Laser Musical Instrument

Group 24
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Motivation

- Engaging music with a new approach
- Provide an auditory and visual experience
- Using lasers in a creative way
- Have fun with Senior Design

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Overview

Alpha detector

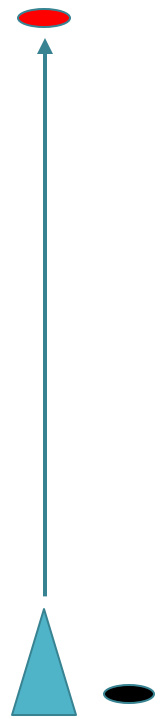
Beta detector

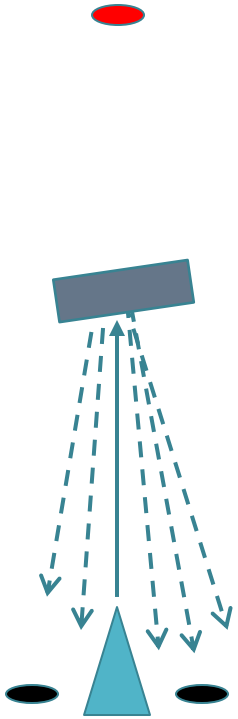
Laser diode

Emitted laser beam

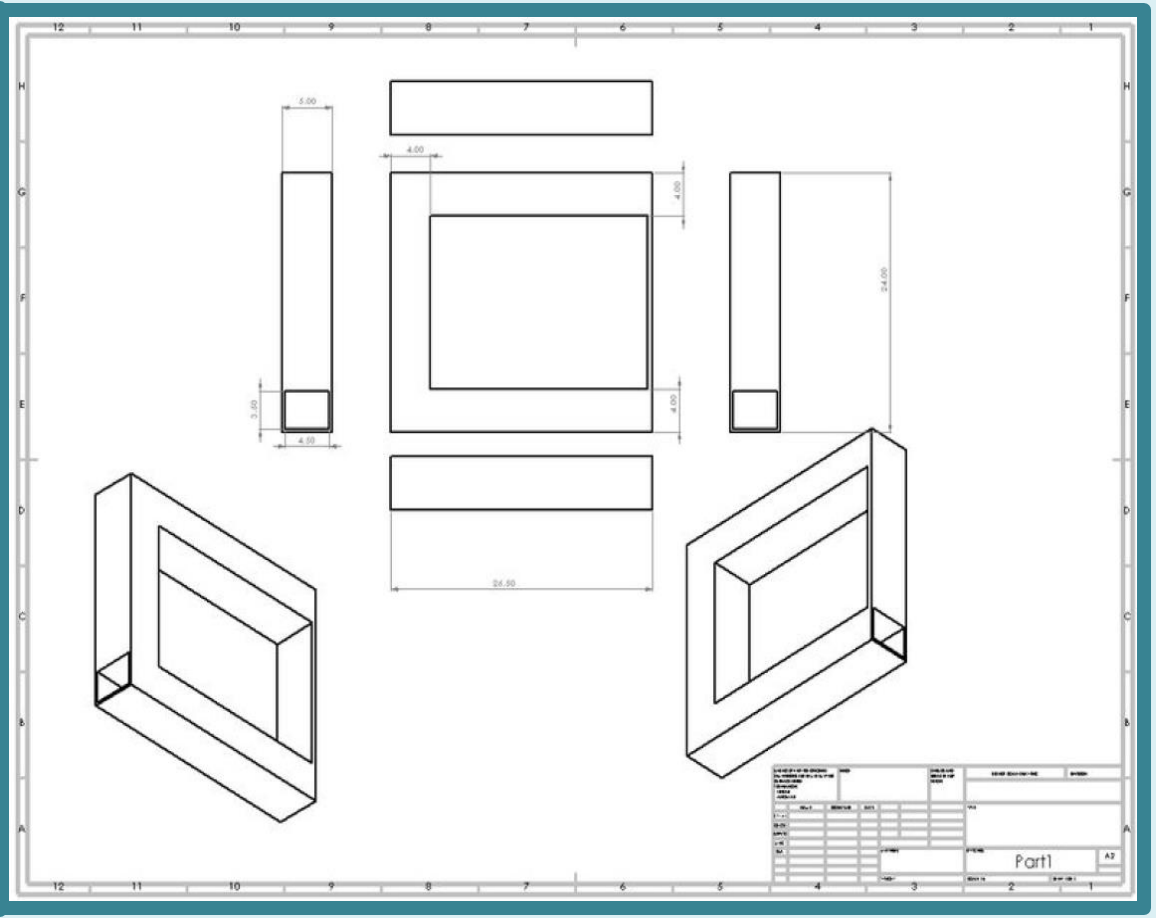
Reflections

Reflective surface/Hand





Main Operation



Housing Frame

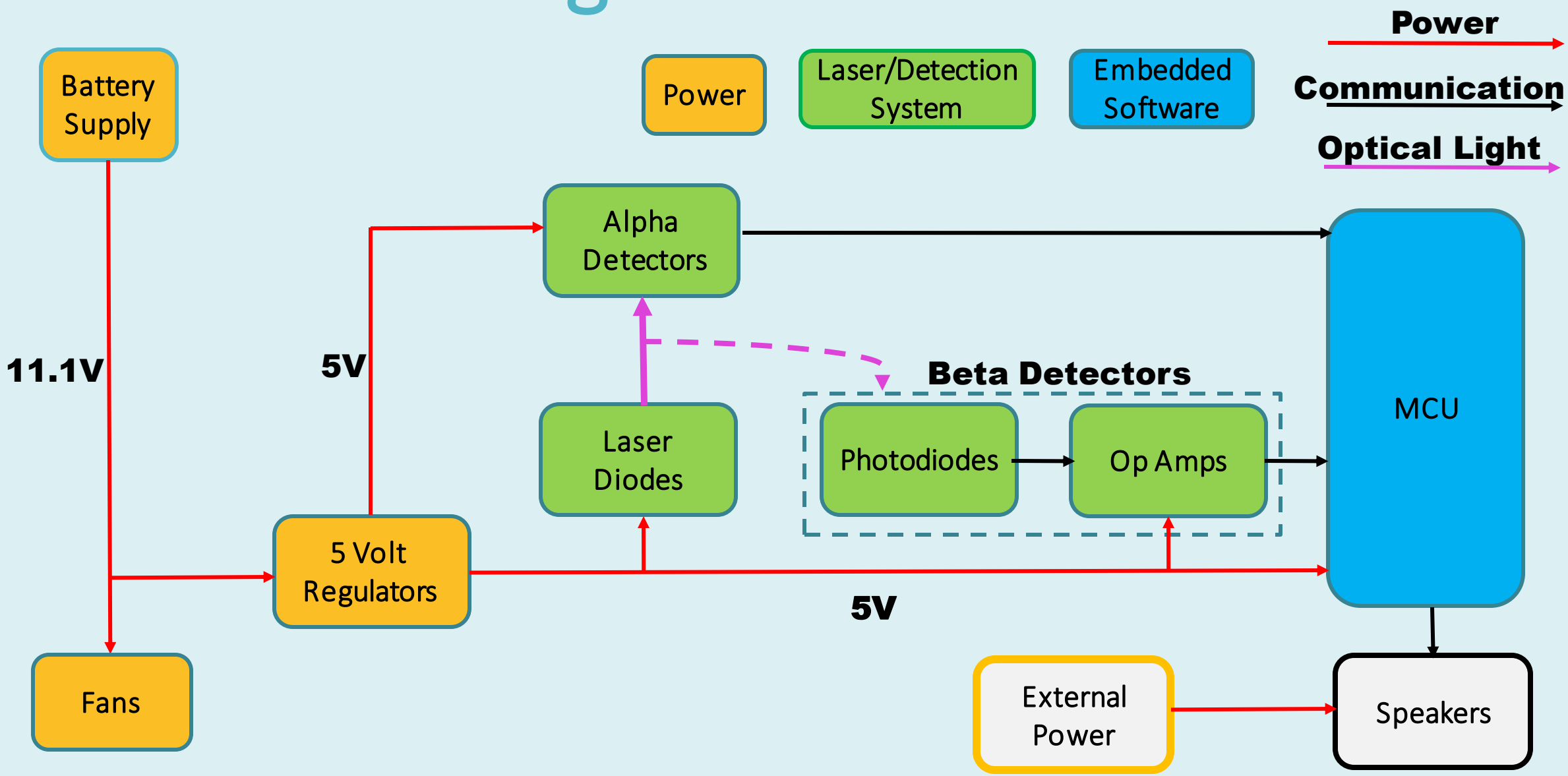
Goals and Objectives

Primary	*Secondary*	*Stretch*
Intensity detection for variability in pitches	Replication of a vibrato sound	The ability to change the note tuning for each laser
Minimum an octave range of notes	Laser beam to be visible	Replicate the feel of playing a real string instrument
To be played from a table top or stand	Protection circuit design for reverse voltage and overcurrent	Replication of sound decay that occurs when a string is plucked

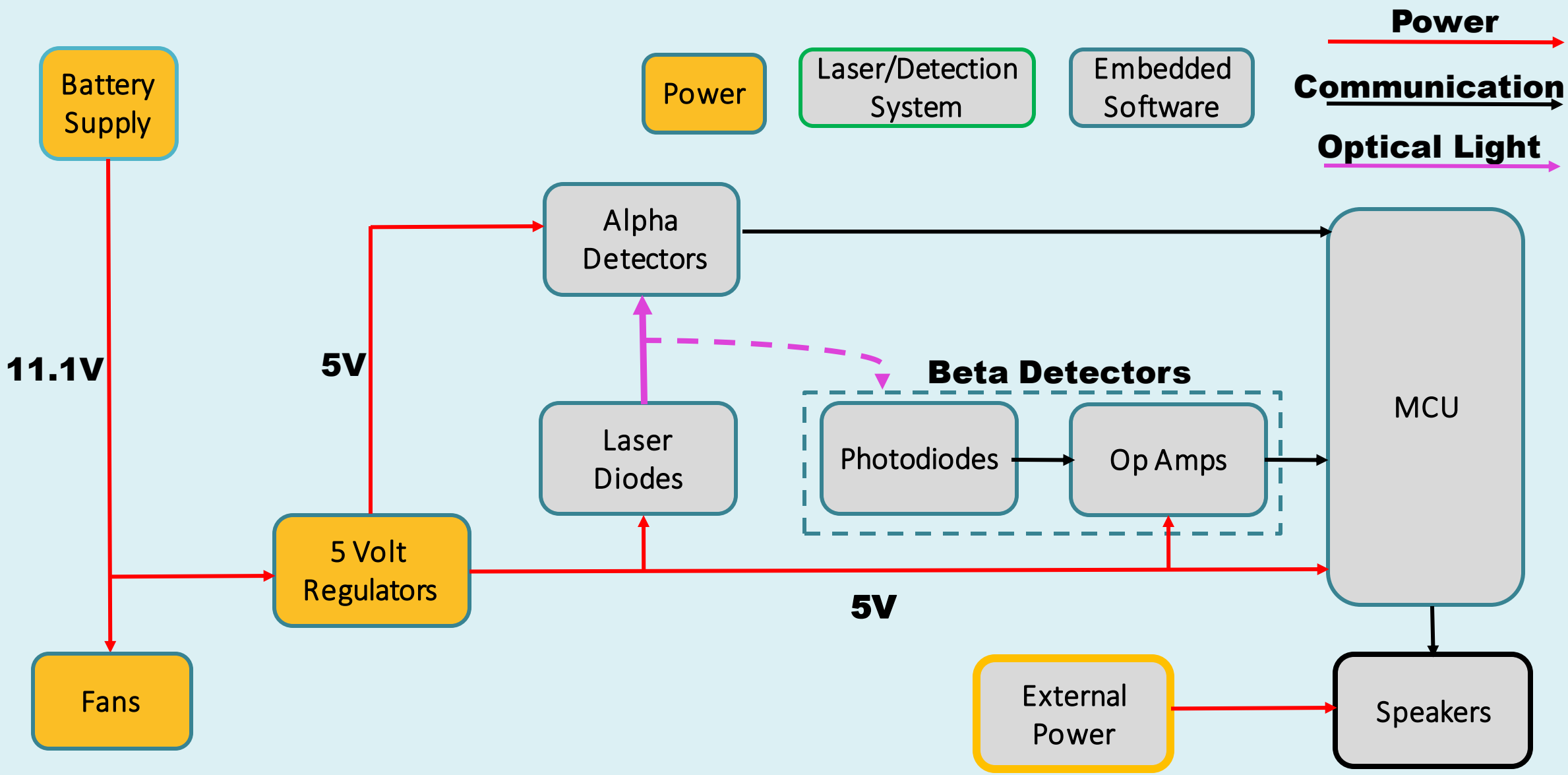
Specifications

Parameter	Design Specification
Pitch Range	65 hertz - 3951 kilohertz
Weight	≤ 50 pounds
Voltage operation	≤ 13 volts
Size	≤ 36 Inches in any single direction
Response Time	≤ 1 second
Audible Output	≥ 35 decibels
Run Time	≥ 30 minutes

