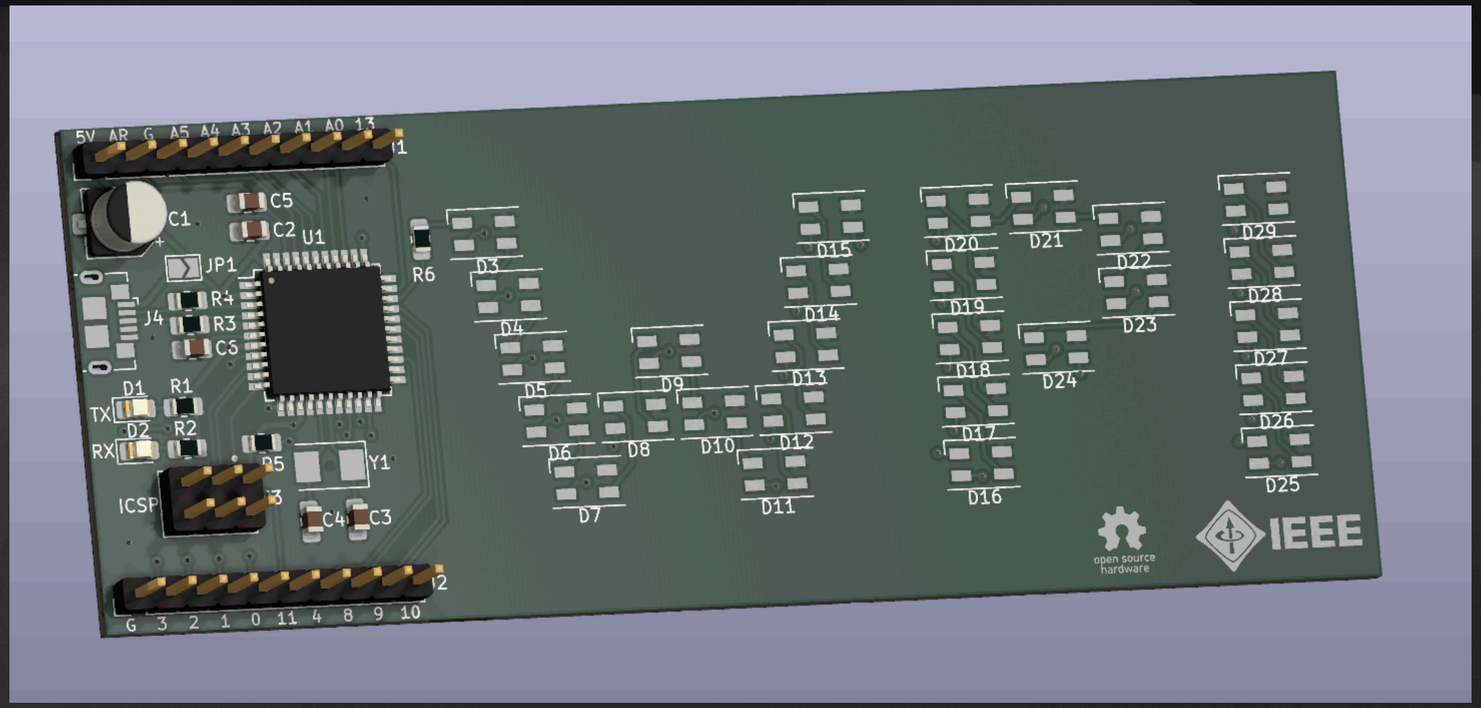
- Kioxia 128 GB NAND flash memory
- Texas Instruments USB-C controller
- Texas Instruments battery charger
- Cirrus Logic audio codec
- Cirrus Logic audio amplifier
- Texas Instruments display power supply
- Cirrus Logic power management

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

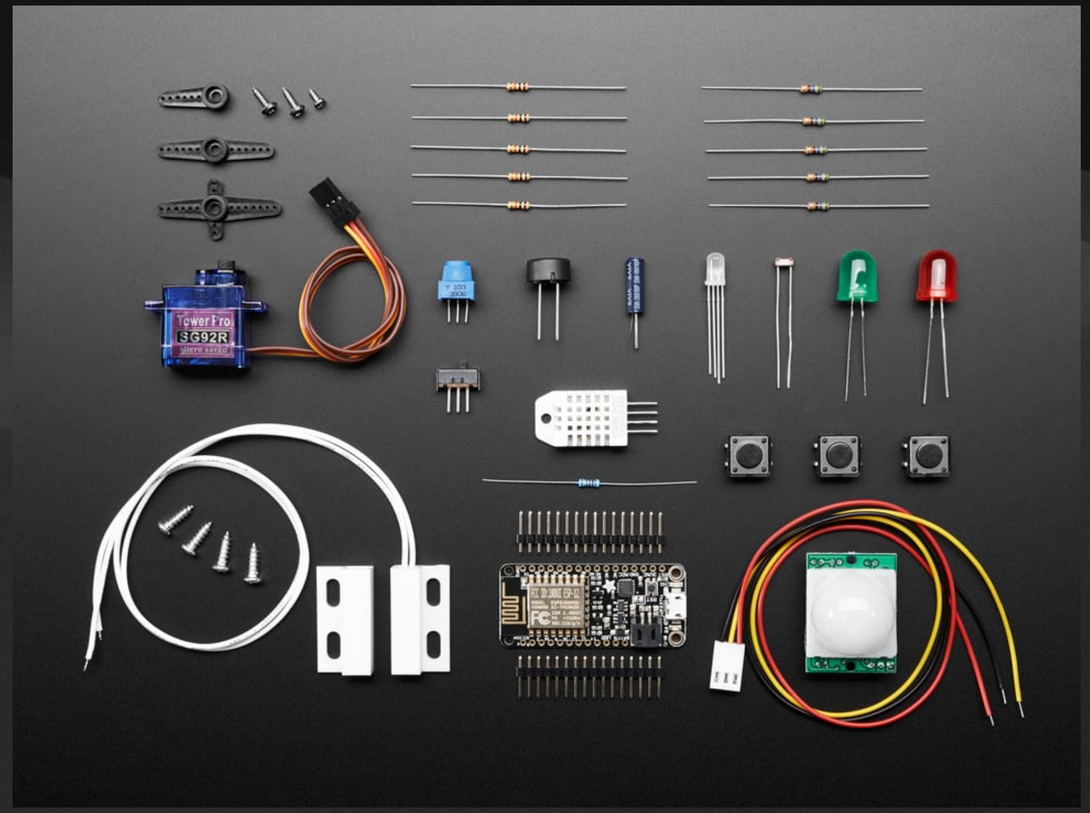
i want to make something

- **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

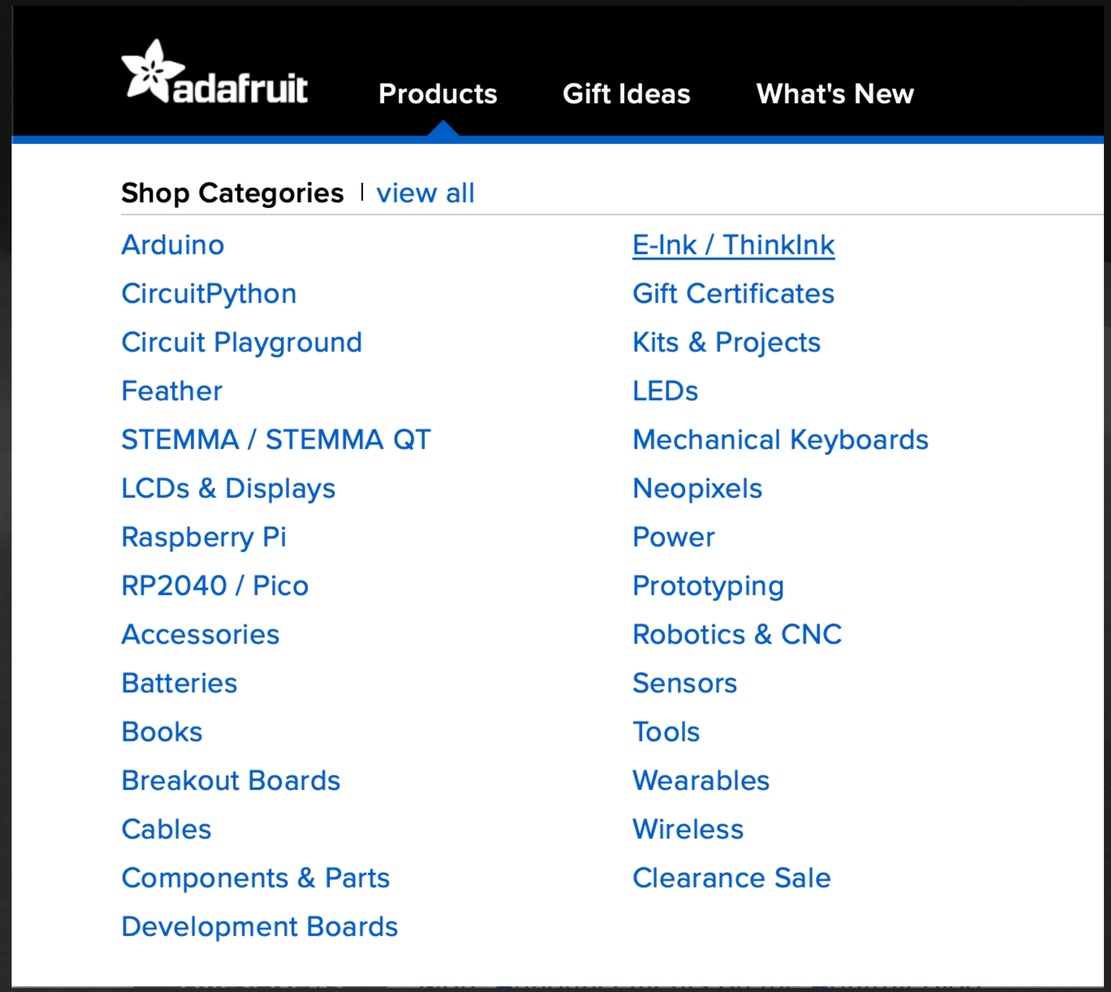
- Start with a project idea
  - Often fun to start with **peripherals** and what you want them to do
- Break down design into **major components**
- Research possible components and how to connect them to your peripherals
- Worry about details (passives) later



research and design

research

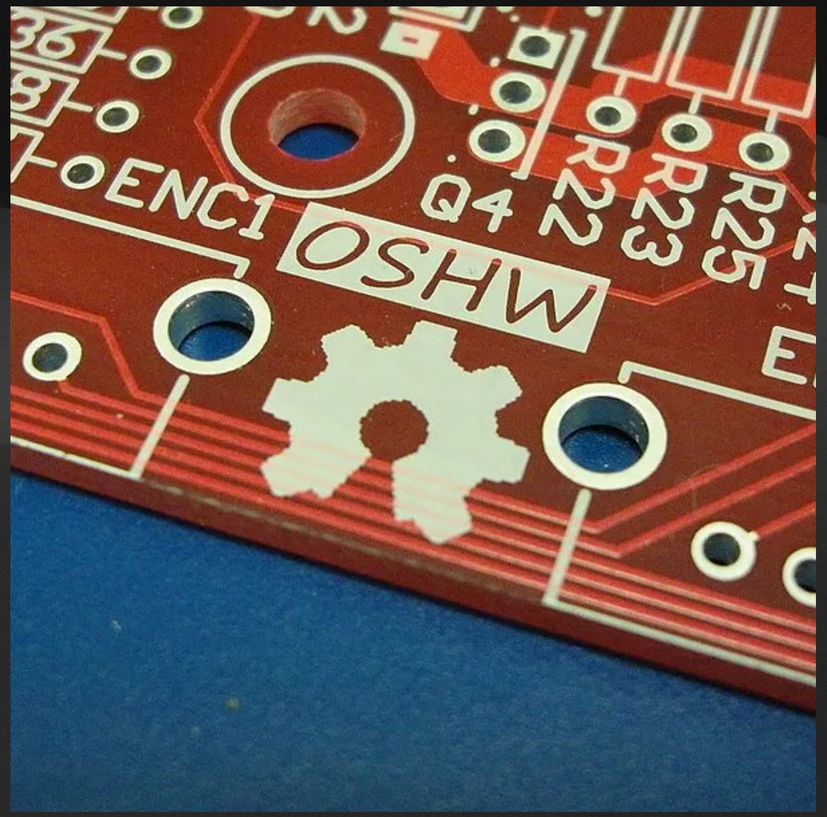
- **Cool parts, inspiration, docs:**
  - Adafruit
  - SparkFun
- **Major parts distributors:**
  - DigiKey
  - Mouser



