Blocks o' Code (v3)

Sponsored by Dr. Mike and Dr. Weeks

Jordan Merkel

Destiny Ellenwood

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Camilla Torres

The Team

Jordan Merkel

Computer Engineering

Destiny Ellenwood

Computer Engineering

Annesley Kolb

Electrical Engineering

Camilla Torres

Electrical Engineering

Team Member Roles

Team Member	Primary Responsibilities
Jordan	Project Lead, Fullstack Software Integration, Firmware development, UI/UX Design, Network Architecture
Camilla	PCB Design, Power Distribution, PCB Assembly & Testing
Annesley	PCB Design, PCB Assembly & Testing, CAD modeling
Destiny	Firmware development, Software Integration, UI/UX Design, Reliability & hardware/software validation.

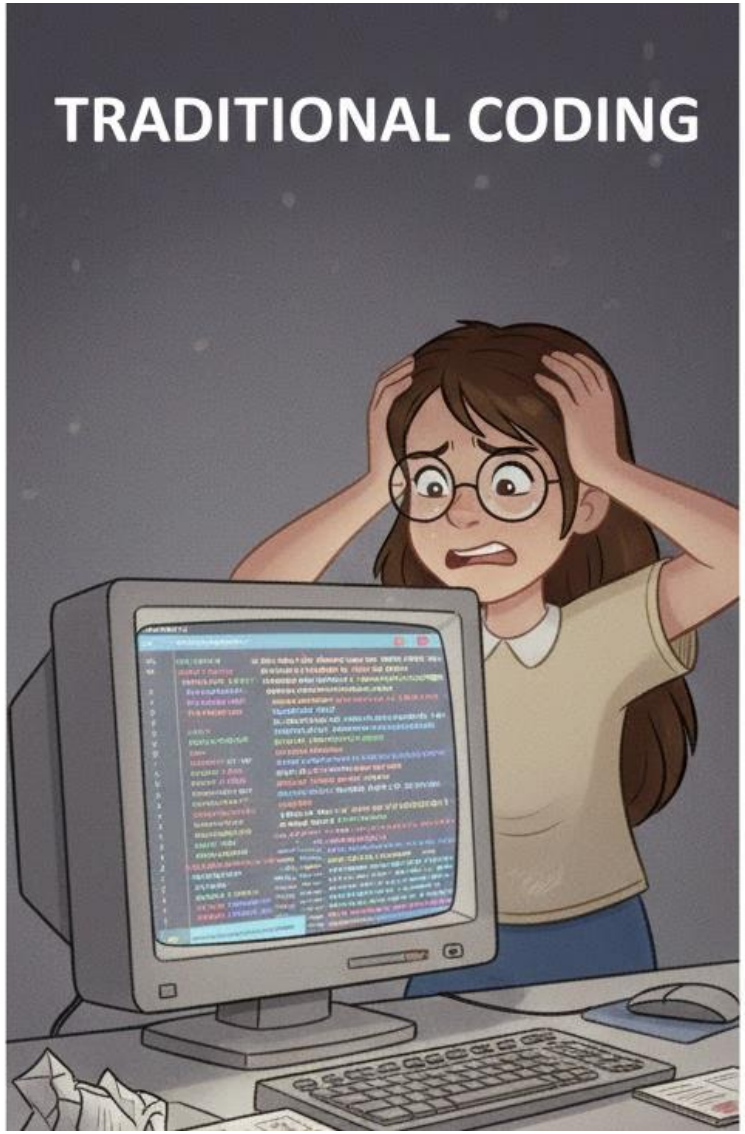
Project Overview

What is Blocks of Code?