Overall Block Diagram



Power


Power
Communication
Optical Light
Power
Laser/Detection System
Embedded Software
Battery Supply
11.1V
5V
Alpha Detectors
Laser Diodes
Beta Detectors
Photodiodes
Op Amps
MCU
5 Volt Regulators
5V
Fans
External Power
Speakers

Power Requirements

Design Guidelines

- Portability → Battery Pack
- Light weight
- Small enough to fit inside frame of instrument
- Power whole system for at least 30 min
- Voltage operation below 13 volts
- Withstand high current draw from lasers
- Supply a high enough voltage for cooling fans
- For prototype cells should be removable from pack
- 5 volt regulator

Power Management

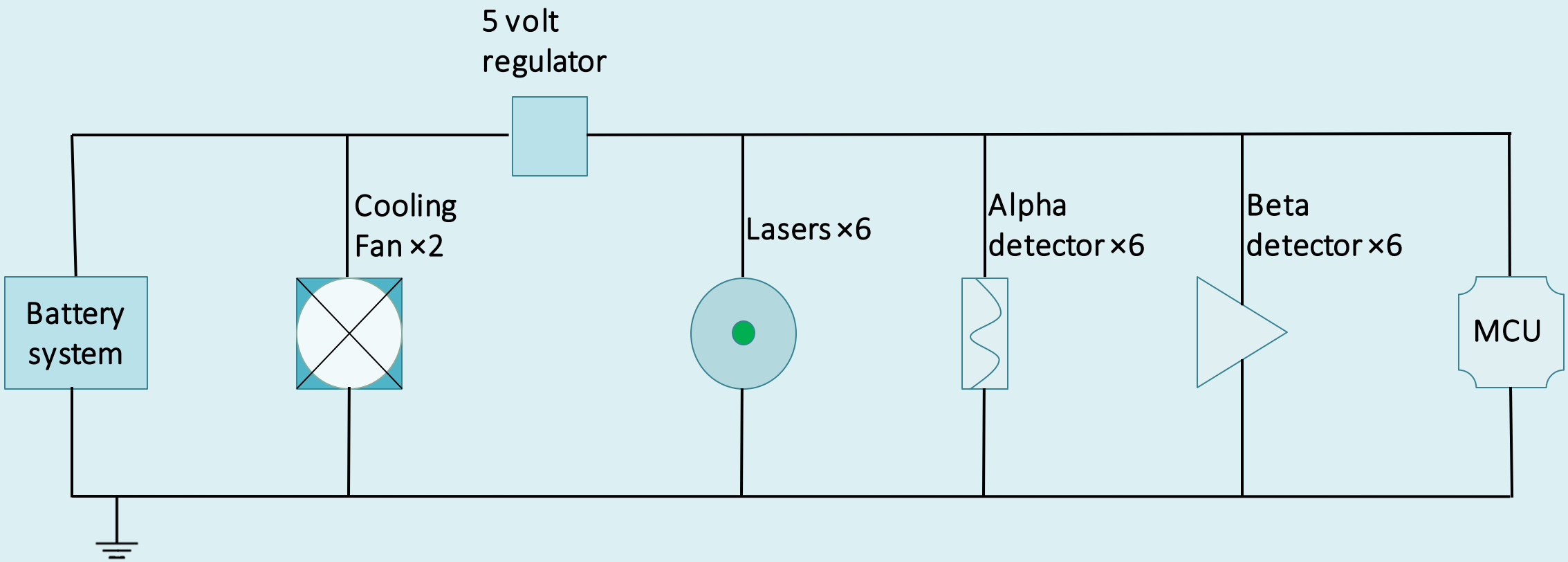
- Battery pack to have a nominal voltage of 11.1 volts
  - Higher voltage only to power cooling fans

- Rest of the system operates from 5 volts switching regulator
- Alpha detectors
- Lasers
- Op-amps

- Speakers are powered externally by a wall outlet

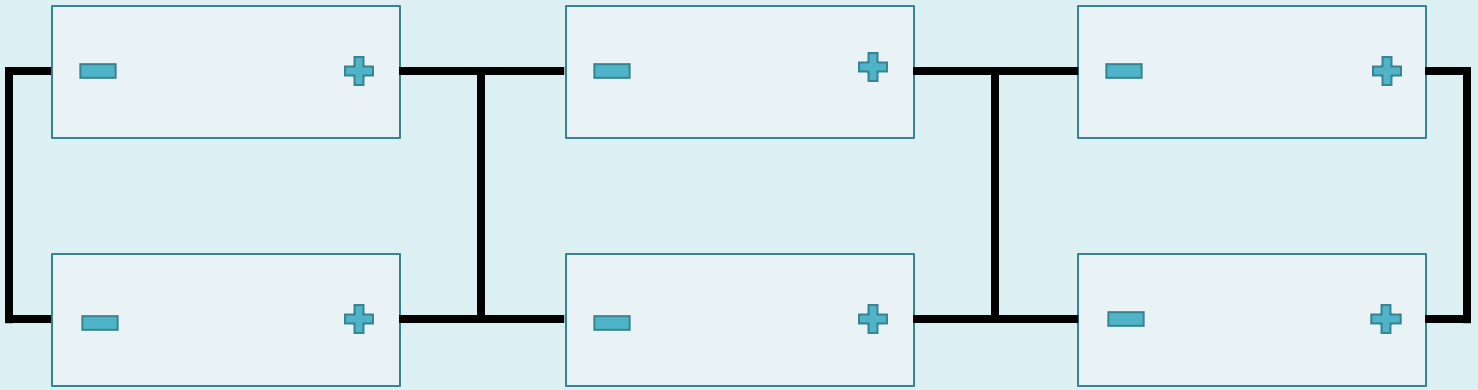
- Estimated current draw from battery between 2-3 Amps

Power Diagram



Battery Design

- Comprised of six li-ion 18650 cells
  - 11.1 Volts nominal
  - 6000mAh capacity
- Pack orientation to be 3 series 2 parallel
  - Interconnections inside pack to aid in balancing
- Pack to be comprised of three cell holders for ease of swapping cells
  - 12AWG wire used for holder connections
- Cells are all Samsung INR18650-30Q
  - Cells are rated for 15A max output
  - 3.7 Volts per cell
  - Capacity of 3000mAh

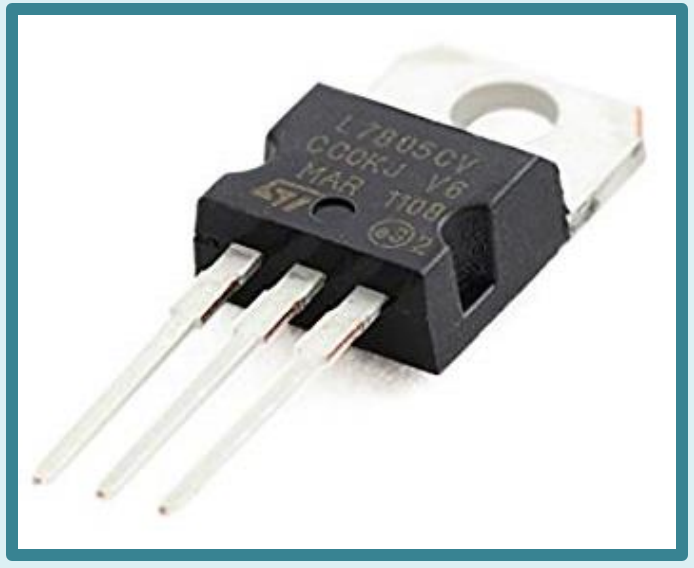


Cell Selection

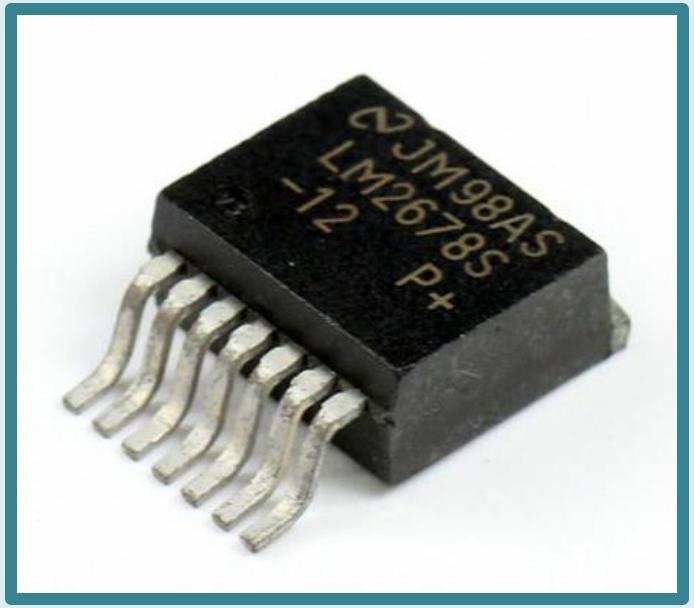
Battery	Capacity	Continuous Discharge rating	Price per cell
Samsung INR18650-30Q	3000mAh	15A	$4.99
Samsung INR18650-25R	2500mAh	20A	$4.99
LG HG2 18650	3000mAh	20A	$5.49
Panasonic NCR18650BD	3180mAh	10A	$4.99
Lishen 21700	4500mAh	13.5A	$5.99

Voltage Regulation

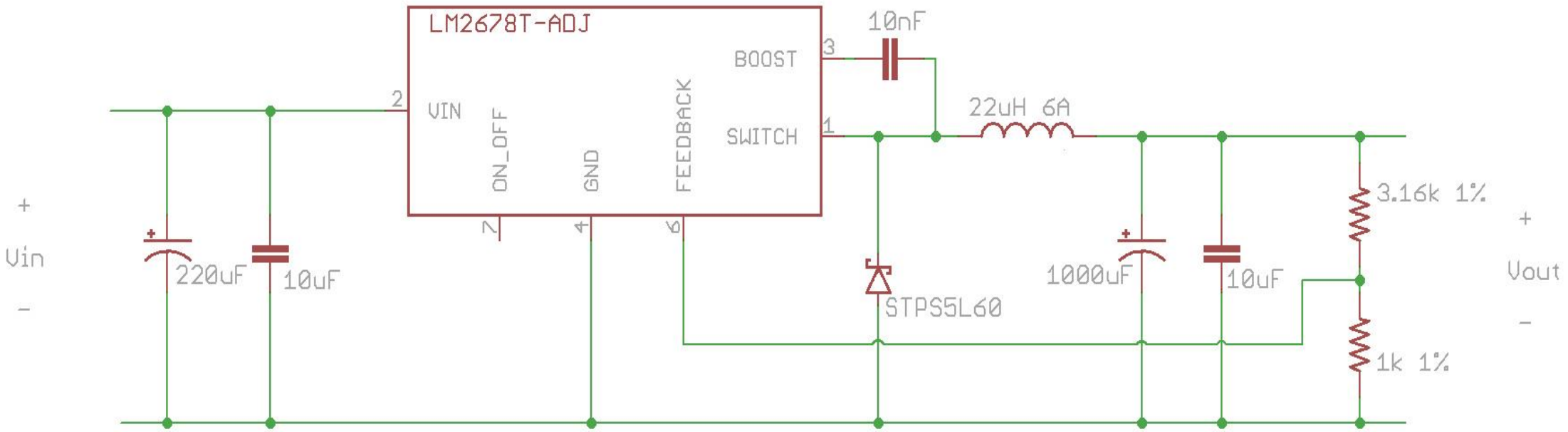
Part	Regulation Type	Efficiency	Max Current rating	Voltage input	Price per unit
L7805CV	Linear	__	1.5A	35V	$0.40
LM2678	Switching	84%	5A	8V - 40V	$5.82
LM2576	Switching	77%	3A	7V – 40V	$1.84



- Linear regulator creates too much heat with current loads in system
- A single LM2678 can regulate for the whole system