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
- Open source your project to inspire others and showcase your technical skills



Some project examples…

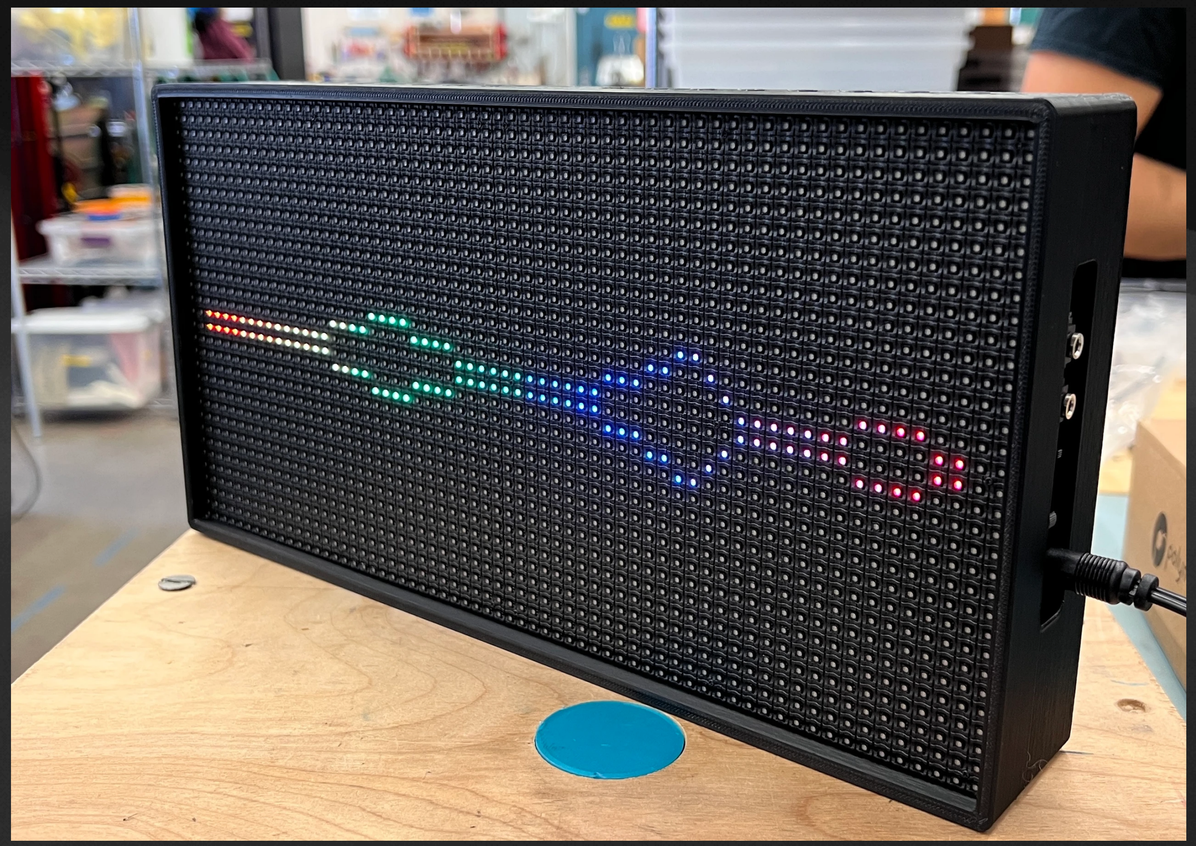
project examples
to get you excited!

1. 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

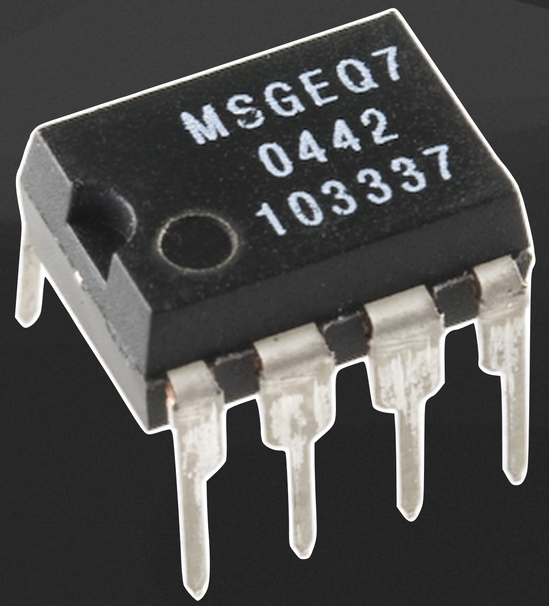


github.com/dgorbunov/TeensyVisualizer

teensy visualizer

components

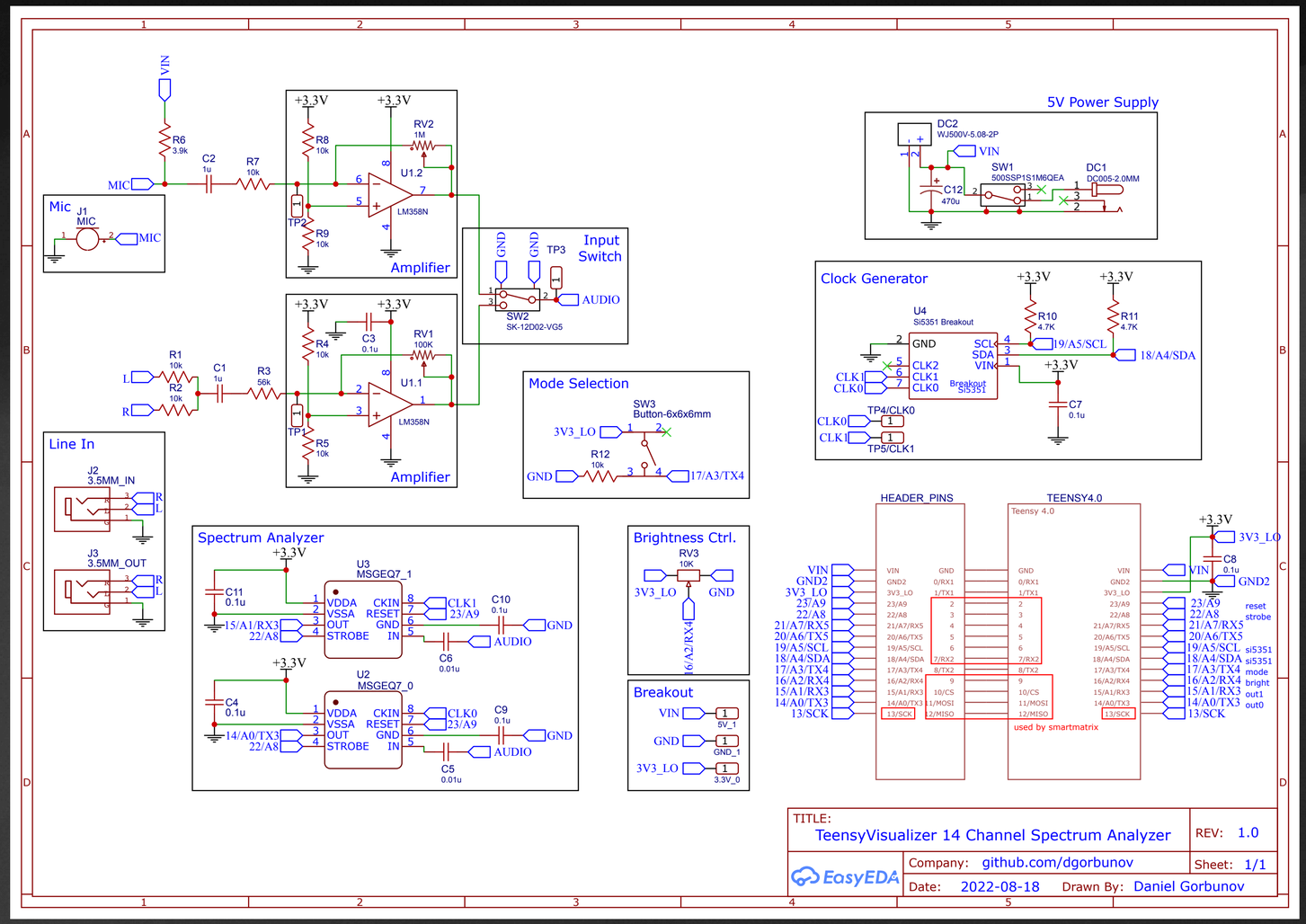
- Microcontroller (Teensy 4.0)
- LED matrix
- SmartLED driver board
- Line-in jack
- Microphone + Amplifier (LM358)
- Variable clock generator
- Graphic EQ chip (MSGEQ7)