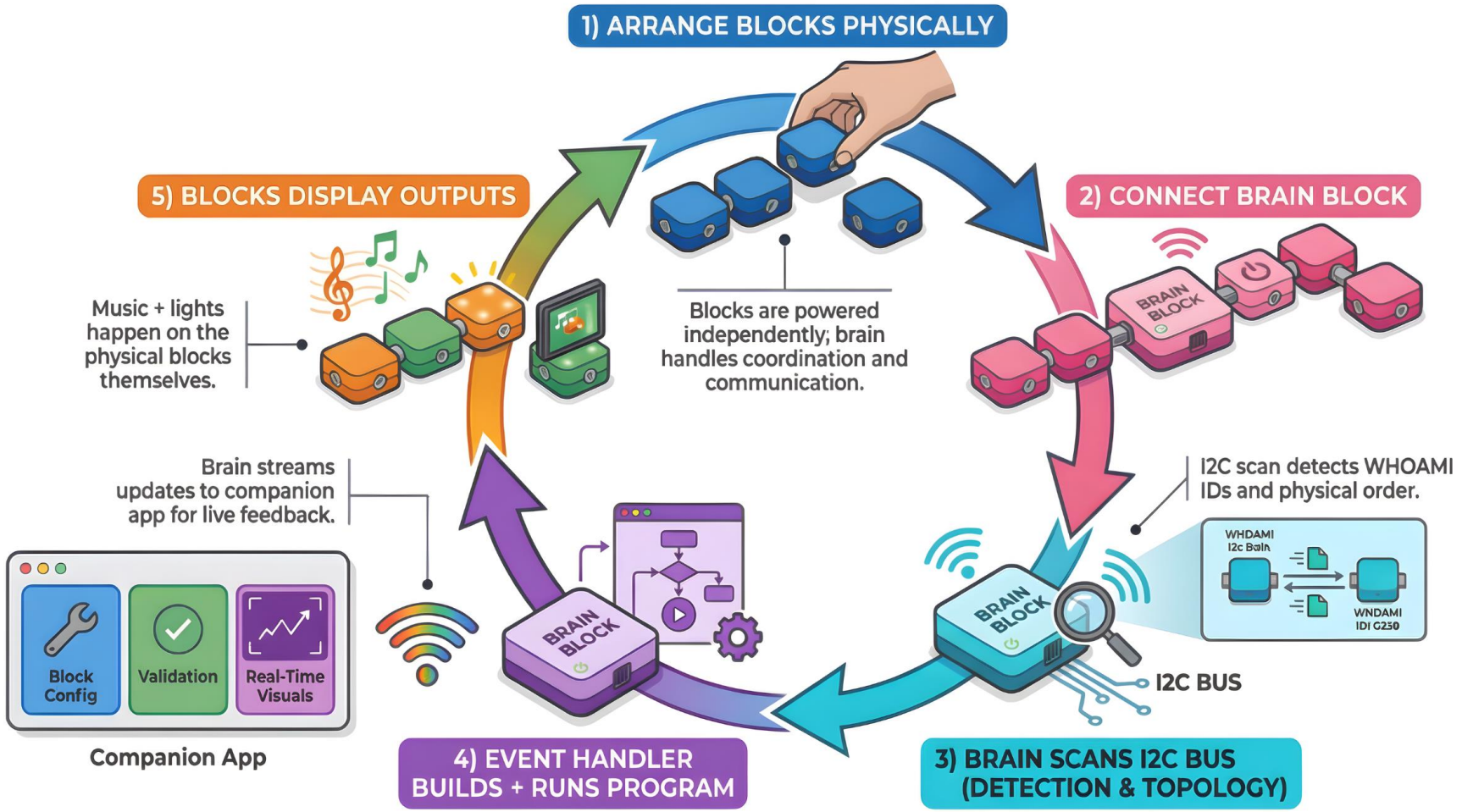
- Physical coding system for teaching programming
- Designed for kids and beginners
- Uses magnetic blocks to build programs
- No typing or traditional coding required
- Creates real-world outputs like lights and sound
- Makes learning interactive and hands-on