Voltage Regulation



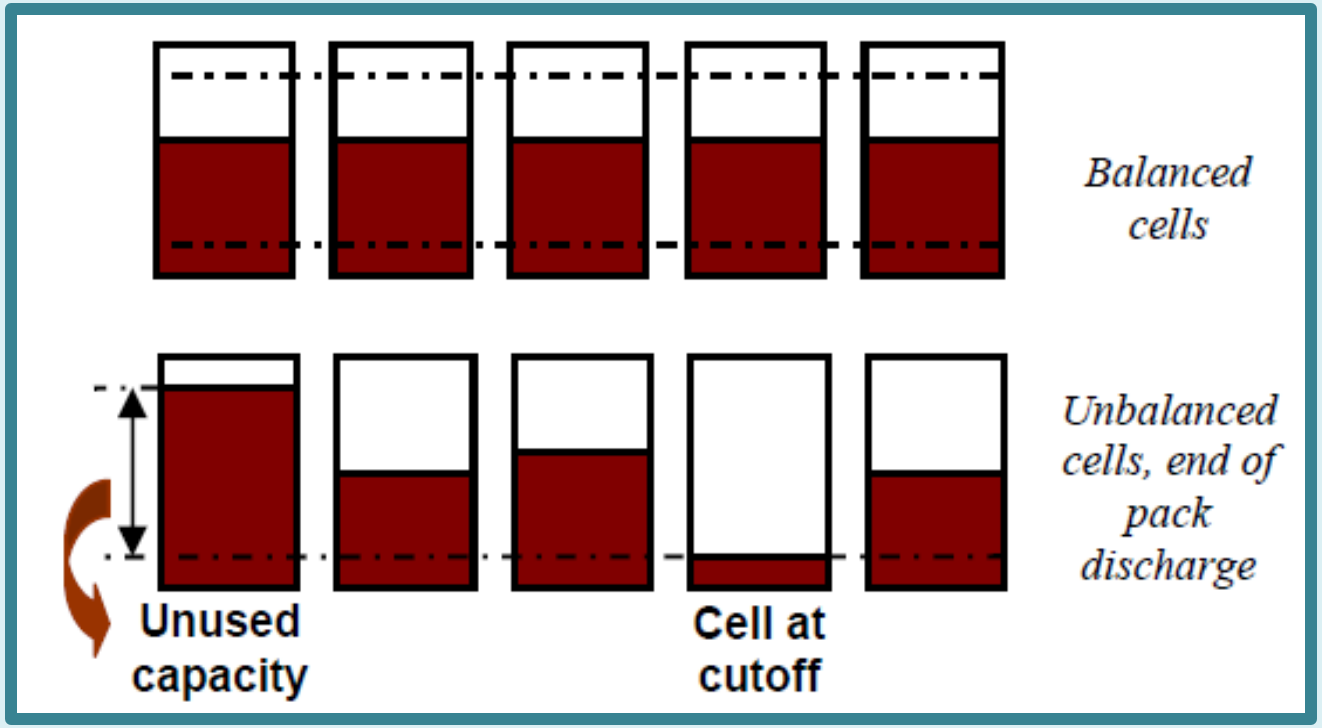
LM2678

Current Consumption

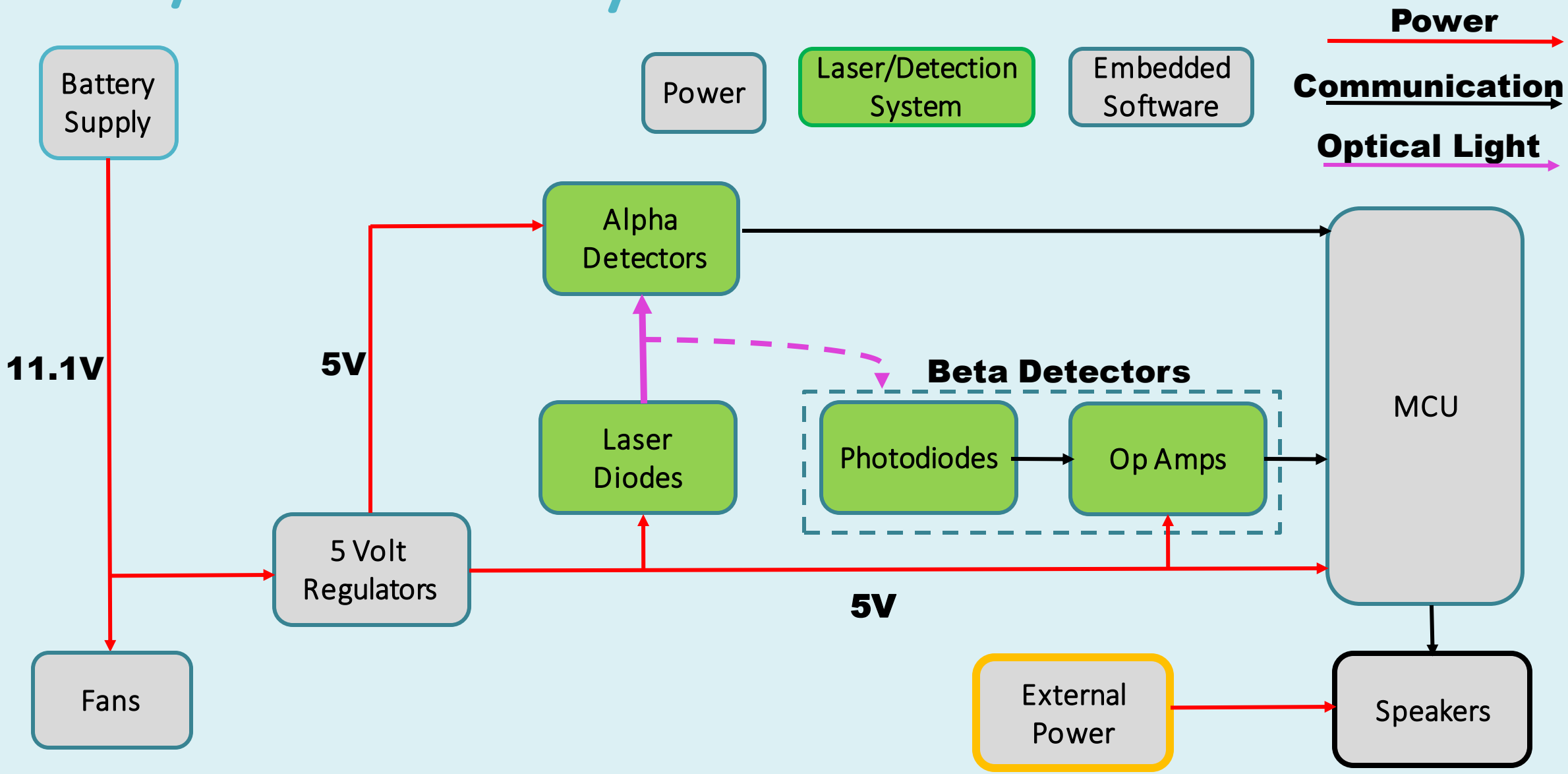
Part	Current (Turn-on spike)
Alpha Detectors	Light: 430 µA
	Dark: 40 µA
Beta Detectors	Light: 423 µA
	Dark: 423 µA
Lasers	@ 5 V: 208 mA
Op-Amp	423 µA
Fan	@ 12.3 V: 62.0 mA (106.9 mA)
	@ 11.1 V: 53.0 mA (100.1 mA)
Arduino	No Sound: 39.62 mA
	Sound: 46.30 mA
Linear Voltage regulator (L7805CV)	6 mA
Switch Regulator	9mA
Maximum Current	**2.15A**

Current Work for Power System

- Cell testing:
  - Balancing
  - Max voltage
  - Drain rates
  - Impedance
- Adding smoothing capacitors
- Adding protection for:
  - Over currents
  - Under voltage
  - Back currents



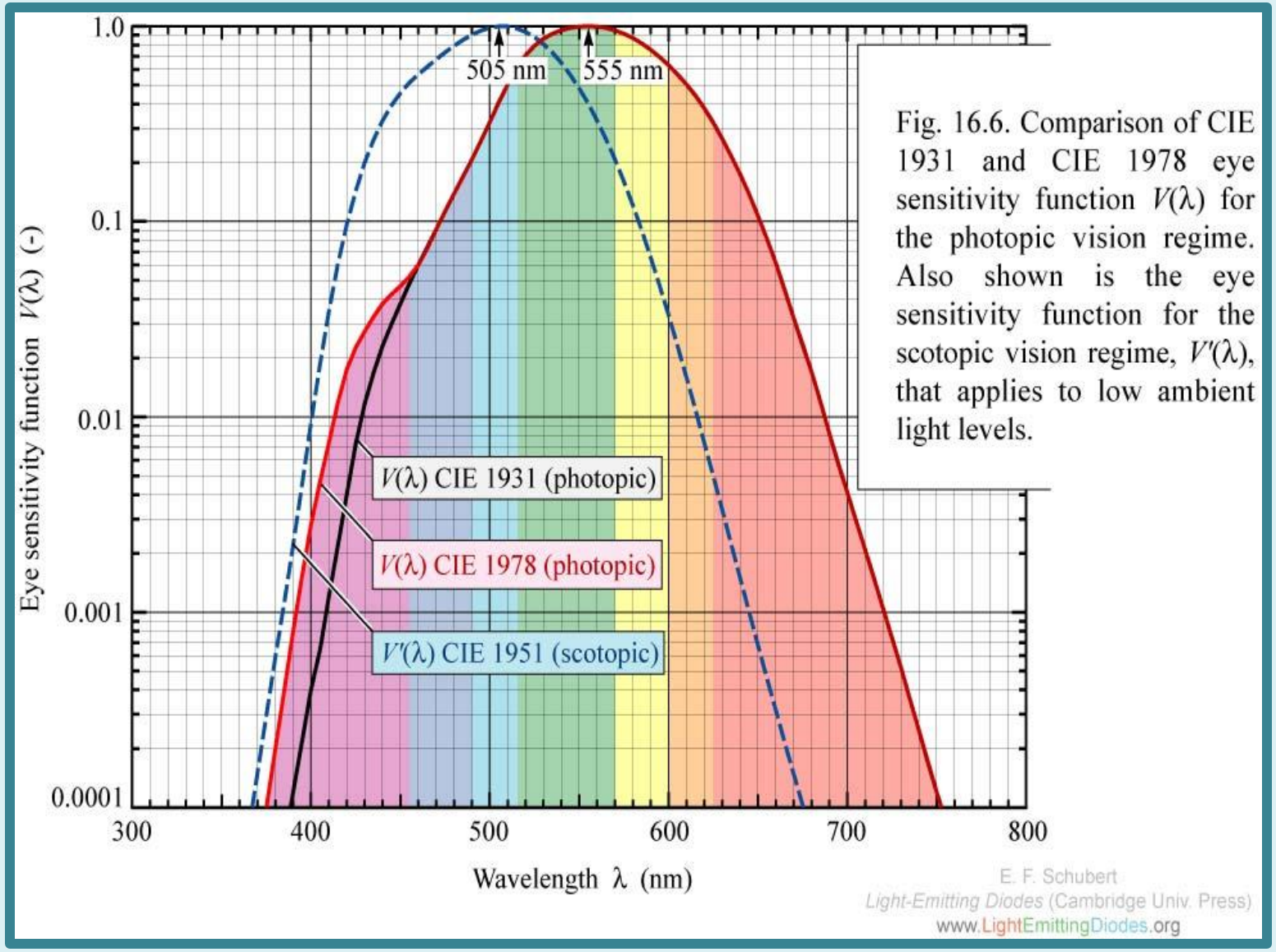
Laser/Detection System



Laser/Detection System

Laser Selection Criteria

- Visibility
- Balanced Output Power
- Semiconductor
- Compact
- Low Cost



Laser/Detection System

Laser Comparison

Laser Diode	Wavelength	Rated Output Power	Visibility[1,2,3]	Cost	Supplier	Size
Red	650 nm	5 mW	0.107	$0.20	Amazon	6.5 mm diameter 18 mm long
Violet/Blue	405 nm	10 mW	0.0185	$6.98	Amazon	12 mm diameter 35 mm long
Green	532 nm	10 mW	0.885	$5.89	eBay	12mm diameter 54 mm long

- Visibility (0 = not visible, 1 = most visible)

1. J. Schwiegerling, Field Guide to Visual and Ophthalmic Optics, SPIE Press, Bellingham, WA (2004).
2. *V(λ)* CIE 1978 (photopic)
3. *V'(λ)* CIE 1951 (scotopic)

Laser/Detection System

Laser Safety

- Rated power ≠ Actual power
- Stray beams
- Reflections

Solutions

- Aperture laser beam
- Extend housing roof
- Attenuate beams
- Attach laser safety signs
- Provide eye-safe goggles
- Further development

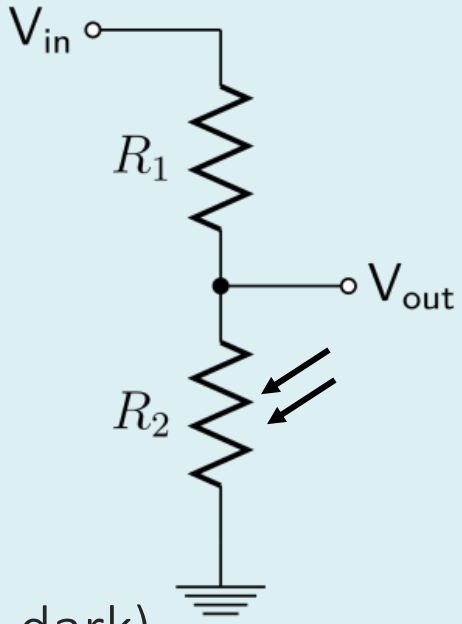
Image: https://www.safetysign.com/products/4946/danger-laser-beams-sign

Laser/Detection System

Alpha Detectors

Top detector. Acts as the on/off switch and determines which string is being played.