github.com/dgorbunov/TeensyVisualizer

teensy visualizer

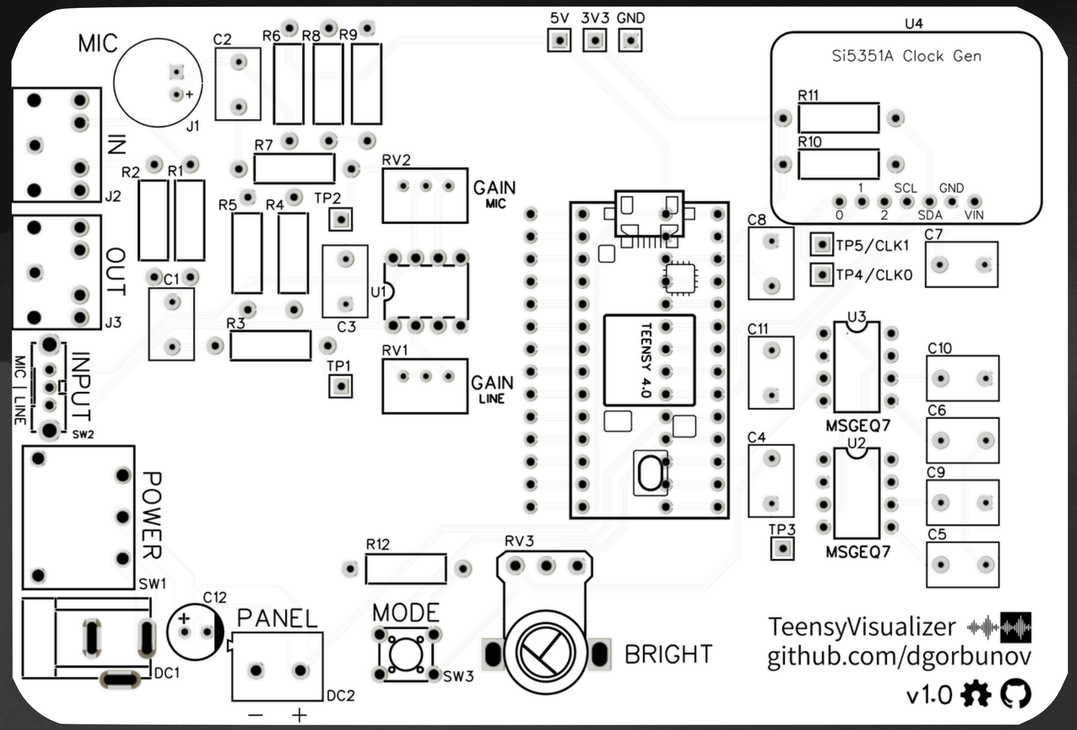
schematic

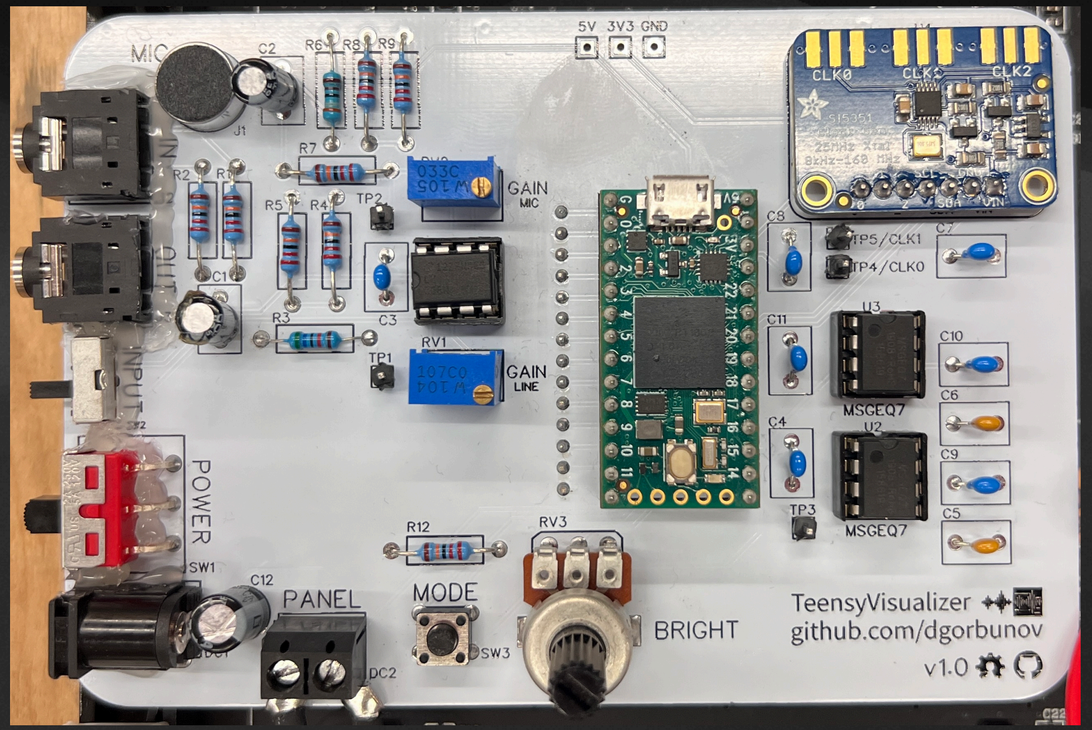


github.com/dgorbunov/TeensyVisualizer

teensy visualizer

board



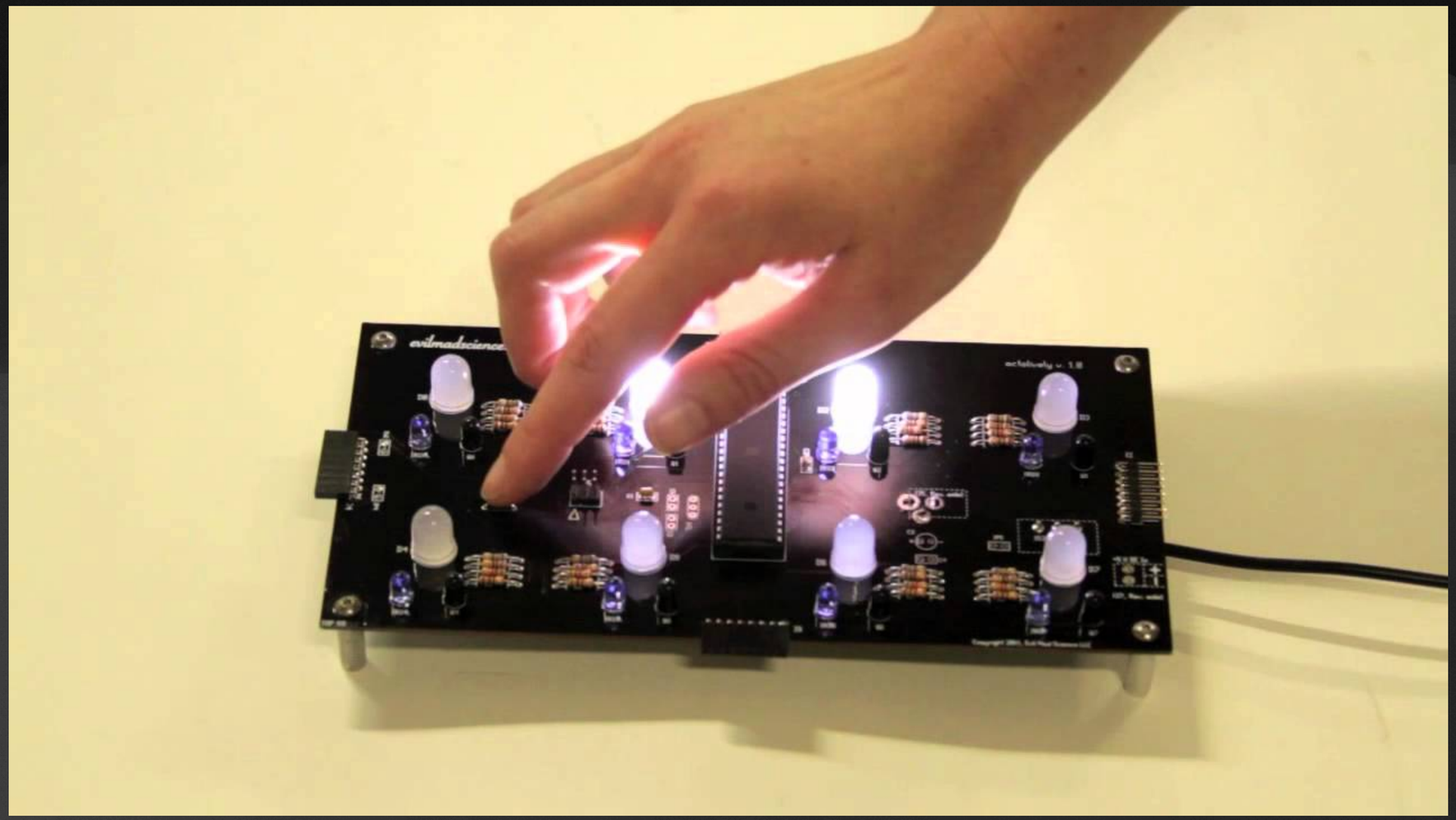


github.com/dgorbunov/TeensyVisualizer

Interactive LED Art

reactive LEDs

inspiration



github.com/dgorbunov/ReactiveLEDMatrix

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