Problem and Motivation

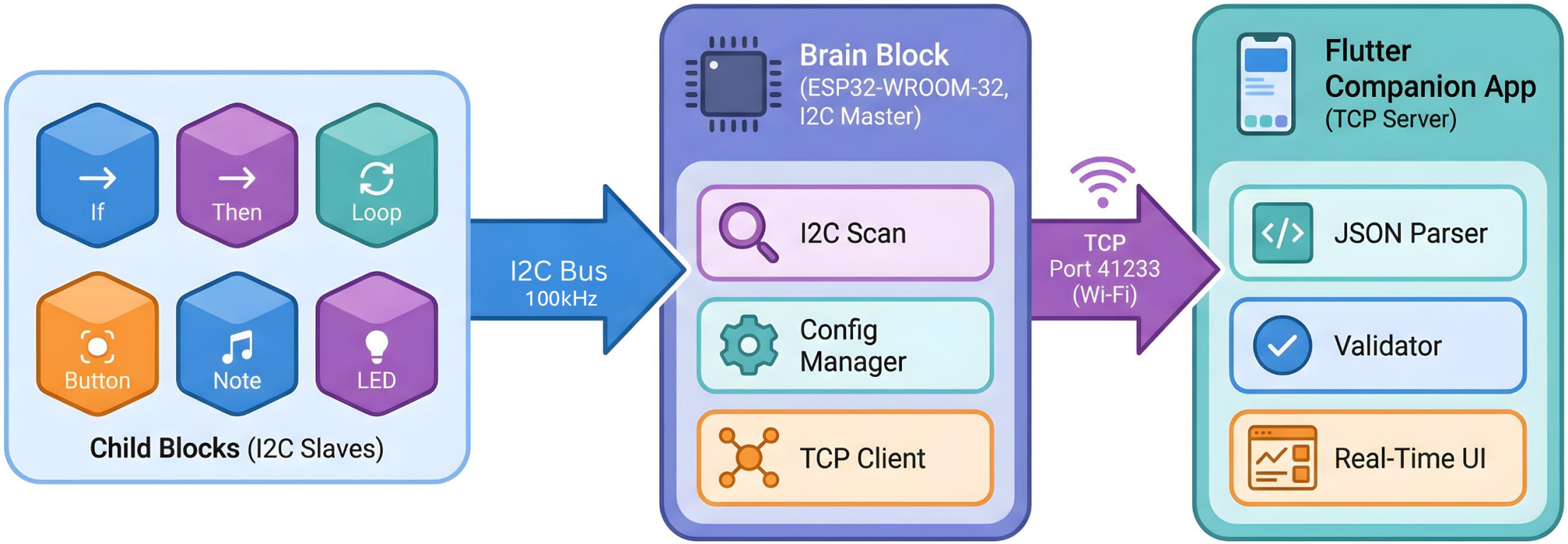
- Complex Syntax
- Unclear Cause-and-Effect
- Limited Accessibility