Prevents cross-overs.



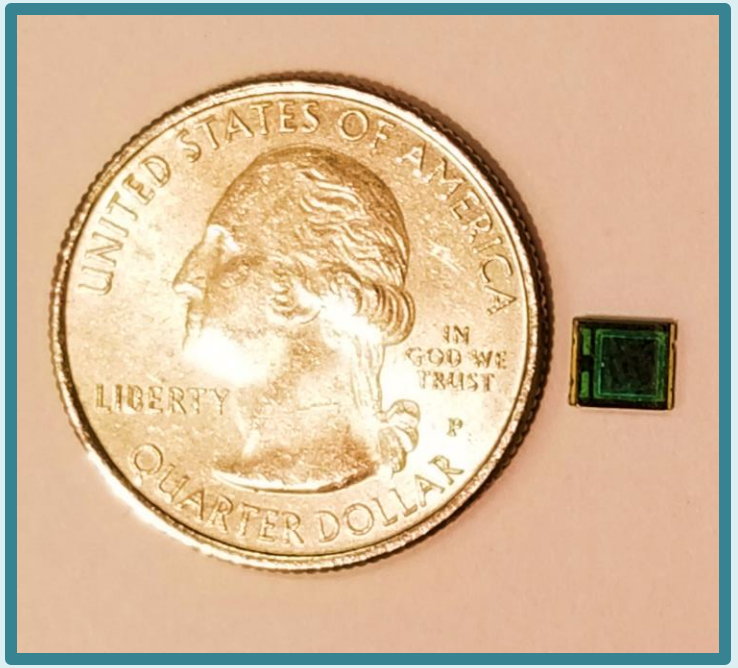
- Low cost (< 10 ¢ each)
- Great for switch functionality
- Simple voltage divider
- Low current draw (<430 µA in light, <40 µA in dark)
- Durable against constant laser emission

Laser/Detection System

Beta Detectors

- Bottom detector for intensity detection.
- Detects amplitude modulation of reflected light and determines the note that is played.

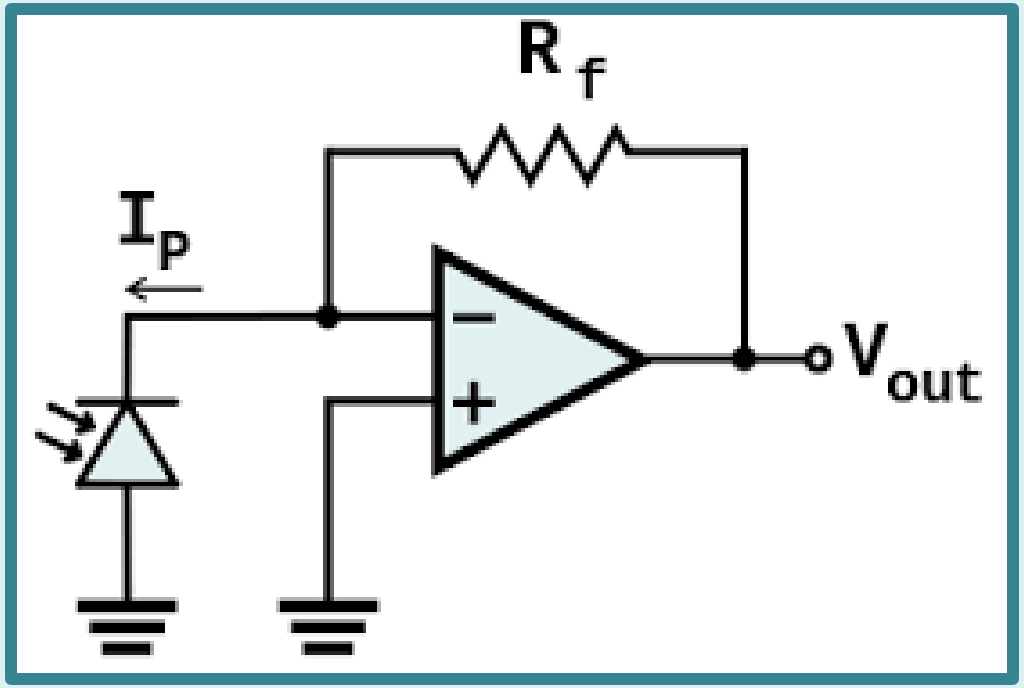
Photodiodes	Spectral Range	Responsivity	Cost
Vishay VEMD5510C	440 nm – 700 nm, Peaks at 550 nm	1,000 lux	$1.47
Vishay TEMD5510FX01	430 nm – 610 nm, 830 nm – 1100nm Peaks at 540 nm	10,000 lux	$1.16
Excelitas Technologies VTD34H	400 nm – 1100 nm Peaks at 900 nm	1,000 lux	$2.75



Laser/Detection System

Beta Detectors

- Output voltage values are for voltage reads on the MCU.
- Photodiodes create a current from light intensity.
- Comprised of three parallel photodiodes and a transimpedance amplifier.
    - Output voltage is dependent on the input diode current



Laser/Detection System

Beta Detectors

Op-amp Name	Supply Voltage (V)	Quiescent Current (mA/amplifier)	Op-amps/ chip	Input Voltage noise	Input Current noise	Input Impedance	Cost per chip
TLV2171	2.7 - 36, ±1.35 - ±18	0.525	2	27nV/√Hz	NG	$0.1 \times 10^9\ \Omega$	$1.25
TL082	±5 - ±18	1.4	2	18nV/√Hz	0.001pa/√Hz	100||3 MΩ||pF	$0.59
LM358	3 - 32, ±1.5 - ±16	0.5	2	40nV/√Hz	NG	10MΩ||pF	$0.16
OPA2320	1.8 - 5.5	1.45	2	0.8nV/√Hz	0.6fA/√Hz	NG	$2.91

Laser/Detection System

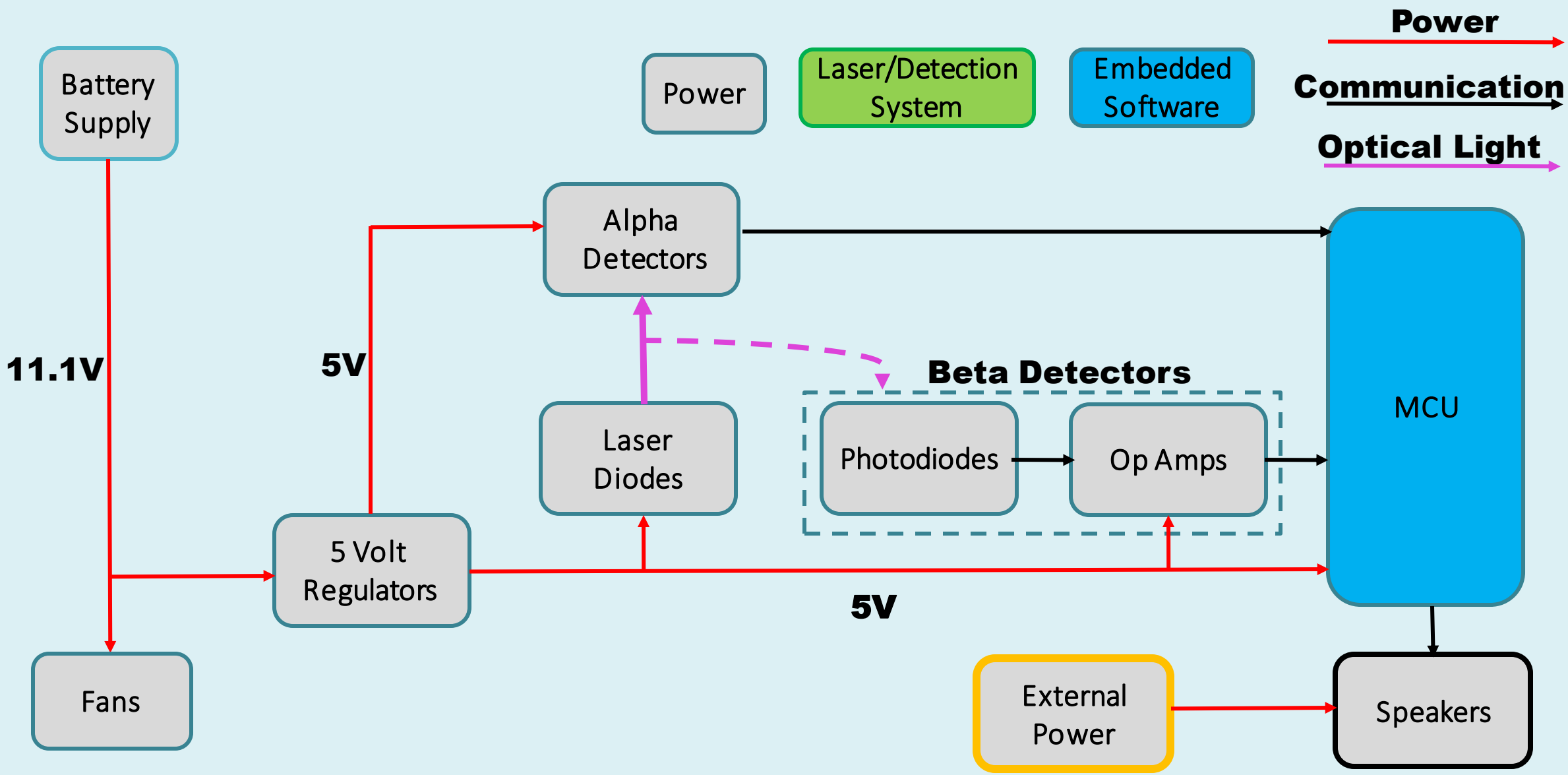
Beta Detector Issues

- Early saturation detection
- Over powered by DC power
- Insufficient voltage range for musical note assignation
- Ambient light

Possible Solutions

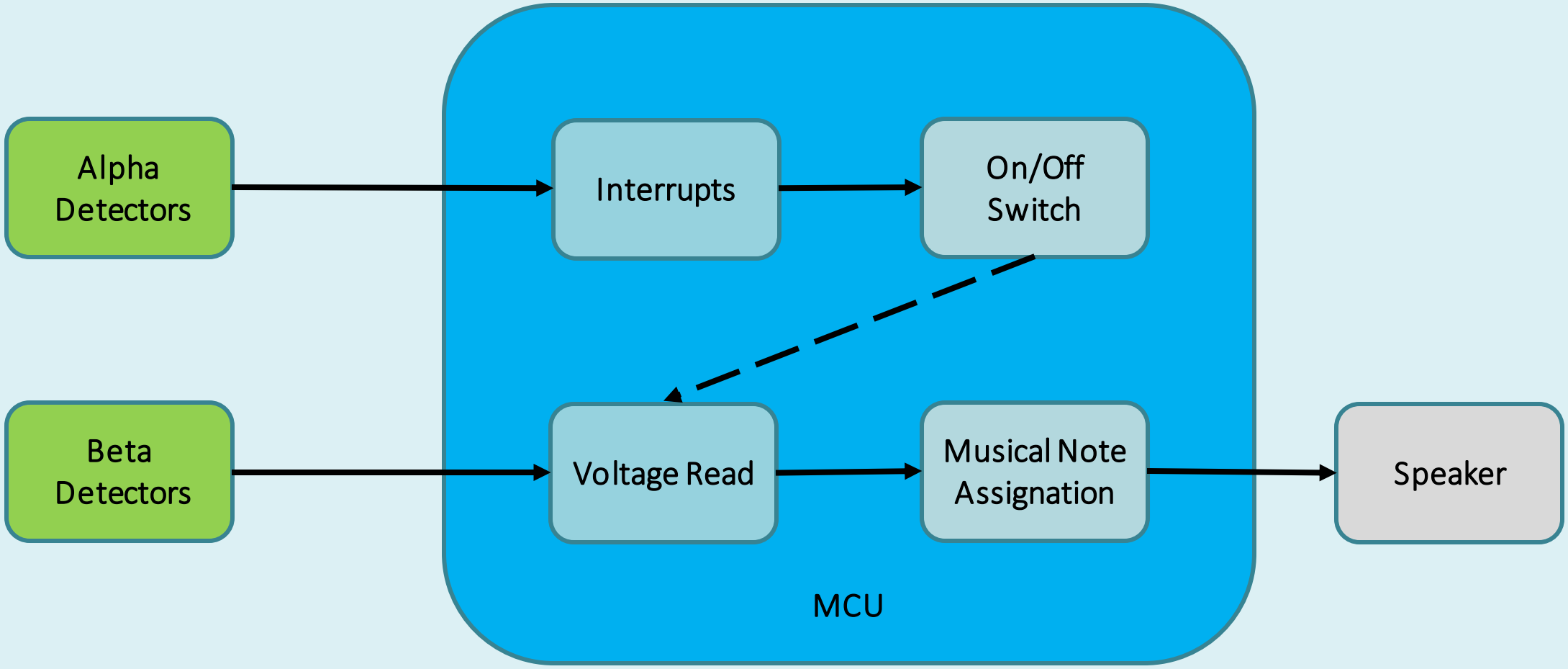
- Increase number of photodiodes
- Optimize op-amp
- Add optical/software filters
- Aperture ambient light