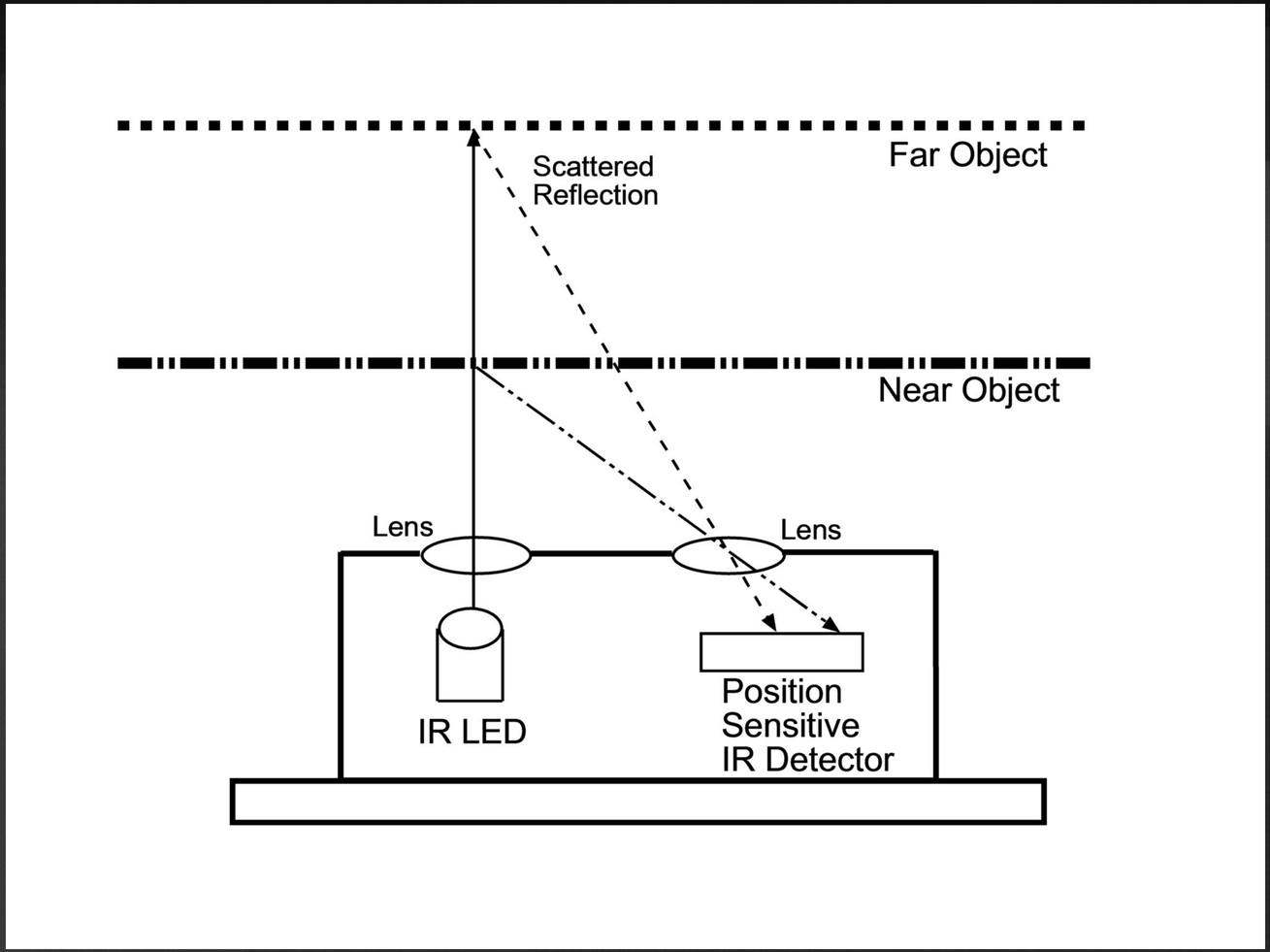
components

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

github.com/dgorbunov/ReactiveLEDMatrix

reactive LEDs

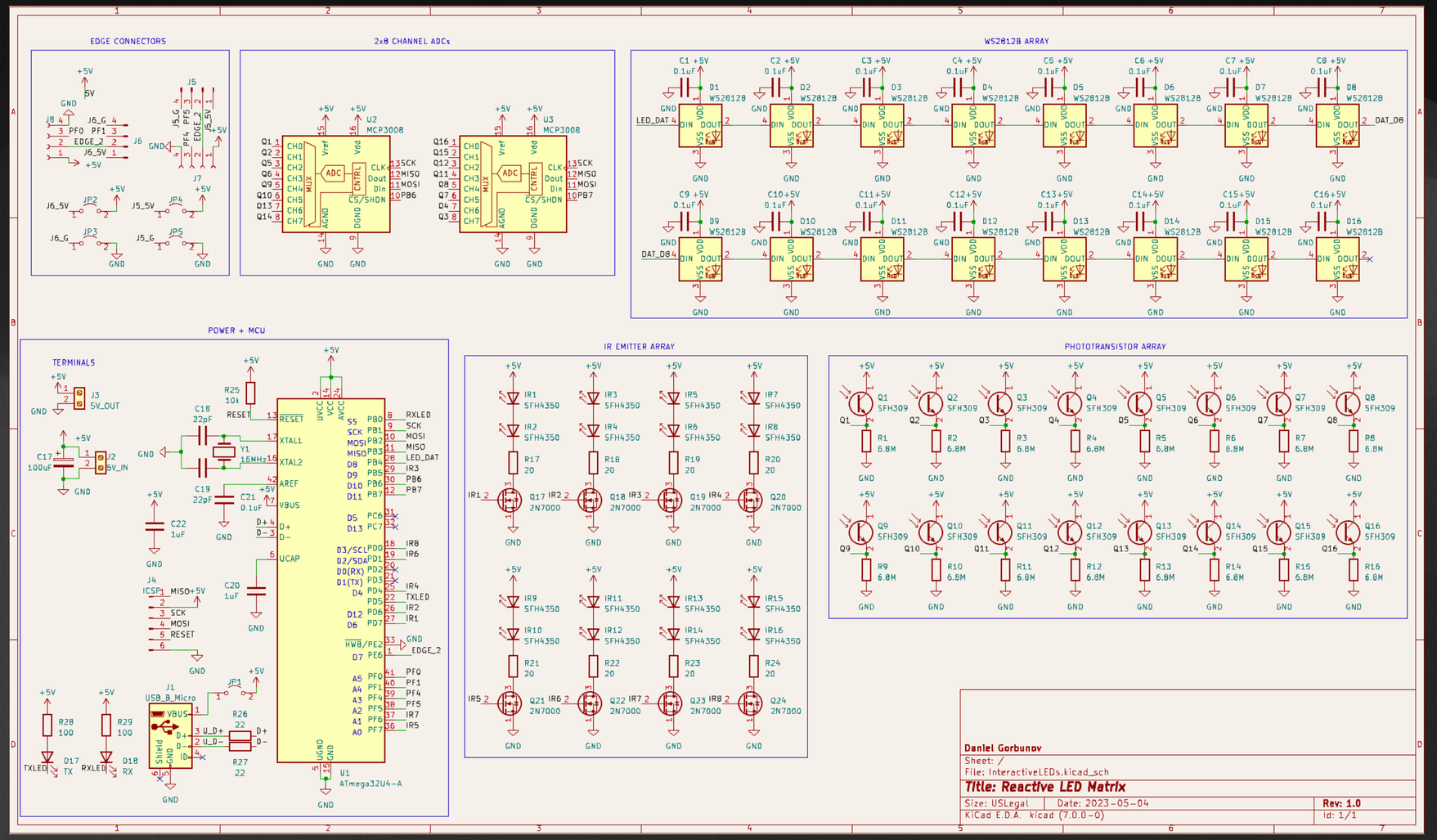
infrared sensing



github.com/dgorbunov/ReactiveLEDMatrix

reactive LEDs

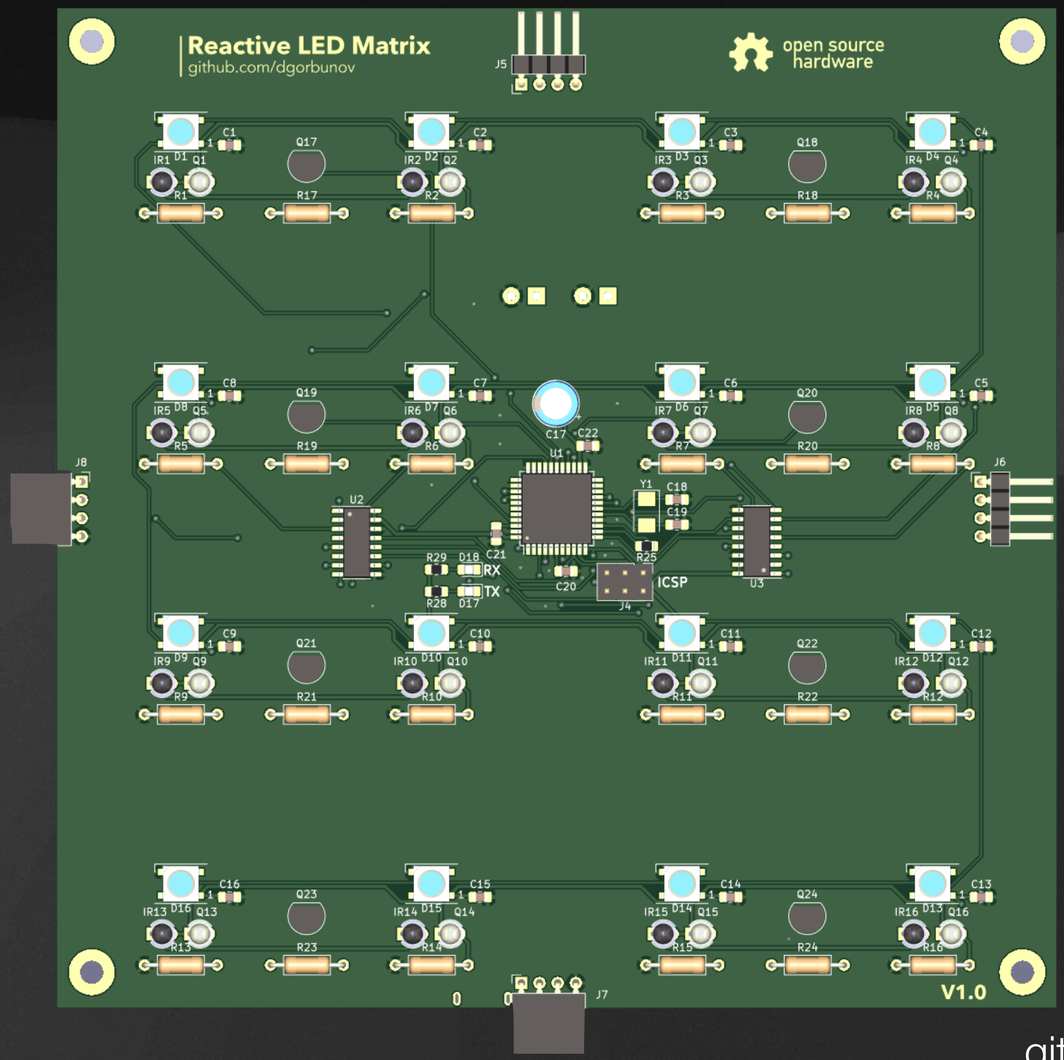
schematic



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 poweredMPosition/orientation should be trackable in 3D space