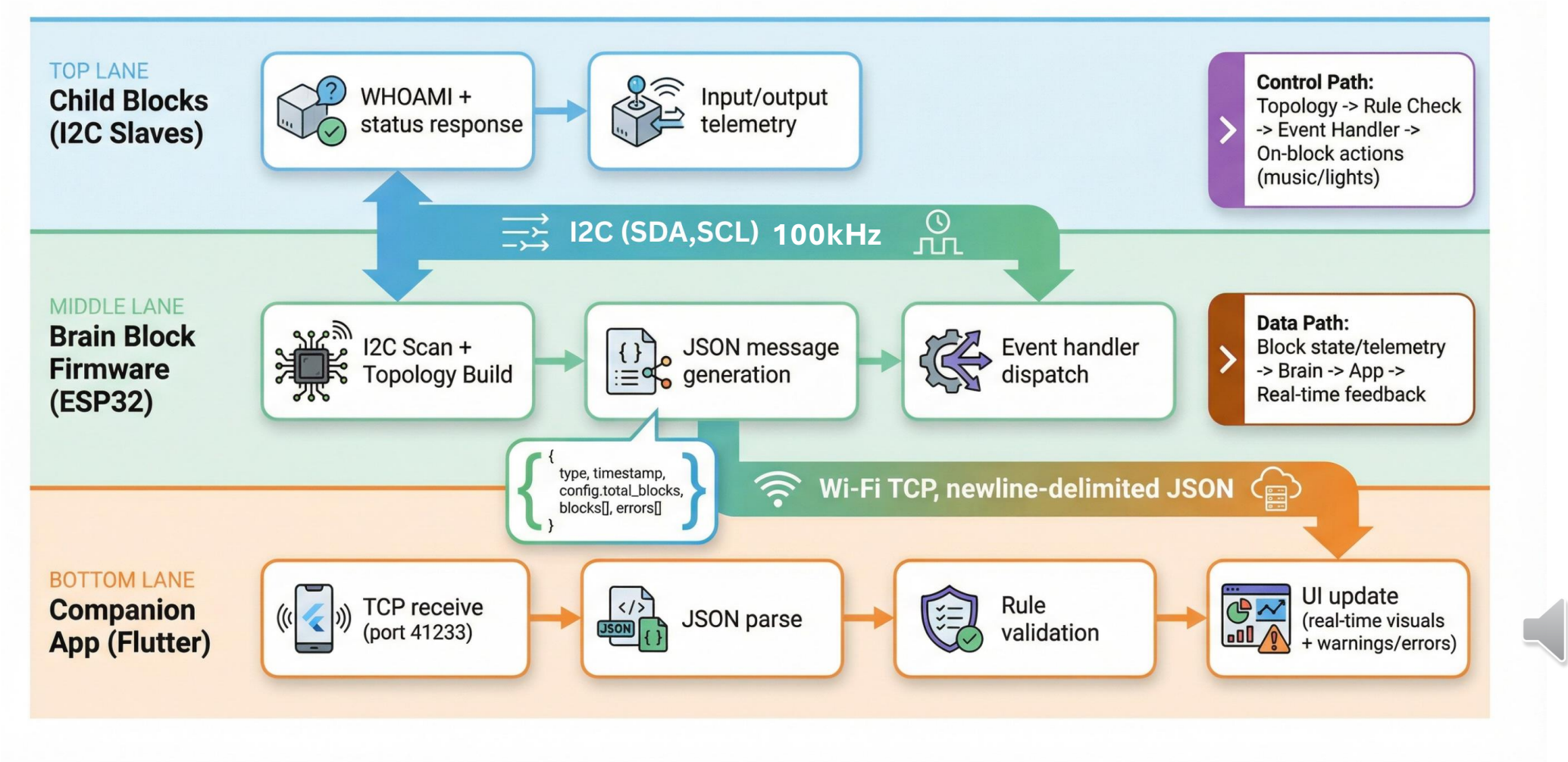
End-to-End Interaction Flow



System Architecture



Data/Control Flow



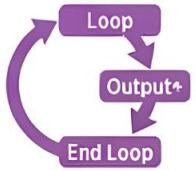
Configuration Rules

Brain Block Rule

Brain block is required and must be at index 0.

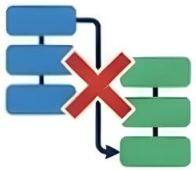
If Sequence Rule

If -> Input -> Then -> Output+ -> End If



Loop Sequence Rule

Loop -> Output+ -> End Loop



Sequence Isolation Rule

If/Loop sequences should not interleave.

Validation Output

Error (must fix)

- Missing Brain Block
- Brain Block not at index 0
- Invalid If sequence
- Invalid Loop sequence

Warning (advisory)

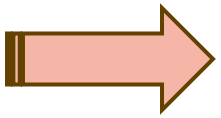
- Interleaved If and Loop sequences

Receive JSON → Parse → **Validate** → UI feedback

Goals and Objectives

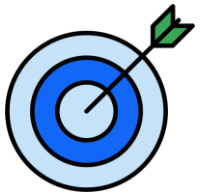
Basic Goal

- Magnetic contact-based block-to-block communication.
- Low-latency I2C (100kHz) keeps commands fast and reliable.
- At least 15 functional blocks with clear visual indications.



Functional Goal

- Brain detects connected blocks in milliseconds and syncs topology to the companion app.
- App mirrors actions instantly for guidance, status, and playback.
- Magnetic contact pads for data and power; low-power design for extended runtime (e.g. ≥ 60 min active).