Embedded Software



Embedded Software

Software Layout

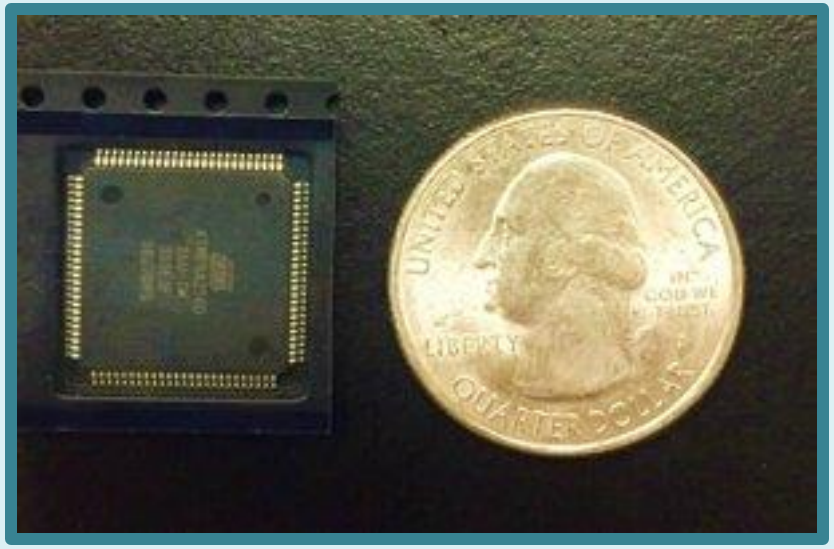


MCU Comparisons

MCU	Analog Inputs	Unit Cost	Digital I/O Pins	Available External Interrupts	Current Consumption
ATMega2560	16	$12.21	54	6	5.5 mA @ 5V, 16 MHz .6 uA @ 5V in power down
AT91SAM3X8E	12	$11.54	54	54	71 mA @ 3.3V, 84 MHz 29.4 mA in sleep mode
ATMega328P	8	$1.90	13	2	5.2 mA @ 5V, 8 MHz .1 uA @ 3 V in power down
MSP430G2553	14	$1.04	14	0	330 uA @ 3V, 1 MHz .8 uA @ 2.2V in low power mode 4
MSP430FG4618	80	$8.35	80	0	600 uA @ 3V, 1 MHz .3 uA @ 3V in low power mode 4

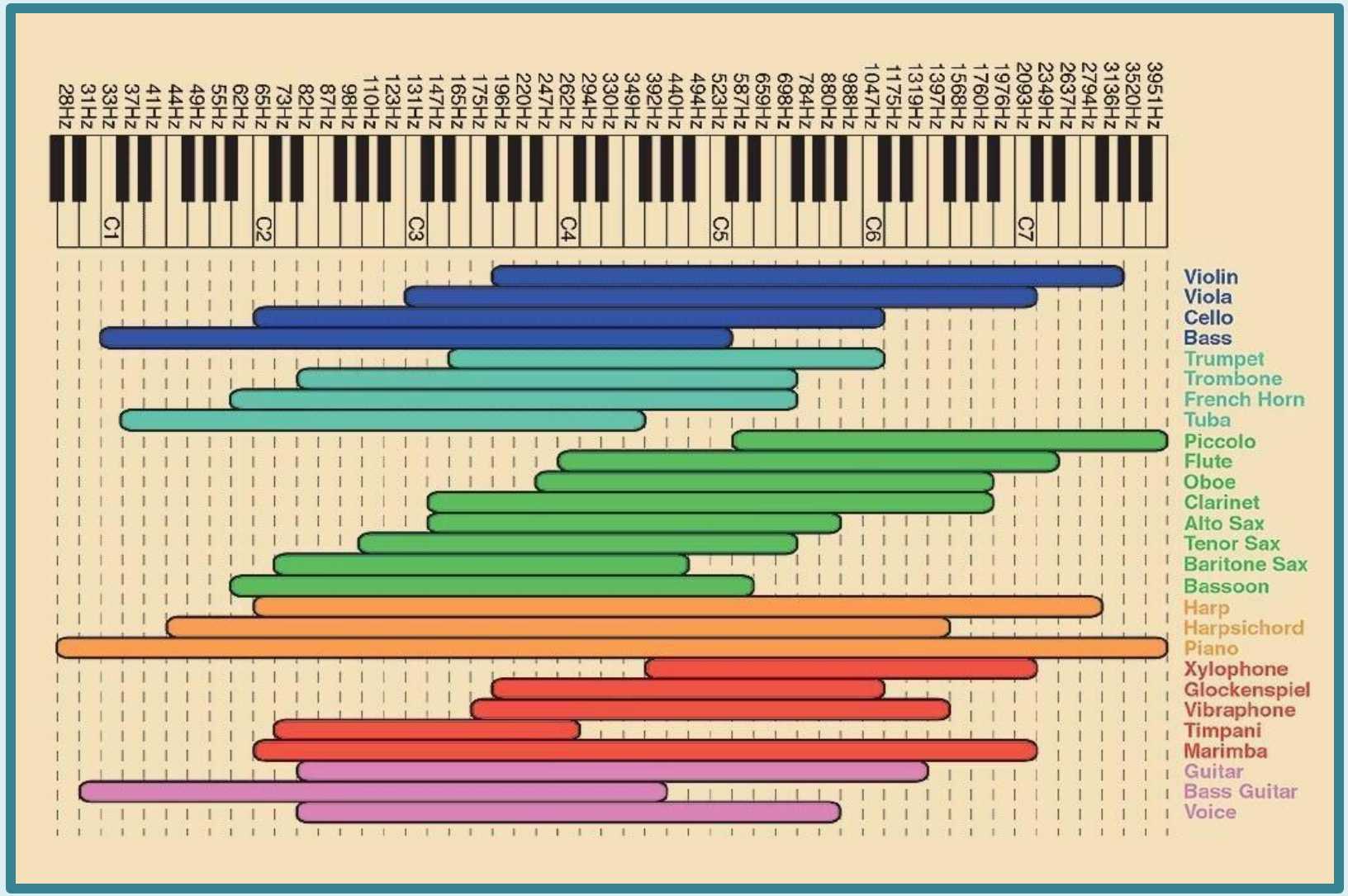
MCU

- Features of ATMega2560
  - Up to six beams
  - Supports C/C++
  - Six hardware timers
  - 16 channel, 10 bit ADC
  - Digital and pulse-width modulation output



Embedded Software

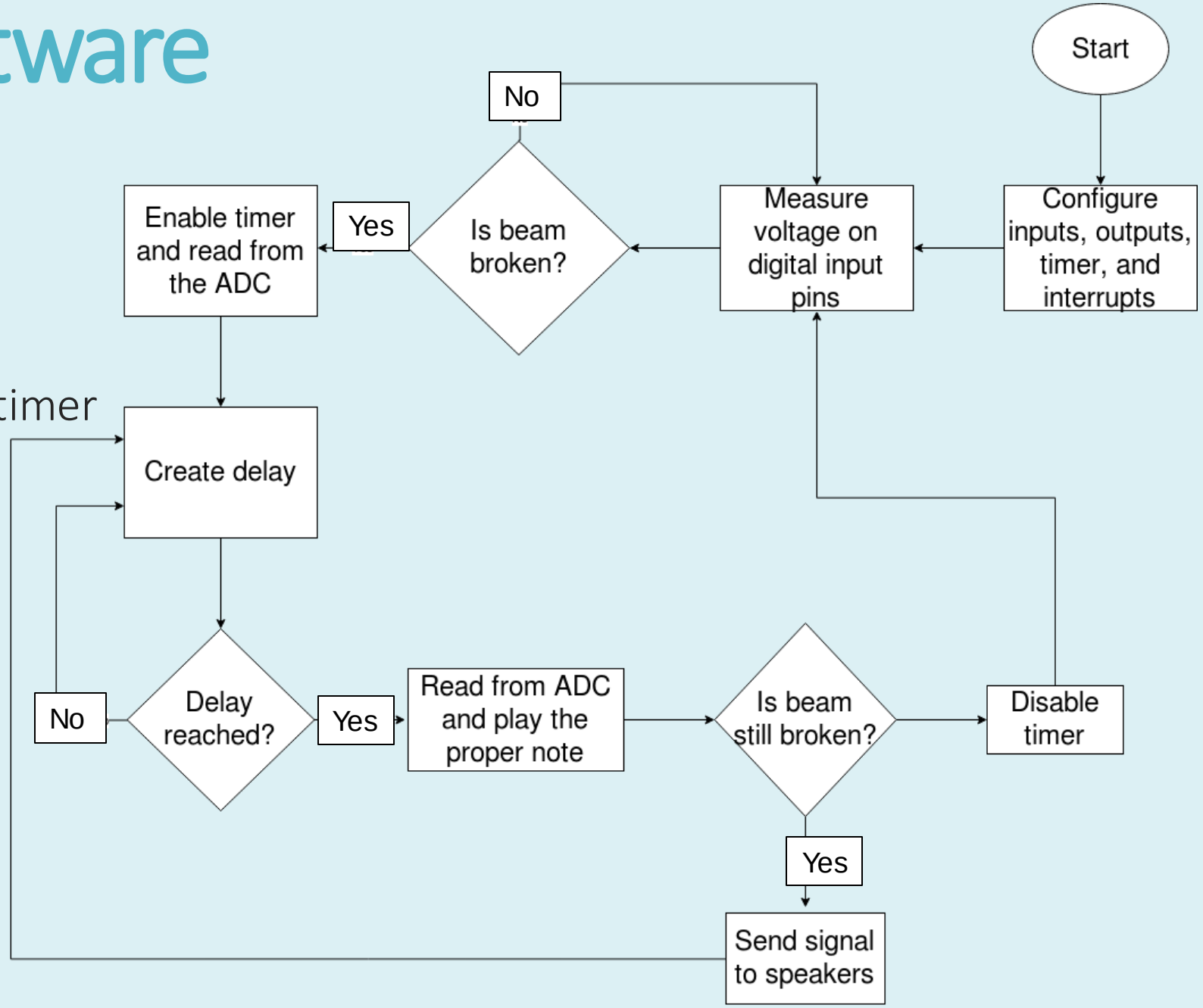
- One octave per beam
  - 12 notes per octave
- C2 – B7
  - *65 – 3951 Hz*
- Arduino IDE
  - Open-sourced