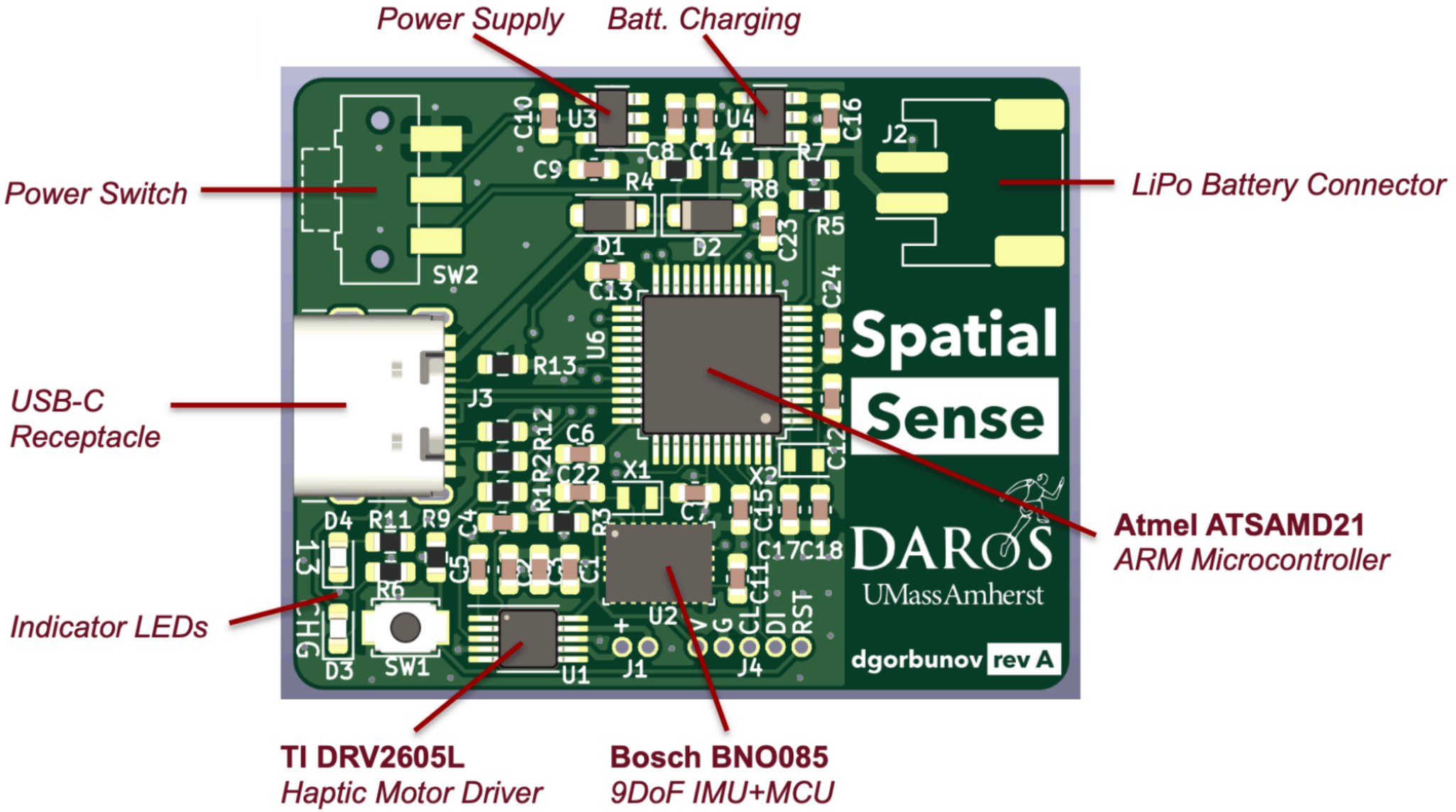
github.com/dgorbunov/SpatialSense

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

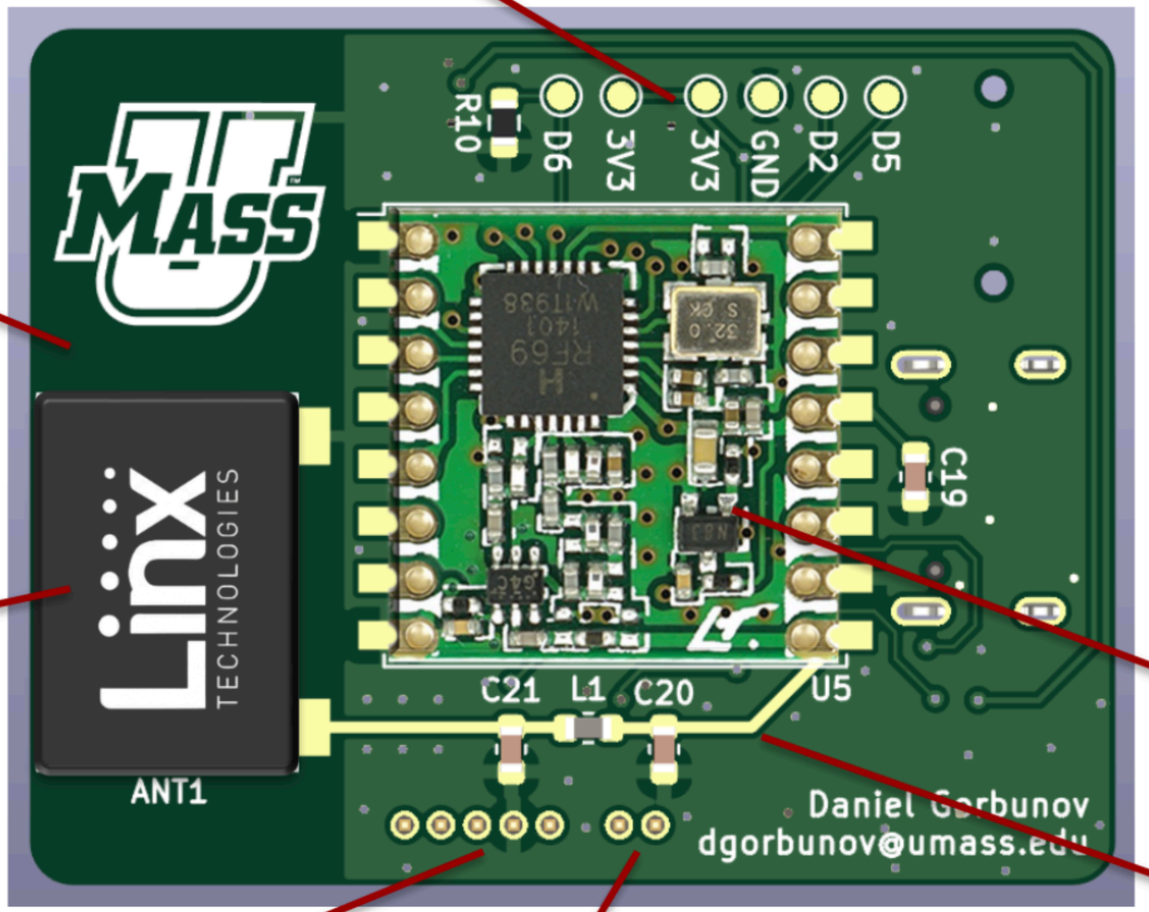


github.com/dgorbunov/SpatialSense

Breakouts (extra features)

RF Plane (no GND)

Linx Antenna
915MHz, Tuned 50Ω Impedance



RFM69HCW
915MHz Packet Radio Transceiver

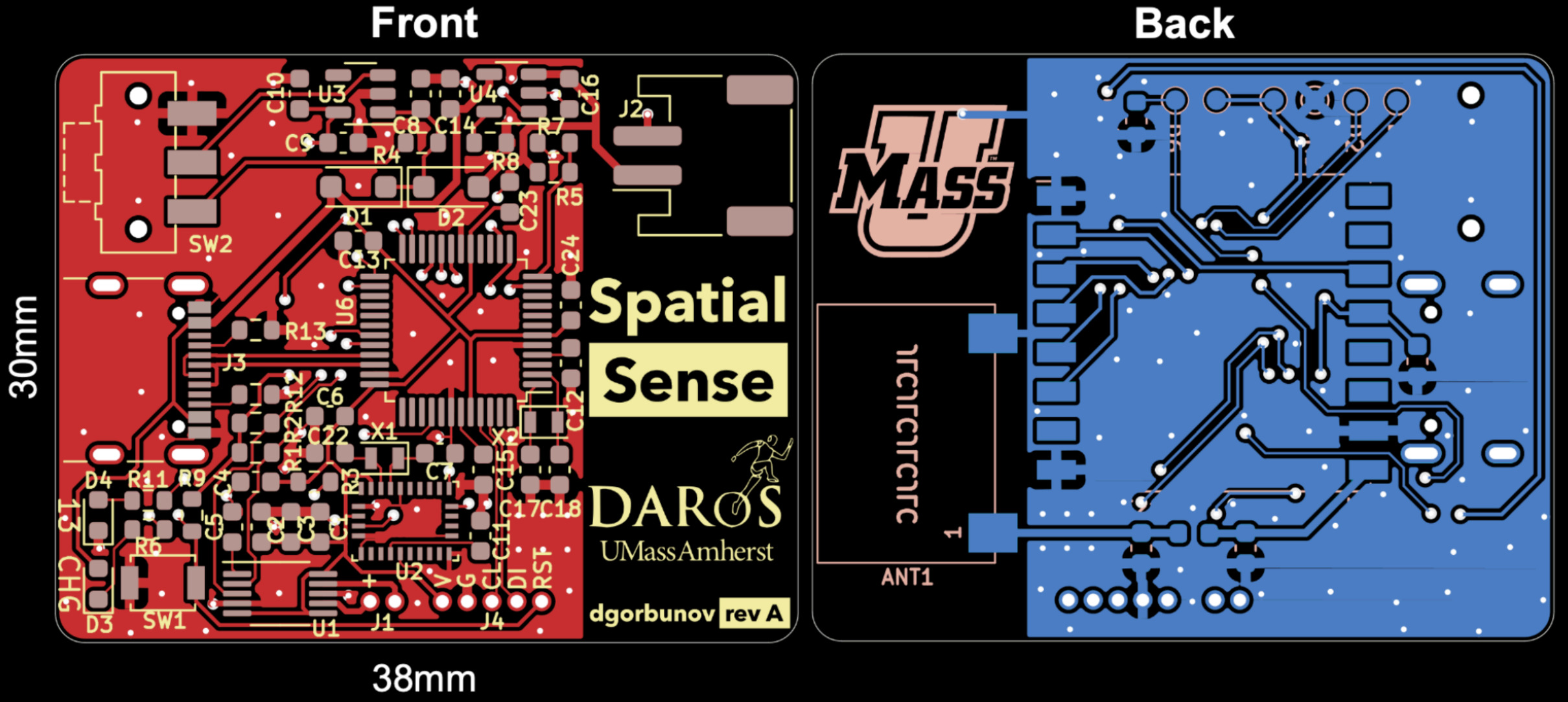
SWD Programming Interface

Vibration Motor Pins

RF Microstrip + Impedance Matching Network

github.com/dgorbunov/SpatialSense

PCB Layout

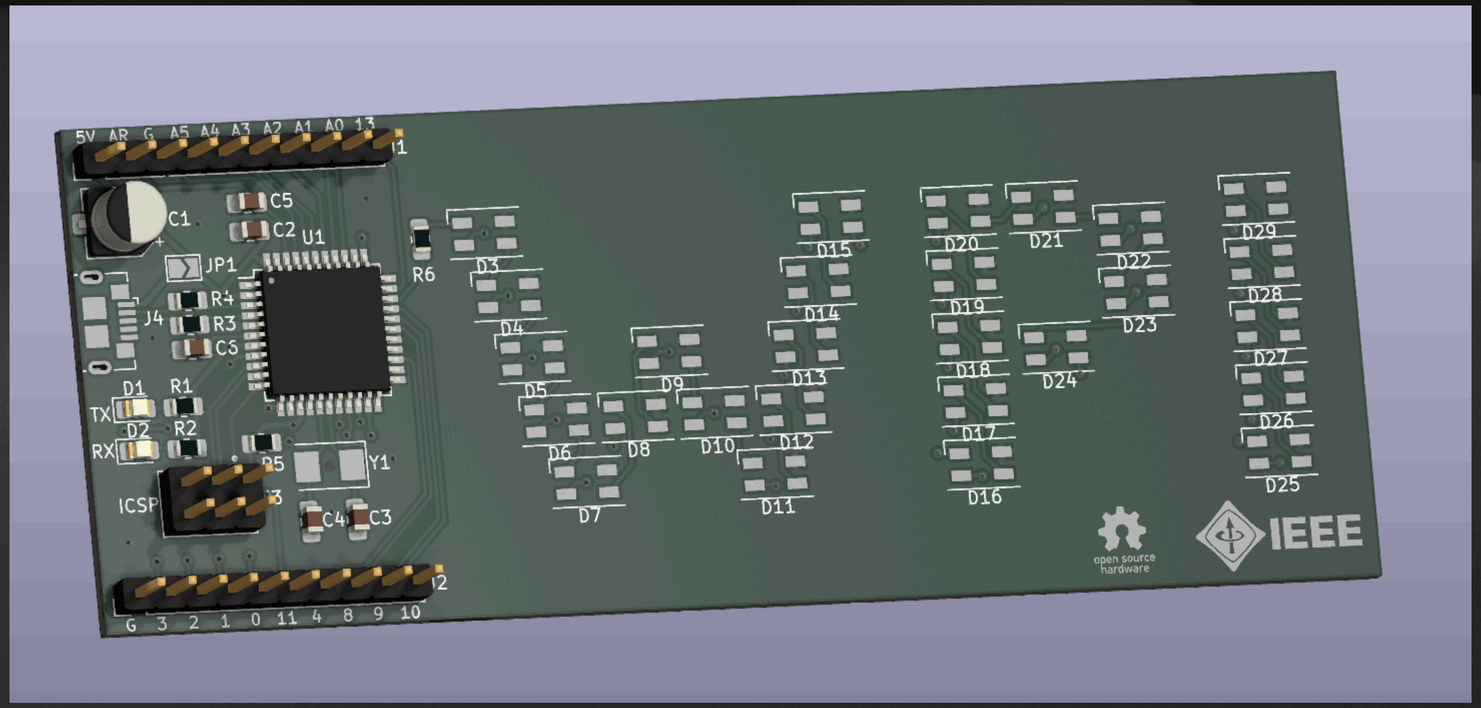


github.com/dgorbunov/SpatialSense

pcb design process

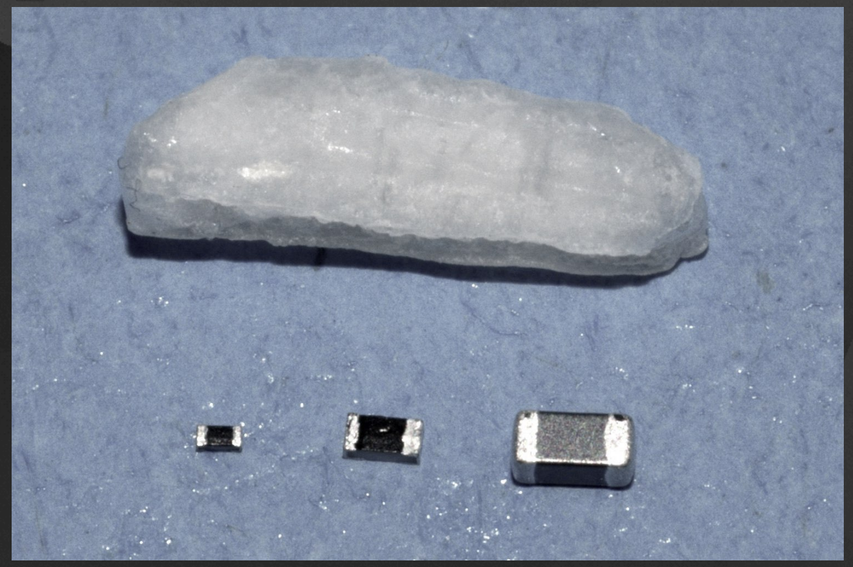
walkthrough

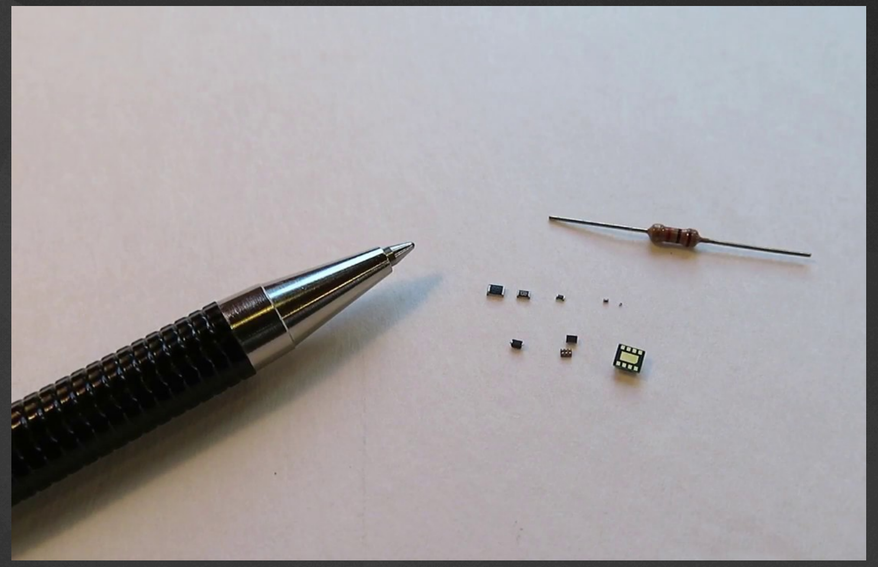
1. Research and Design
2. **Schematic Capture**
3. Layout
4. Routing
5. Order
6. Assembly