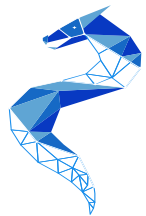


Stretch Goal

- Real-time visualization on PC/tablet.
- 3D-printed block enclosures.
- OLED/ e-paper on-block displays.
- Voice input blocks

Success Criteria

- System validates 3+ sequence types (e.g. If/Then, Loop, LED Color Flash) and supports configurations with 15+ blocks.
- Peripherals such as lights, sound, and UI provide immediate feedback for valid and invalid sequences.
- App mirrors actions in real time for guidance and playback.
- Battery life: ≥ 60 min active runtime; durable, repeatable connections.

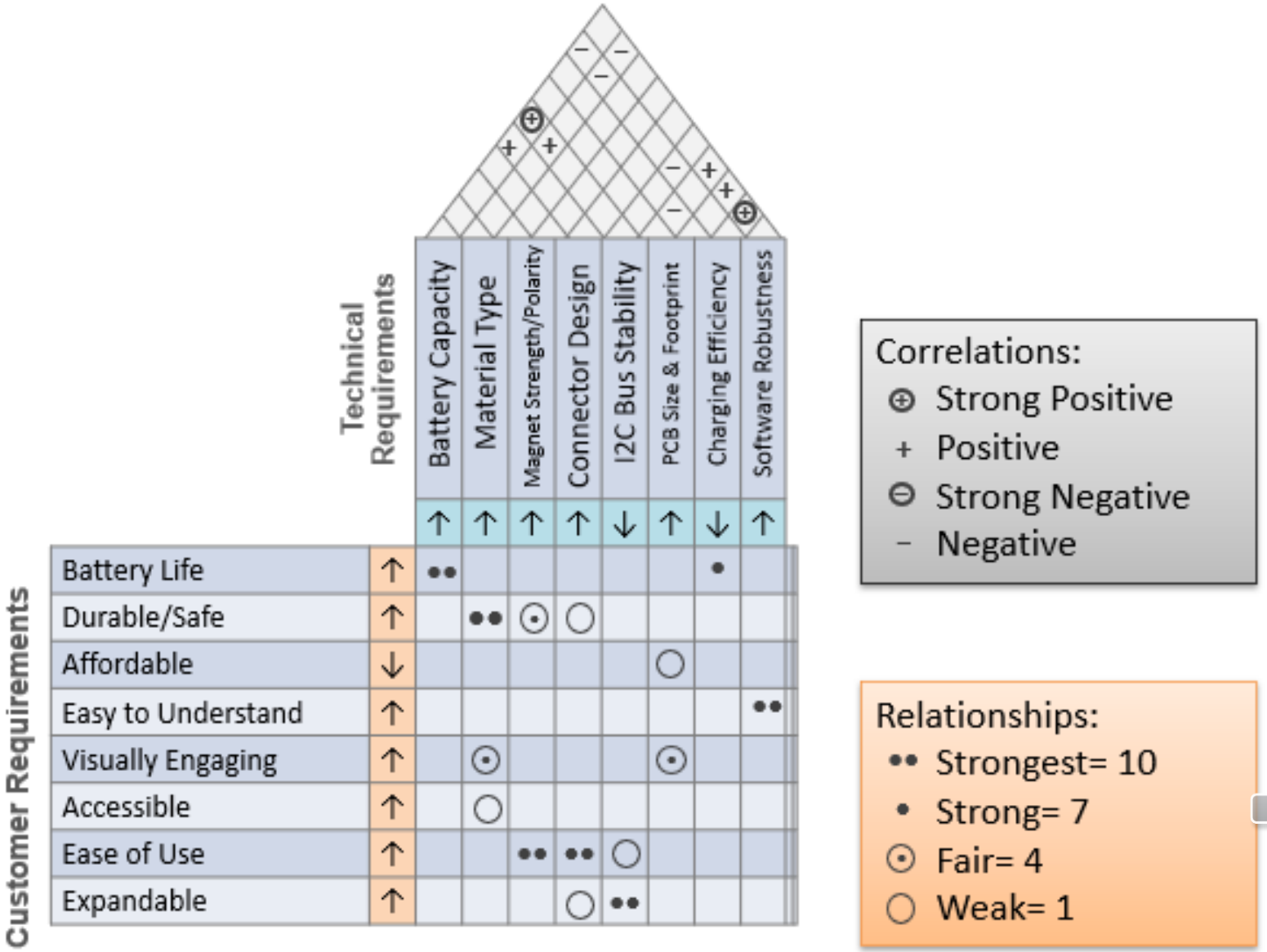


Engineering Specifications

Specification	Target	Measured	Verification
Gateway block – MCU	ESP32- WROOM-32, 240 MHz, Wi-Fi	—	Functionality test
Display- hardware	2.8" TFT SPI, 240x320, 14-pin, touch	—	Power-on + SPI; logic analyzer
Display- block UIs	TFT shows block-type-specific interfaces (e.g. numpad for note/input, animations for feedback)	—	Power-on + SPI; logic analyzer
Addressable LED strips	WS2812B; chainable	—	Power-on + data line; oscilloscope
LED matrix	4x4 RGB WS2812B	—	Power-on + scan; oscilloscope
Speaker	0.3 W into 8 @ 3.3V	—	Oscilloscope + SPL meter
Power module – Battery	200 mAh L-ion, 3.3V/5V	—	Charge/discharge test
Contact resistance	≤ 150 m per interface	—	4-wire ohmmeter
Block topology sync to app	≤ 200 ms	50 ms	Logs; oscilloscope; logic analyzer
Maximum chain length	≥ 15 blocks (I^2C @ 100 kHz)	15 blocks, ~426 ns	Oscilloscope (I^2C decode); rise time check
Active runtime	≥ 60 min	≤ 240 min	Timer to battery cutoff
End-to-end latency	≤ 50 ms	50 ms	Oscilloscope; logic analyzer

*Highlighted = Demonstratable specification

House Of Quality

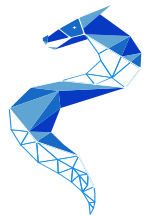


Correlations:
- ⊕ Strong Positive
- \+ Positive
- ⊖ Strong Negative
- \- Negative

Relationships:
- •• Strongest= 10
- • Strong= 7
- ⊙ Fair= 4
- ○ Weak= 1