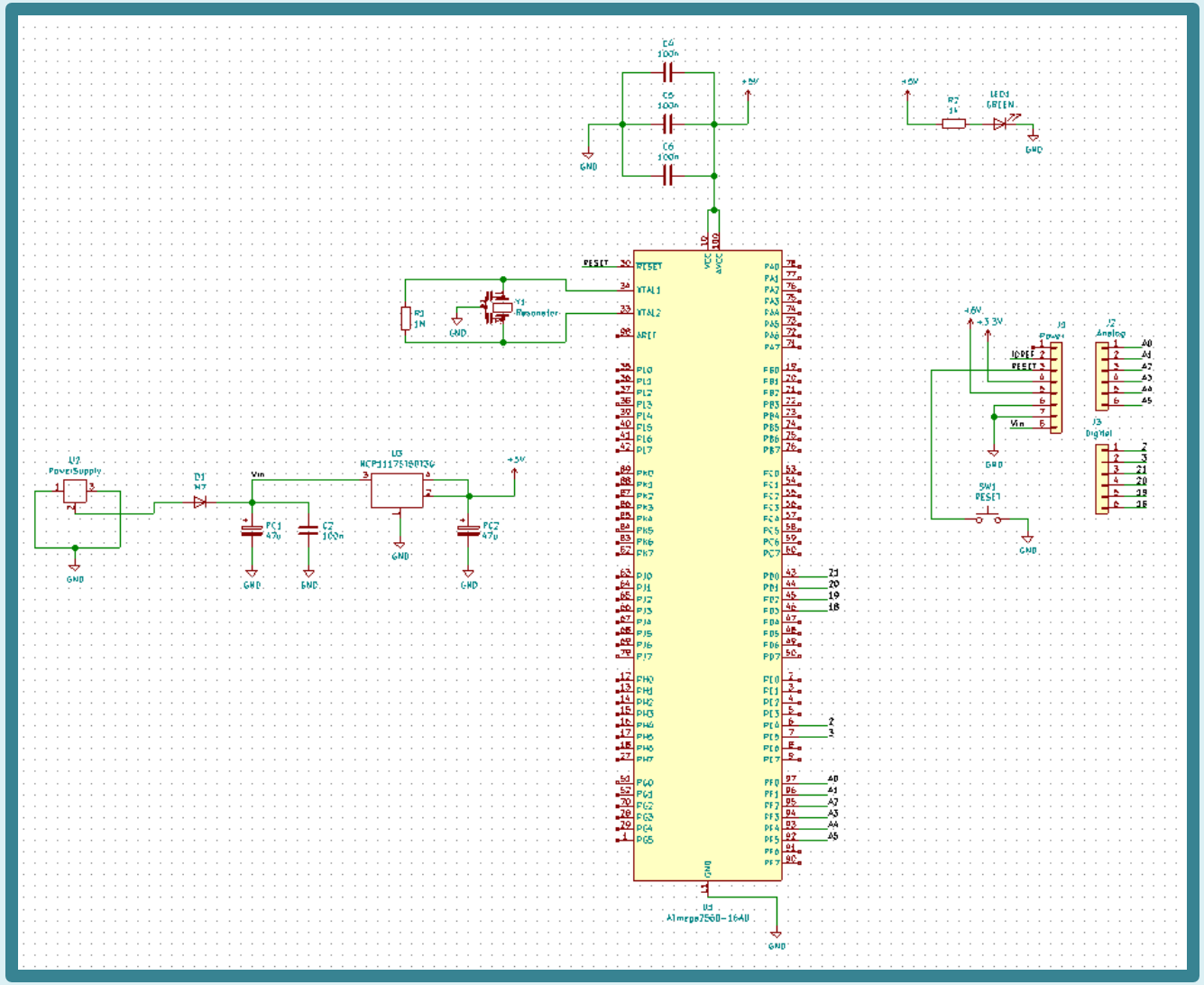
https://www.reddit.com/r/coolguides/comments/ackdf5/this_chart_of_note_ranges_by_instrument/

Embedded Software

- C++
- Main Function plays the note
- Beam ISR enables or disables timer
- Timer ISR reads from ADC