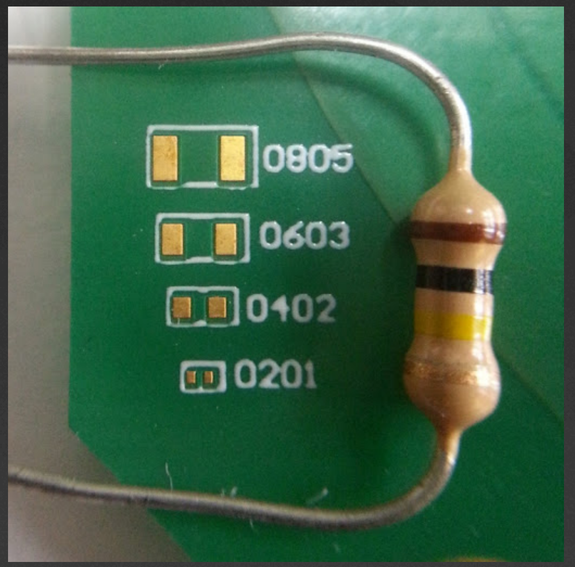


packages
an aside

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



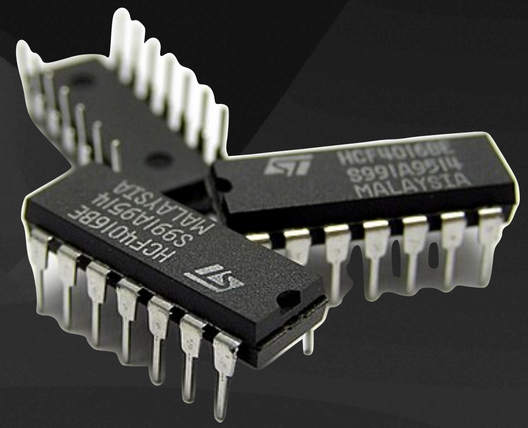


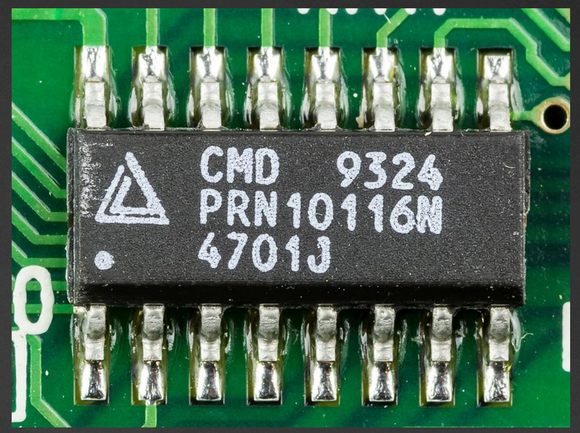


packages

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)

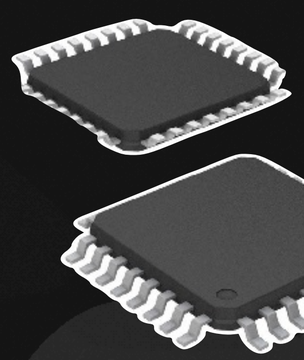




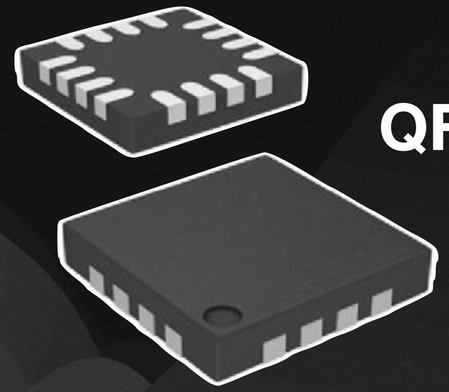
packages

complicated components

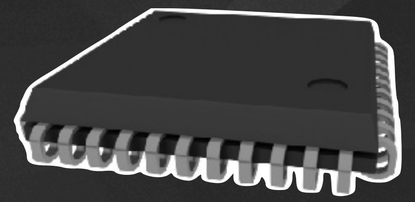
- **IC Packages**
  - Quad flat pack (QFP, TQFP)
  - Quad flat J (QFJ)
  - Quad flat pack no-lead (QFN, TQFN)
  - Ball grid array (BGA, FBGA)
  - Line grid array (LGA)



QFP

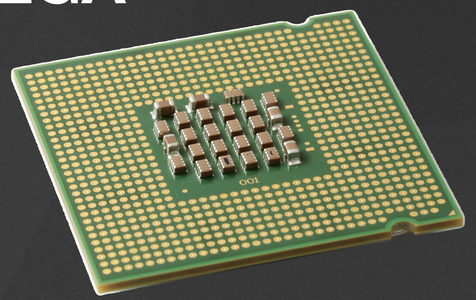


QFN

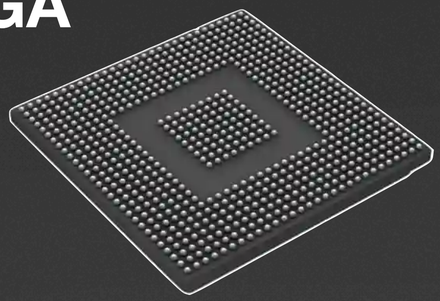


QFJ

LGA



BGA



packages
an aside

Pick the best package for your intended use case and production goals

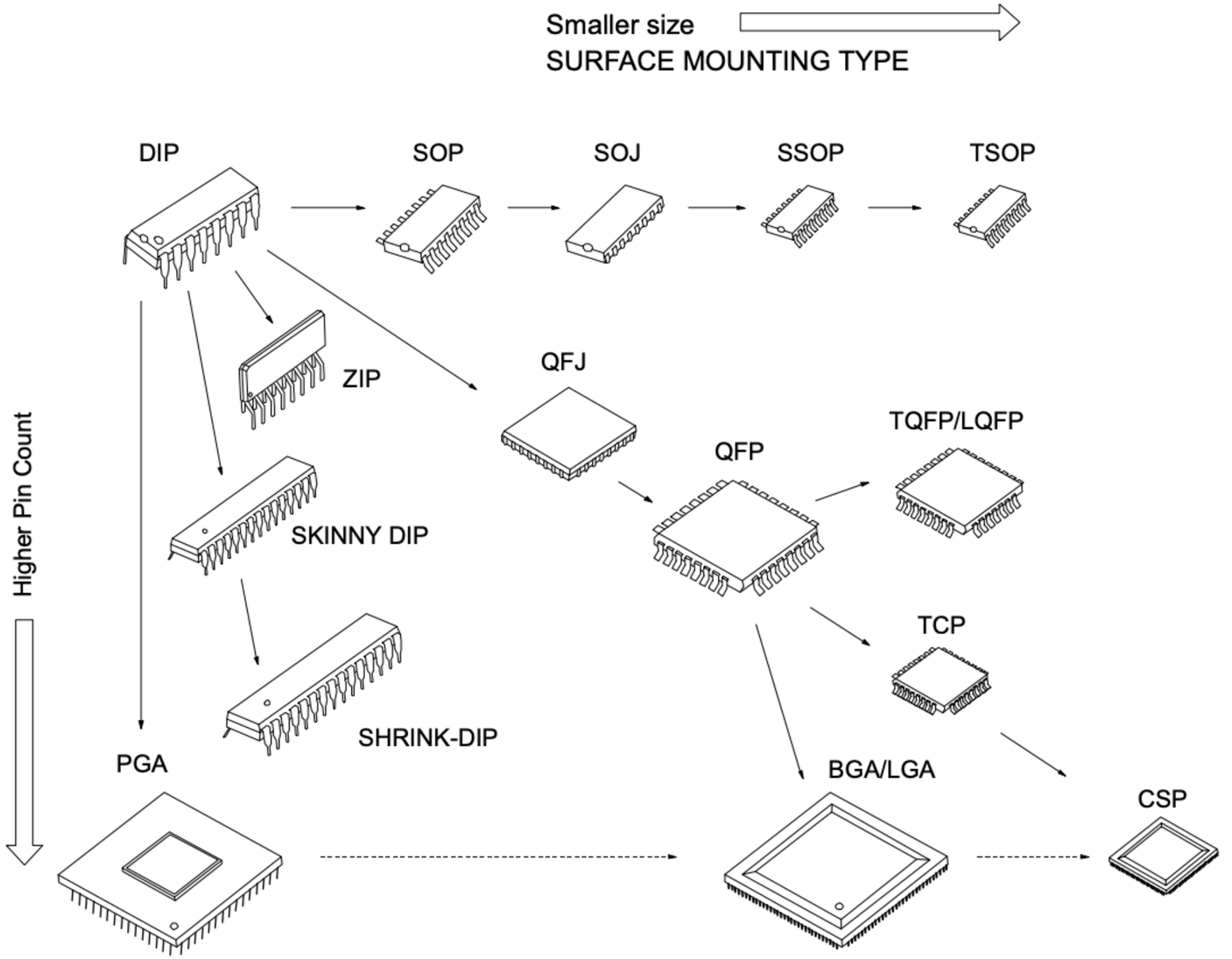


Figure 1.1.1 Packaging Trend

finding parts
process

- Use parts distributors (DigiKey, Mouser) to find specific components
- Read datasheets to find what the exact product variant 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

finding parts
microcontroller

- The Arduino IDE comes pre-installed with a compiler for this microcontroller (it is used on several Arduino boards)
- On-chip USB to Serial converter (no external chip required)
- Few external components required

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finding parts
microcontroller

Opt for external crystal over internal RC oscillator (significantly more stable)