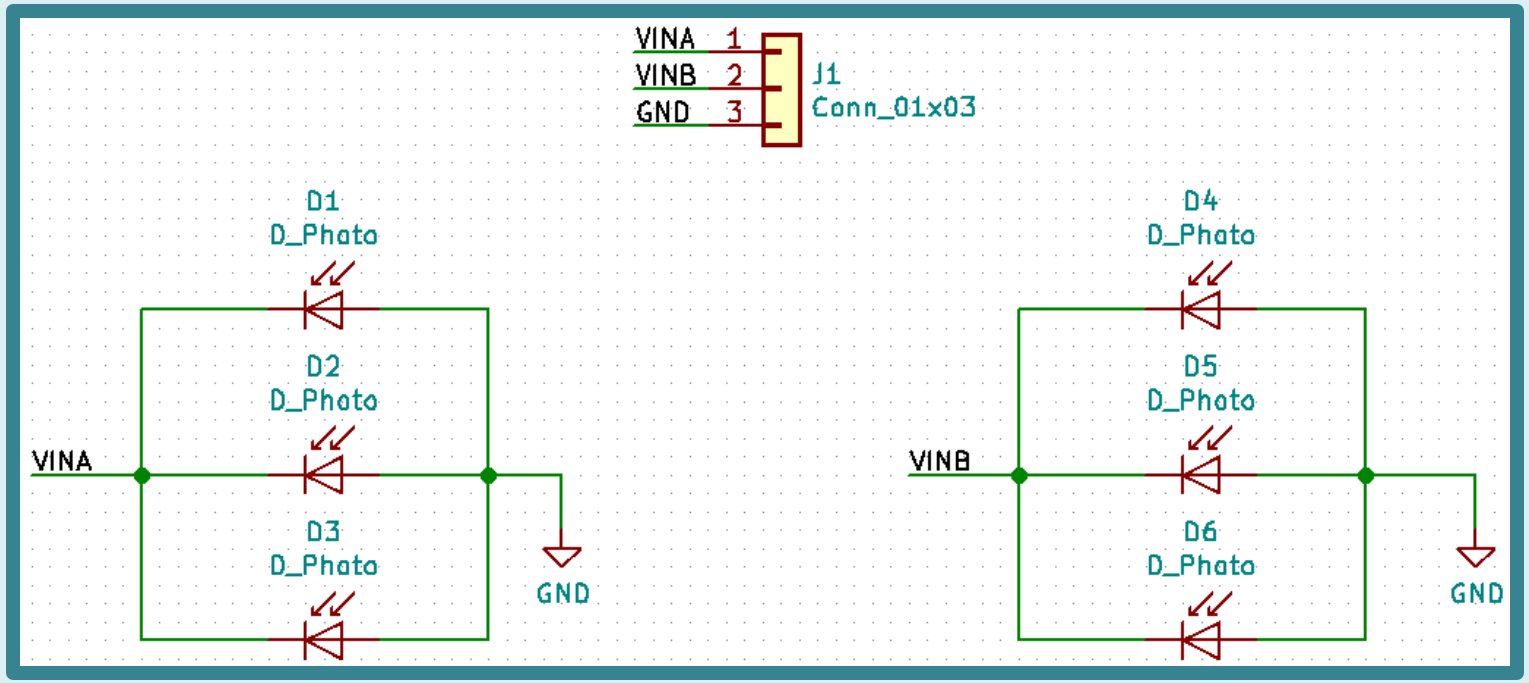


PCB Schematic

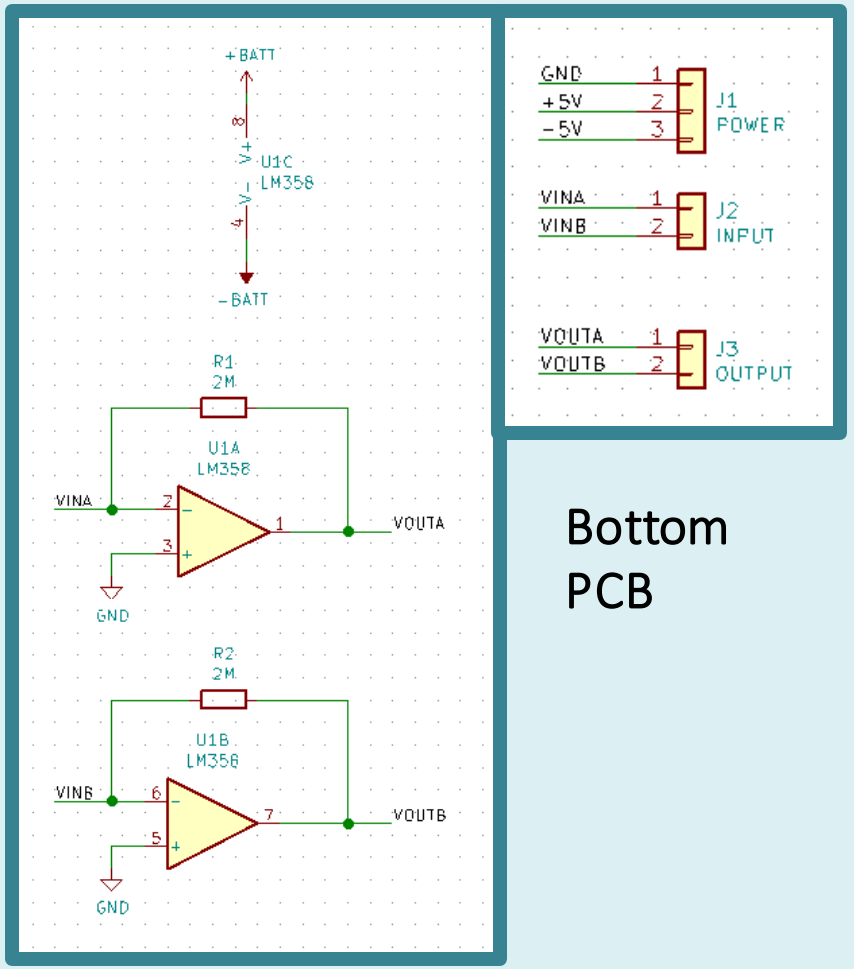


Main PCB

PCB Schematic



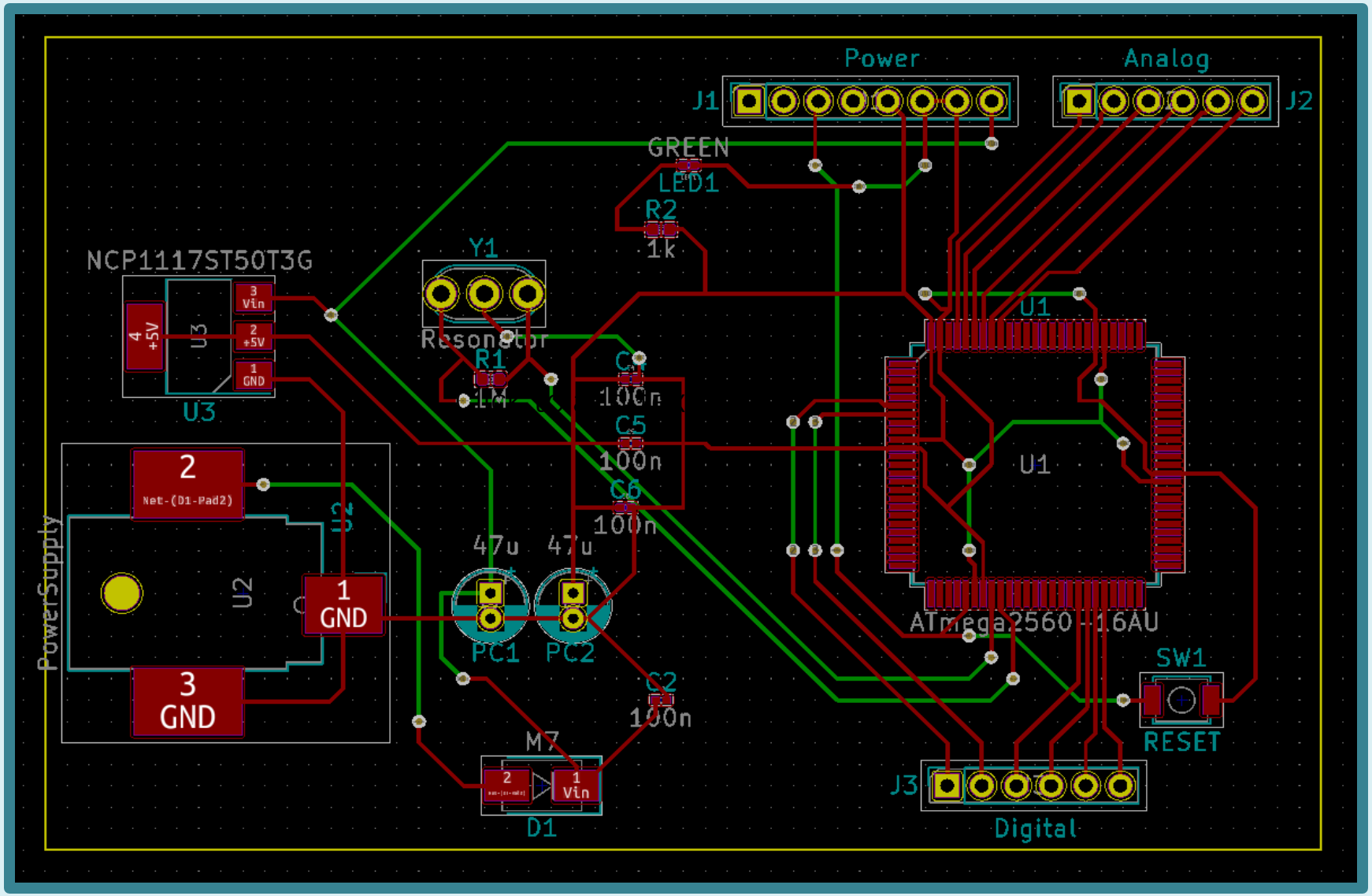
Top PCB



Bottom PCB

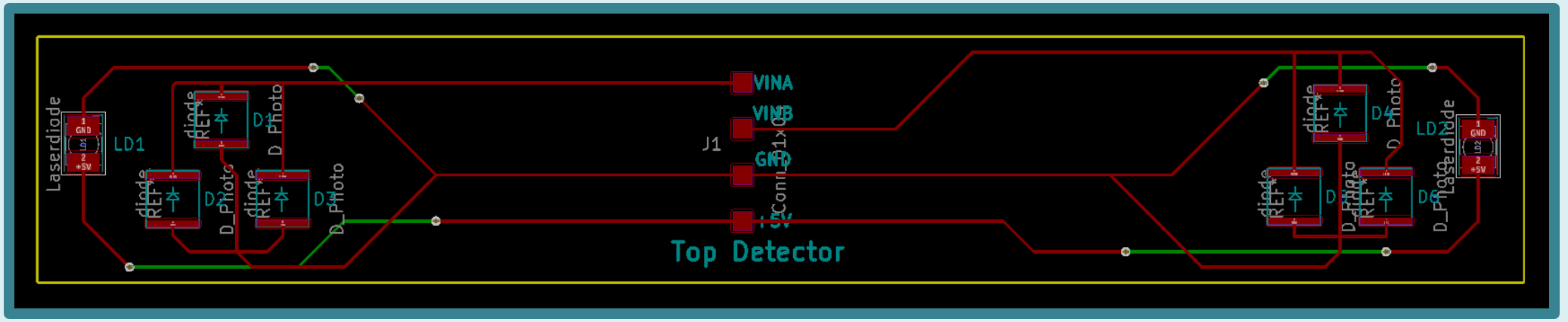
PCB Schematic

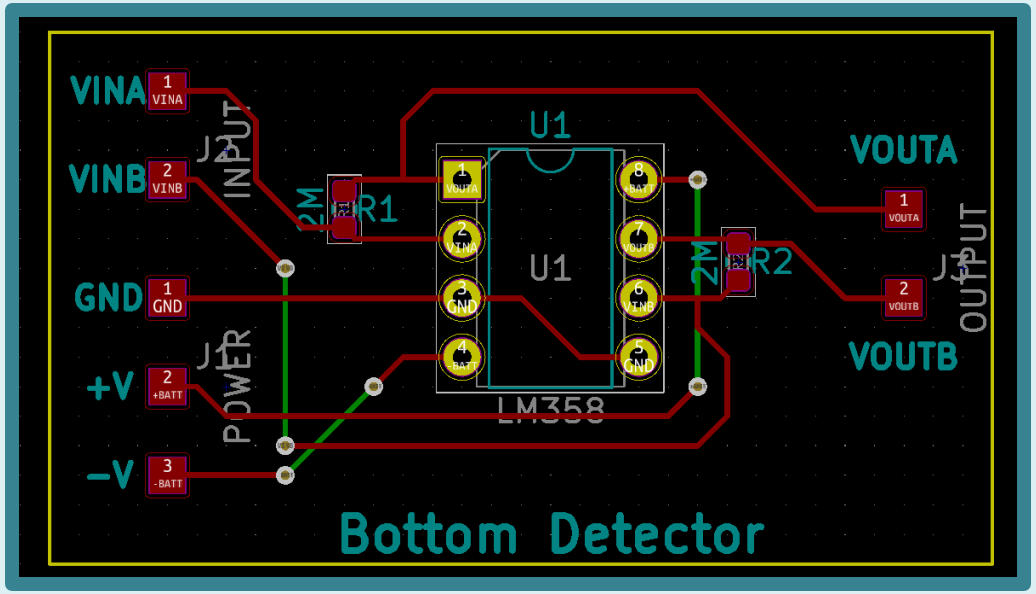
2.9 x 1.9 in



Main PCB

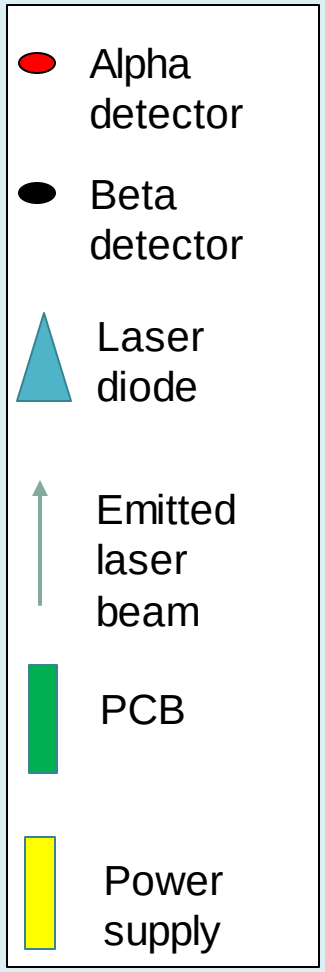
PCB Schematic

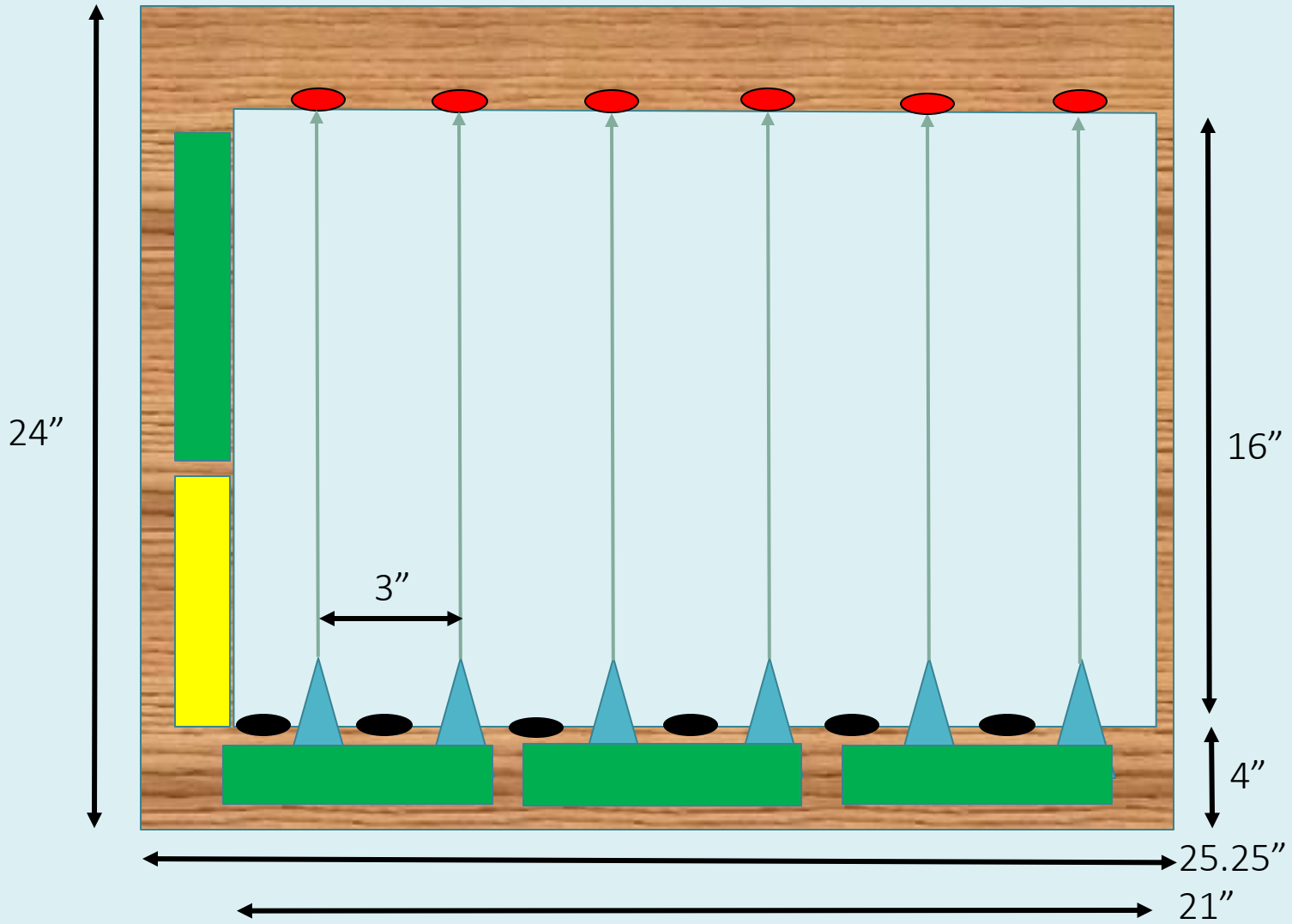




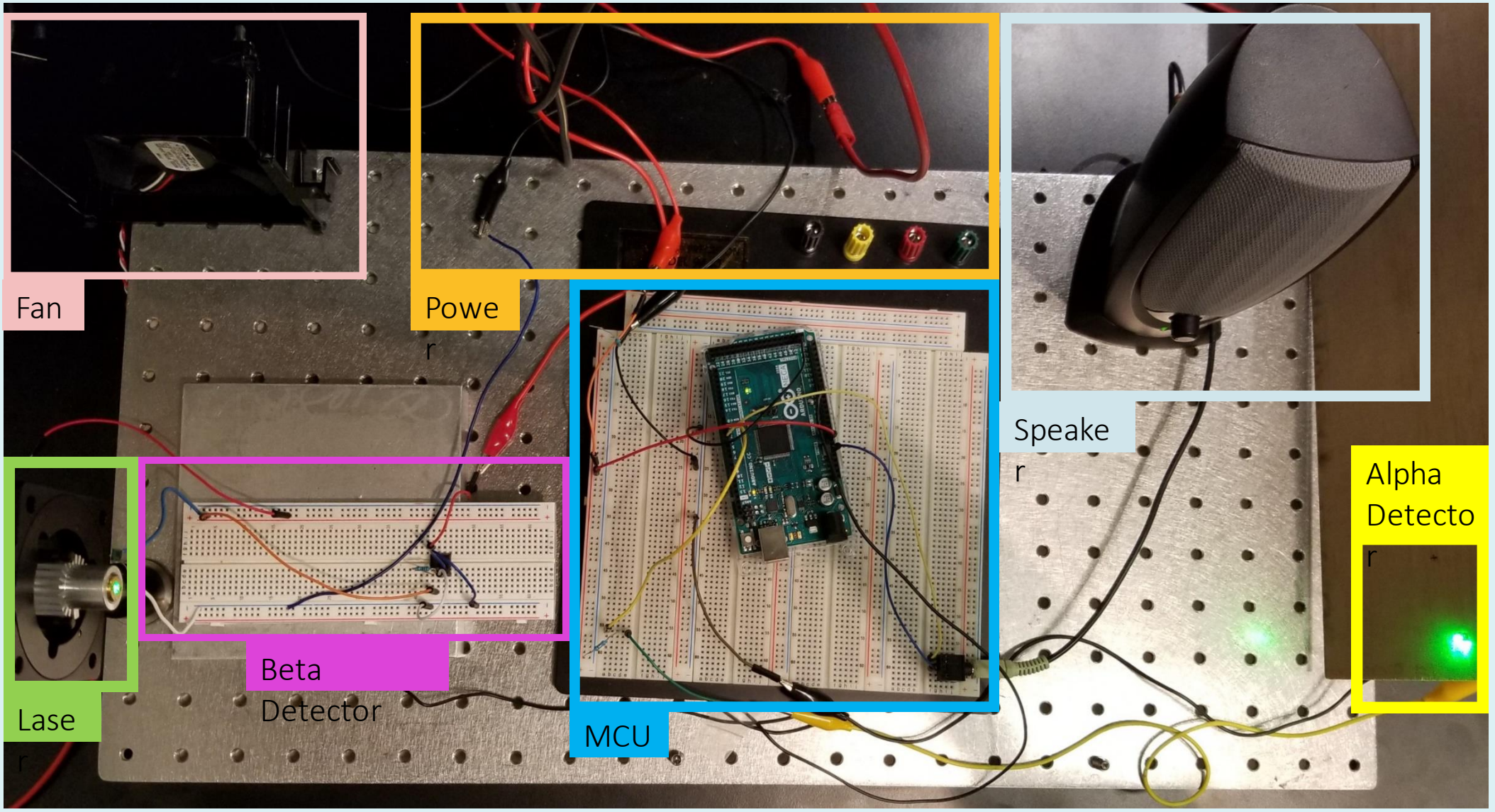
Housing Frame

- Slide Doors
- Dimensions
  - 24”X25.25”
  - Playing field
    - 16”X21”
- Light-weight
- Cheap
- Wood
- Portable