44ML package = larger footprint (TQFP), easier to hand solder

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		

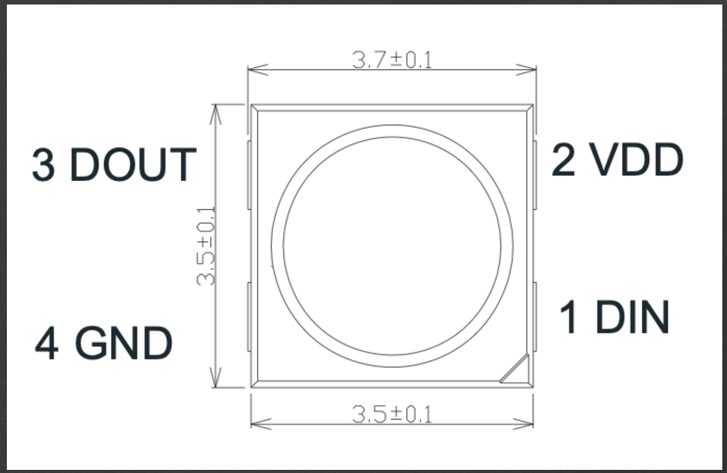
Notes:
1. For more information on running the USB from internal RC oscillator consult application note AVR291: 8MHz Internal Oscillator Calibration for USB Low Speed on Atmel ATmega32U4RC.
2. USB operation from internal RC oscillator is only guaranteed for 0°C to 40°C.
3. These parts are shipped with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

about the board

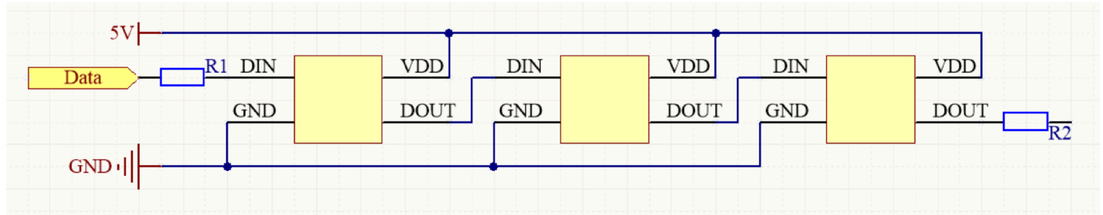
LEDs

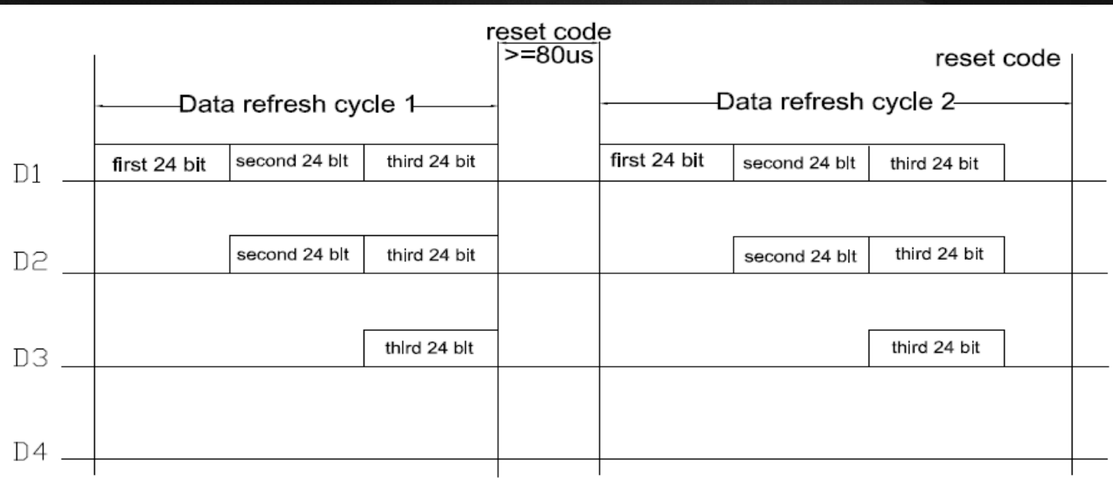
SK6812 MINI 3.5x3.5mm addressable RGB LEDs

Powered by 5V, data daisy chained



16. The typica l application circuit:





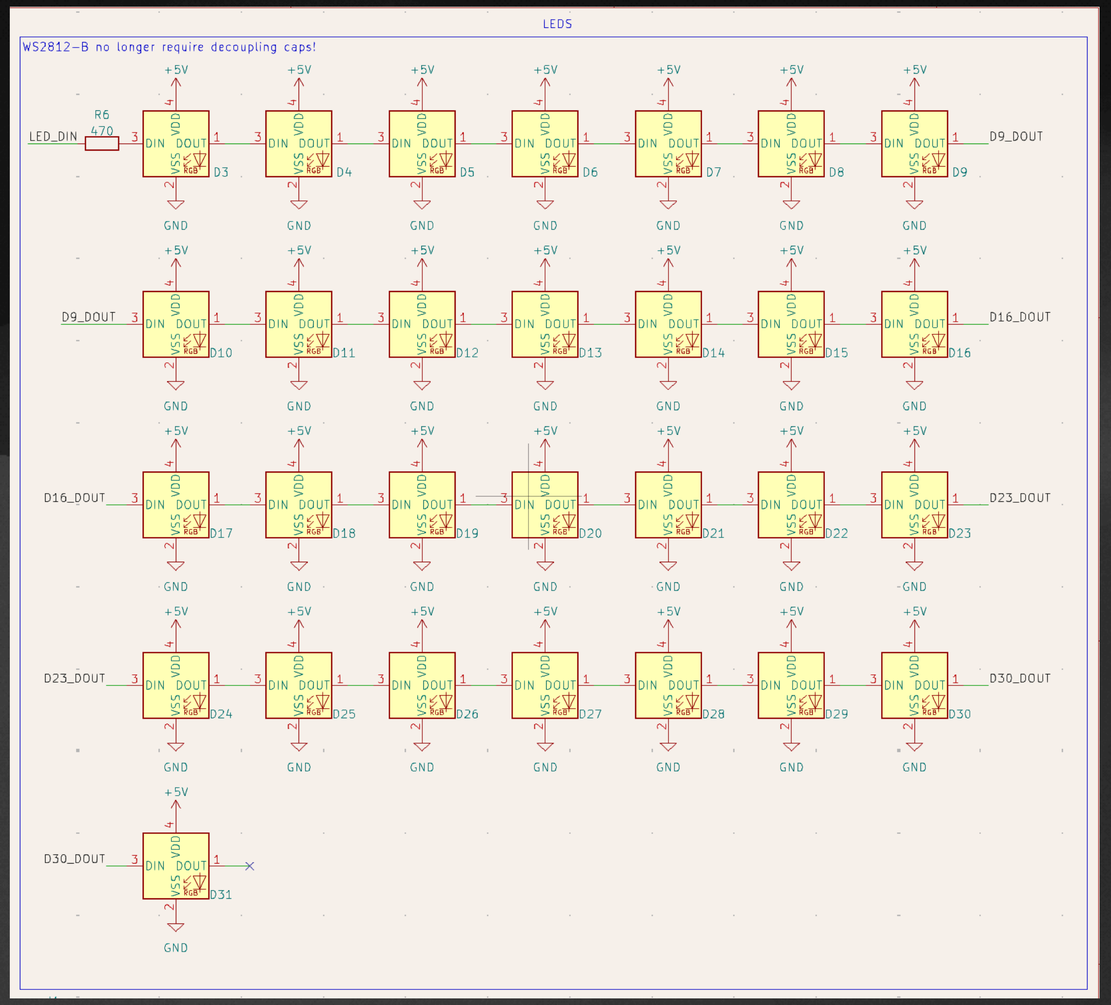
15. The data structure of 24bit:

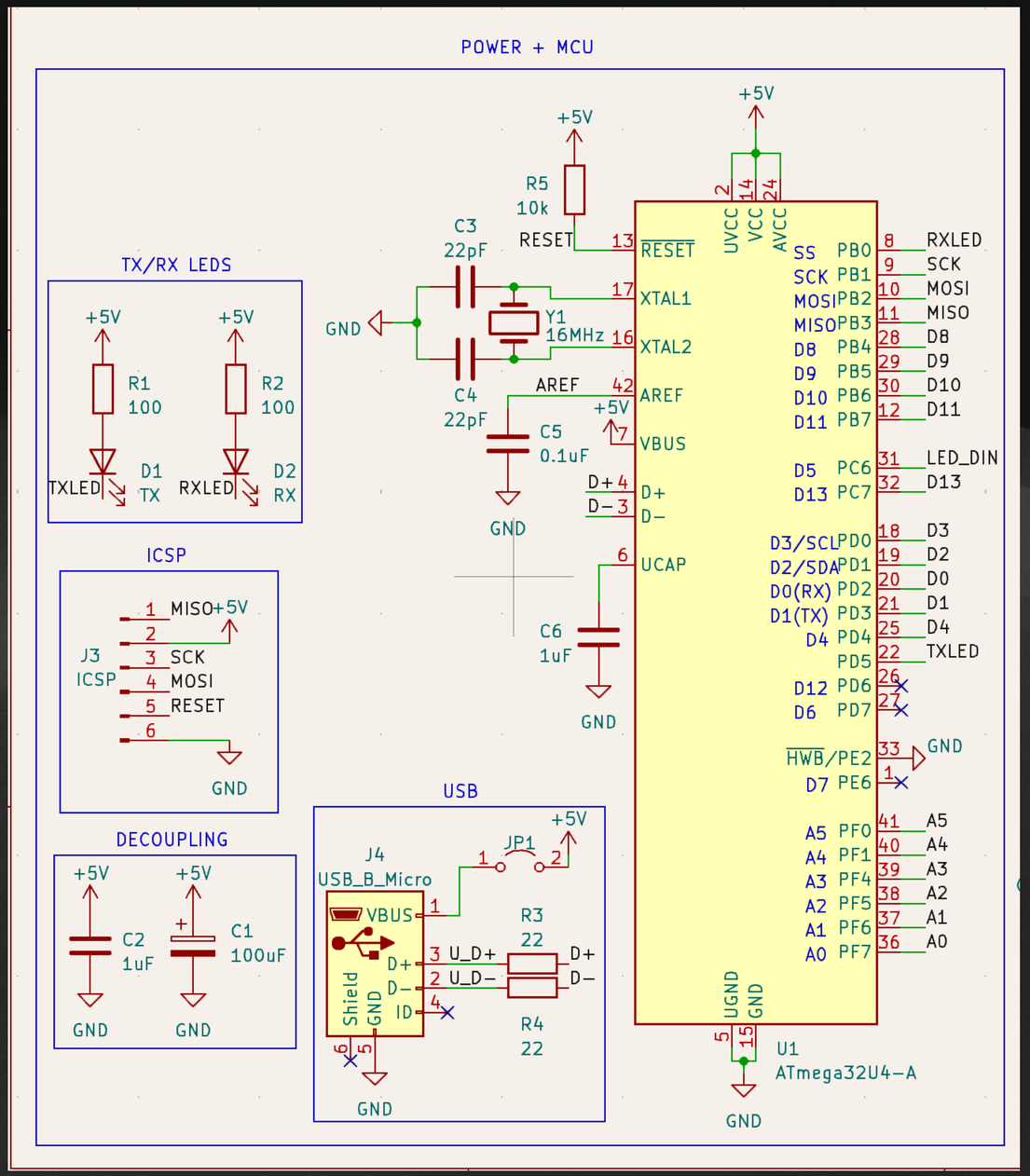
G7	G6	G5	G4	G3	G2	G1	G0	R7	R6	R5	R4
R3	R2	R1	R0	B7	B6	B5	B4	B3	B2	B1	B0