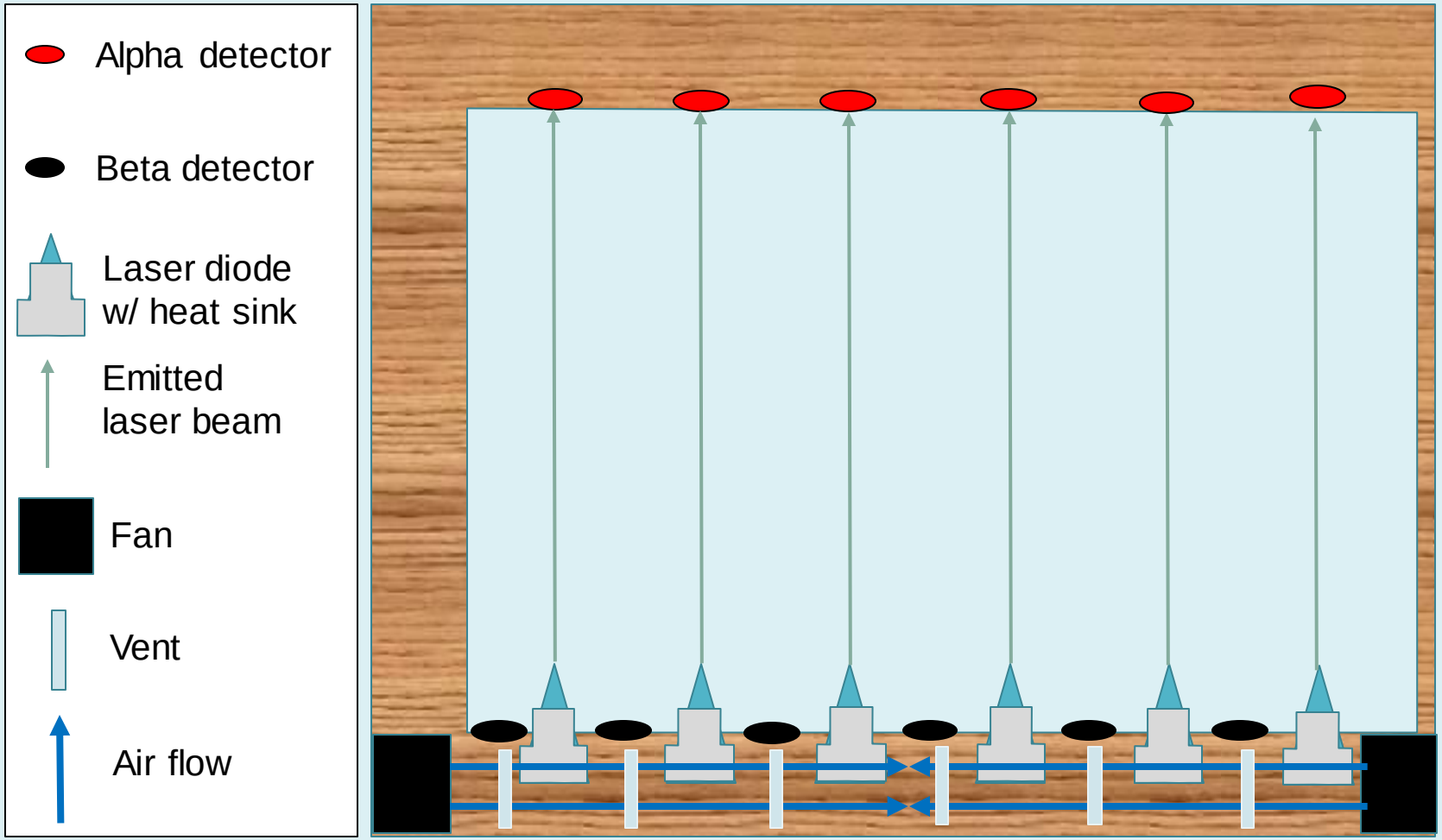


Single String Prototype



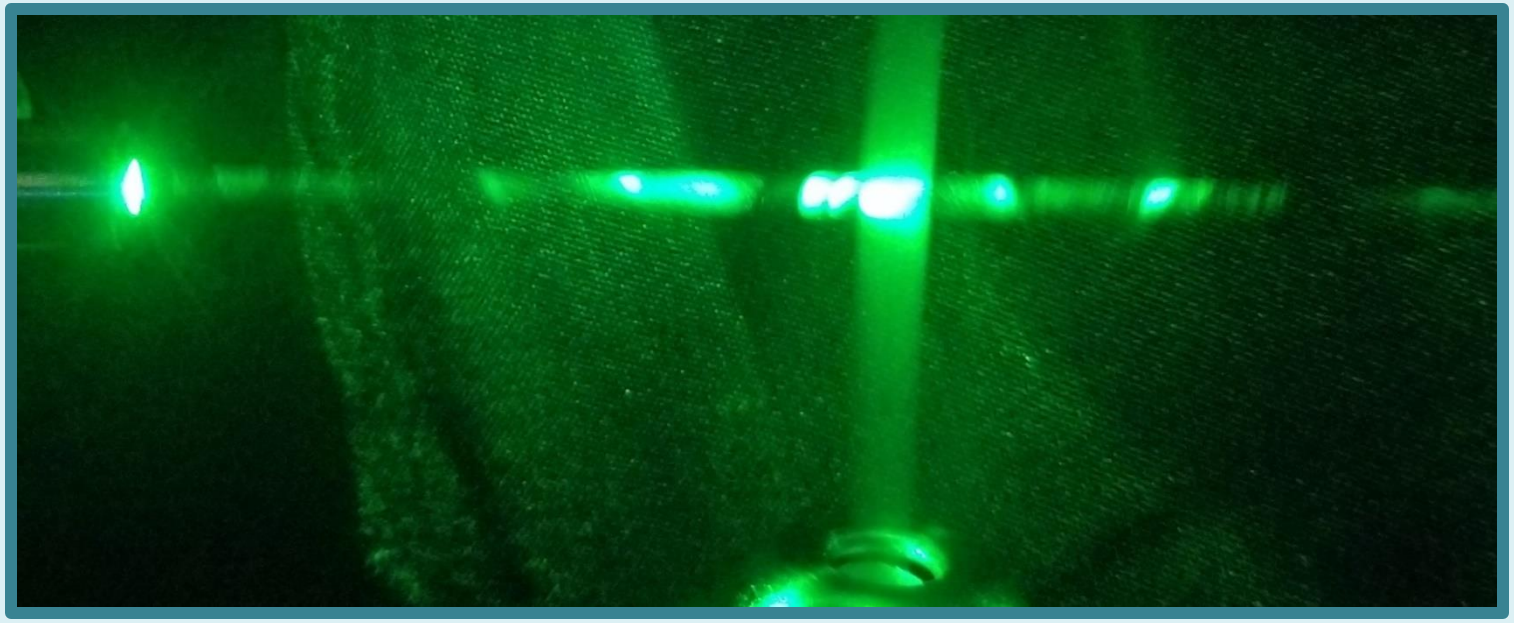
Thermal Management

- Regulate temperature to optimize efficiency
- Heat sinks on laser diodes
  - Lasers dissipate ~ 1W of heat
- Fans
- Vents in Frame



Secondary Objectives

- Increase Beam Visibility
  - Diffuser
  - Black backdrop
  - Dim/low-light environments
- Vibrato
- Tremolo



Administrative Content

Work Distribution

Name	Power	Optics	Embedded Software	PCB	Schematics	Sensors	Thermal Control
Joshua			P	P	S		
David		P				P	P
Lucas	P				P	S	

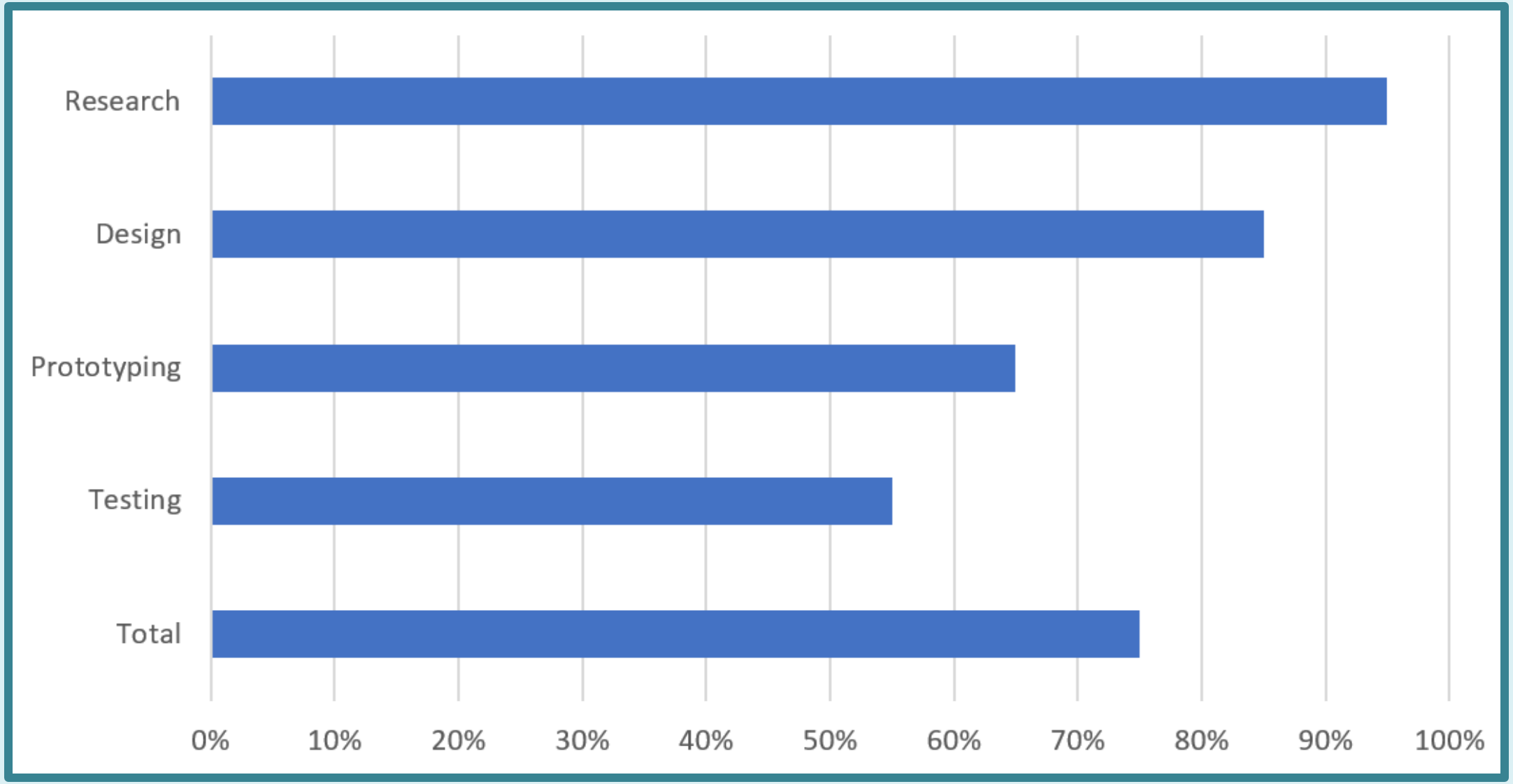
P = Primary S = Secondary

Budget

Item Name	Supplier	Price/Unit (USD)	Quantity	Total Cost (USD)*	Item Name	Supplier	Price/Unit (USD)	Quantity	Total Cost (USD)*
Samsung-30Q	18650 Battery Store	4.49	8	40.53	47 µF electrolytic capacitor	Digi-Key	0.24	20	4.76
First PCB order	JLPCB	0.80	10	25.92	1 MΩ resistor	Digi-Key	0.01	10	0.13
3.5mm mono Jack	Mouser	0.90	5	12.49	1 KΩ resistor	Digi-Key	0.19	10	1.88
Voltage regulator L7805cv	Amazon	0.40	20	7.99	GS1G diode	Digi-Key	0.26	10	2.58
Battery Holder	Amazon	1.50	6	8.99	535-9355-ND oscillator	Digi-Key	0.23	10	2.25
Vishay TEMD5510FX01 PIN photodiode	Arrow	1.16	30	34.80	NCP1117ST50T3G regulator	Digi-Key	0.46	10	4.58
Red laser diodes	Amazon	0.2	10	1.95	Heat sink for laser diodes	eBay	5.71	7	39.98
Green laser diodes	ebay	5.89	12	70.68	Digital Illuminance/Light Meter	Amazon	29.99	1	29.99
18650 Cell Charger	Amazon	14.99	1	14.99	LM358N Op-Amp	Amazon	0.1598	50	7.99
Arduino Mega 2560 Rev3	Arduino Store	38.50	1	38.50	12AWG Wire	Amazon	0.849	10ft	8.49
ATMEGA2560 microcontroller	Digi-Key	12.21	3	49.19	Proposed: $745 + $745 for reconstruction				
TLV2171 Op-Amp	Texas Instruments	1.25	5	13.01	Total : $421.67				

*Total costs include shipping costs

Progress


Research
Design
Prototyping
Testing
Total
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

Issues/Challenges

- Maintain a linear response
- Range detection
- Laser safety
- Start-up is inconsistent
- Coding
- Cell balancing and BMS

Questions?