Note: high starting, in order to send data (G7 - G6 - ....B0)

about the board

specifics

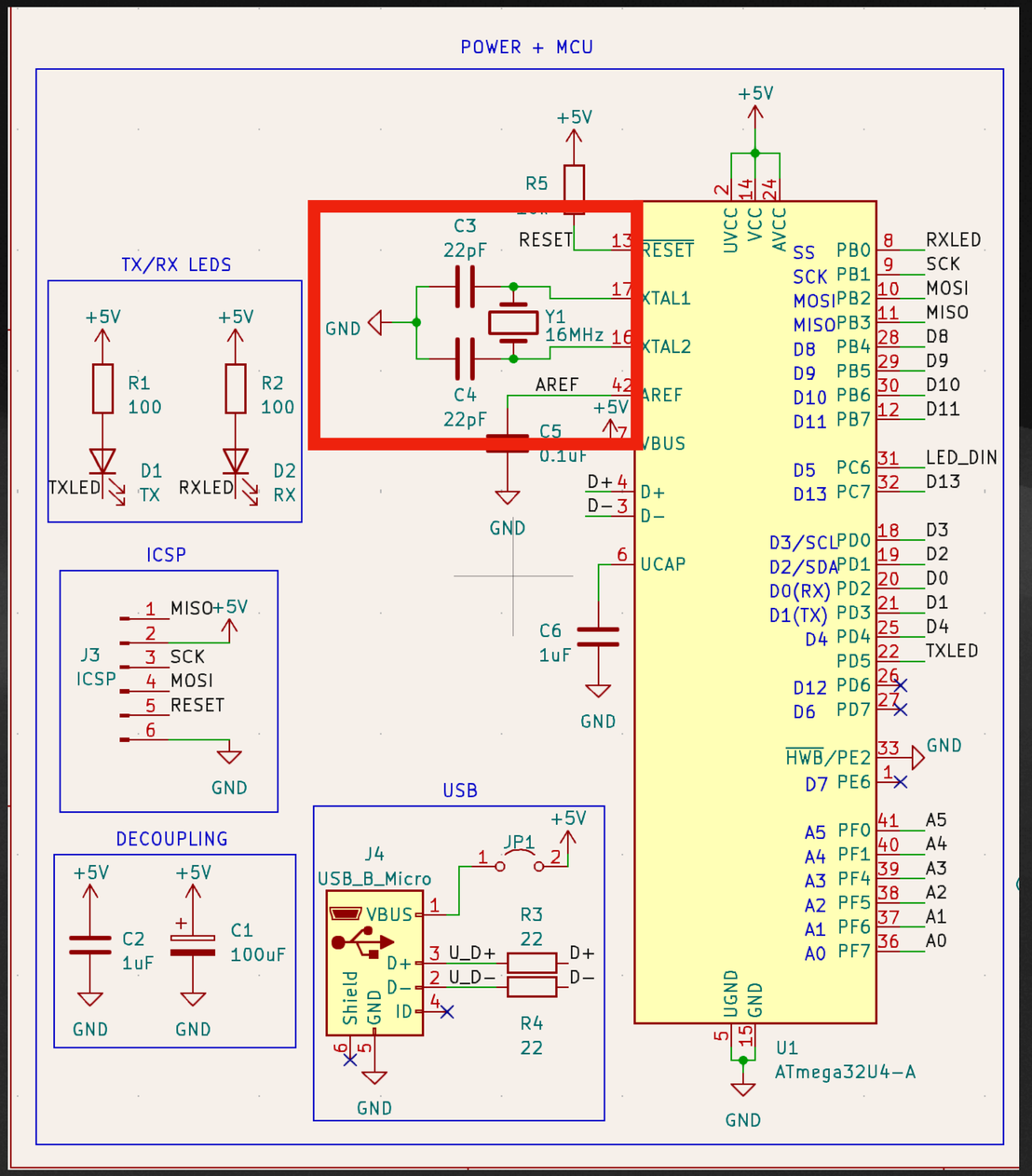




about the board

crystal oscillator

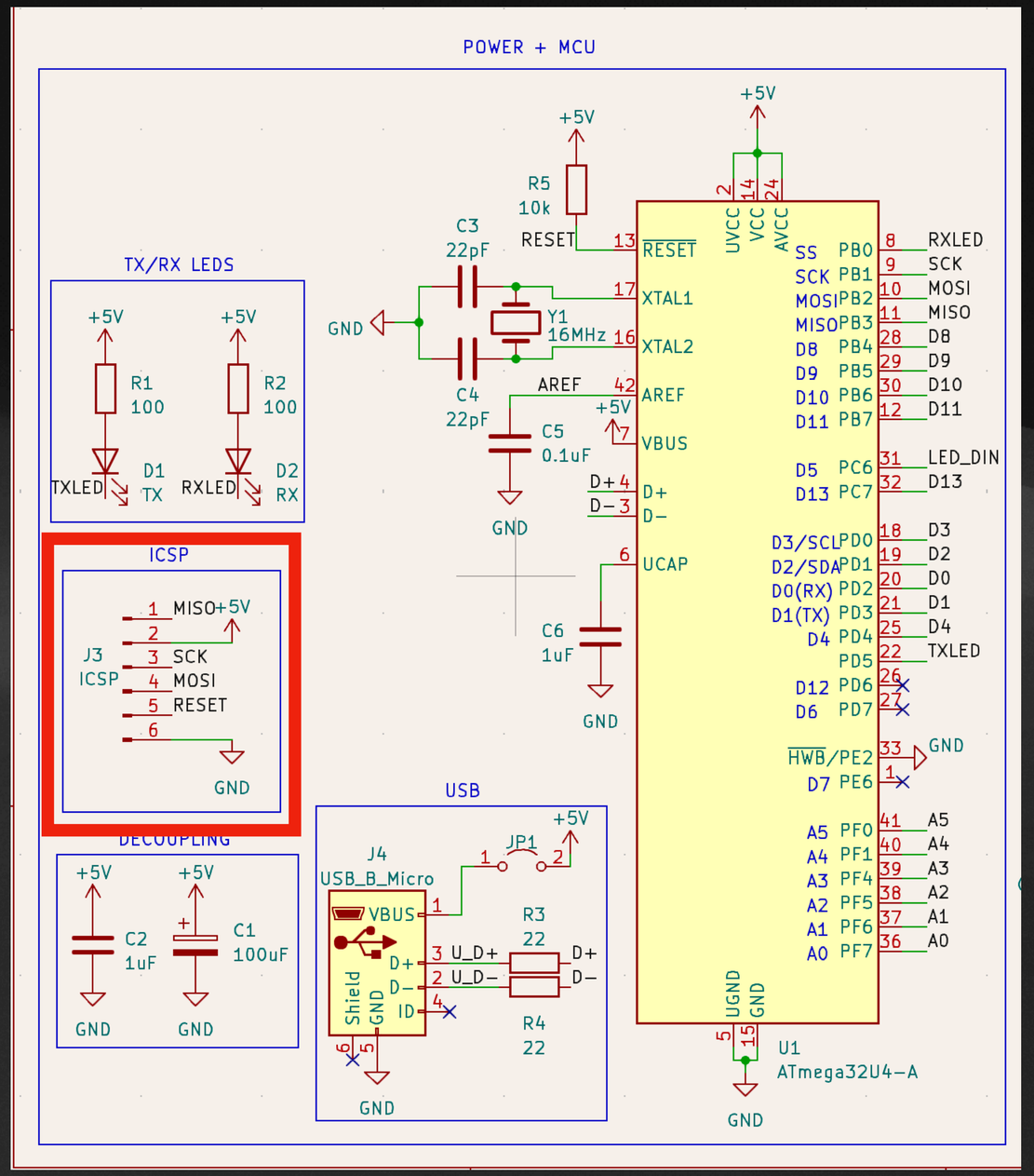
- An applied voltage to the crystal distorts the crystal causing mechanical vibration at its resonant frequency
- This generates a 16MHz clock signal



about the board

ICSP

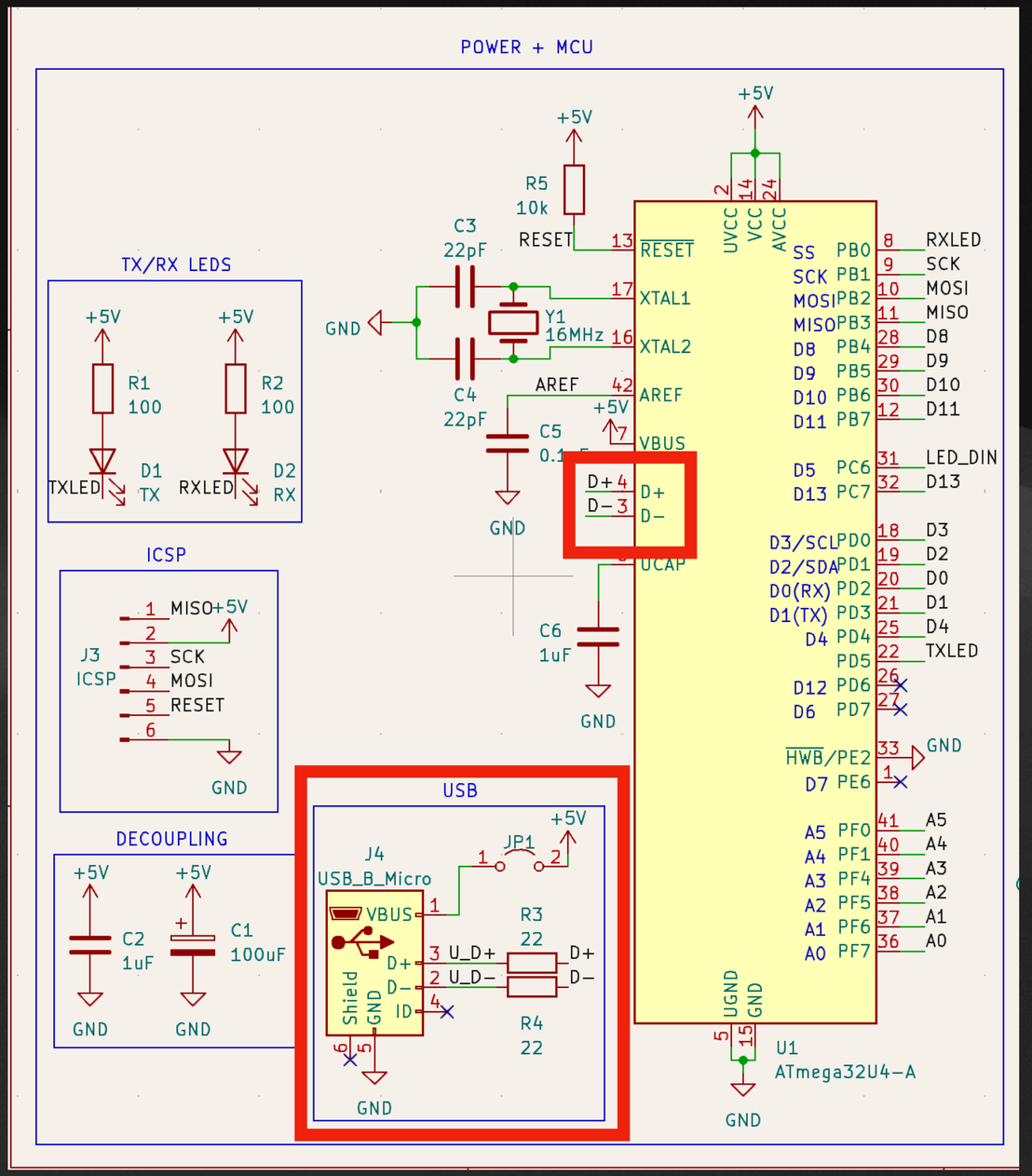
- ICSP = In-Circuit Serial Programming
- Allows us to upload the microcontroller bootloader (from Arduino) directly via SPI



about the board

USB

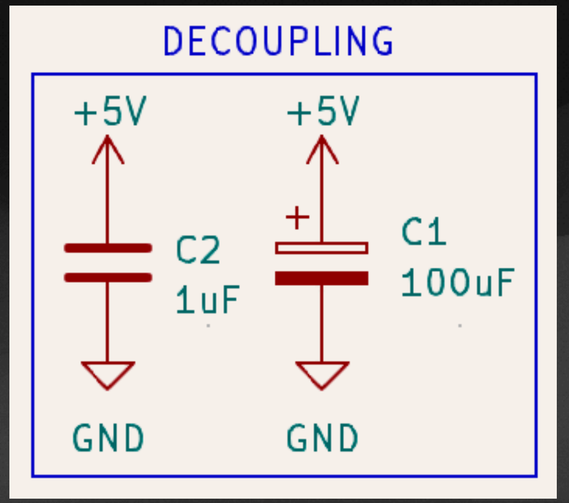
- Microcontrollers usually communicate via a serial protocol called UART
- Our microcontroller has an onboard USB to serial interface, and exposes two USB data pins
- This will allow us to program the microcontroller from the Arduino IDE once the bootloader is flashed.
- There is a 5V jumper should you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