Hardware Selection

Peripheral	Part/description	Purpose	Justification	Alternatives Reviewed
MCU	ESP32-WROOM-32 (Espressif)	Wi-Fi, I^2C master/slaves, processing	Chosen because it provides built-in Wi-Fi, enough GPIO for multiple peripherals, strong ESP-IDF support, and enough processing power to manage communication, UI, LEDs, and audio in one controller.	Raspberry Pi, ESP32-S3, ESP32-C3, Arduino ATMega
Display	SPI TFT LCD touch (HiLetgo)	2.8" UI/feedback on blocks	Selected to give each block a colorful interactive display with touch input while keeping wiring manageable over SPI. It supported the custom LVGL-based interface and provided clear visual feedback during use.	OLED display, non-touch TFT, character LCD
LED matrix	4x4 RGB WS2812B	Grid visual feedback	Chosen because individually addressable RGB LEDs allowed flexible patterns, animations, and block-specific visual output in a compact footprint.	Single-color LED array, 8x8 matrix, discrete RGB LEDs
Addressable LED	WS2812B strip (BTF-LIGHTING)	Block identification/configuration feedback	Selected for bright, easily programmable visual indication of block state and configuration. It was simple to control from one data line and matched the matrix LED ecosystem.	APA102 strip, single RGB status LED, NeoPixel ring
Speaker	Same Sky (CUI) CMS-2580-05SP	Audio feedback	Chosen to provide simple tones and sound cues for user interaction, confirmations, and accessibility. It was compact and appropriate for embedded audio feedback with compatible drivers.	PUI audio AS03608MR-10-R, Soberton SP-2305L
Amplifier	LM386 (TI)	Drive speaker from MCU	Selected because the MCU alone could not drive the speaker loudly enough. The LM386 provided a simple, low-cost analog amplification stage suitable for basic embedded audio output.	PAM8302A, MAX98357A, TPA2028D1, TAS2562



Hardware Selection - continued

Connector options comparison

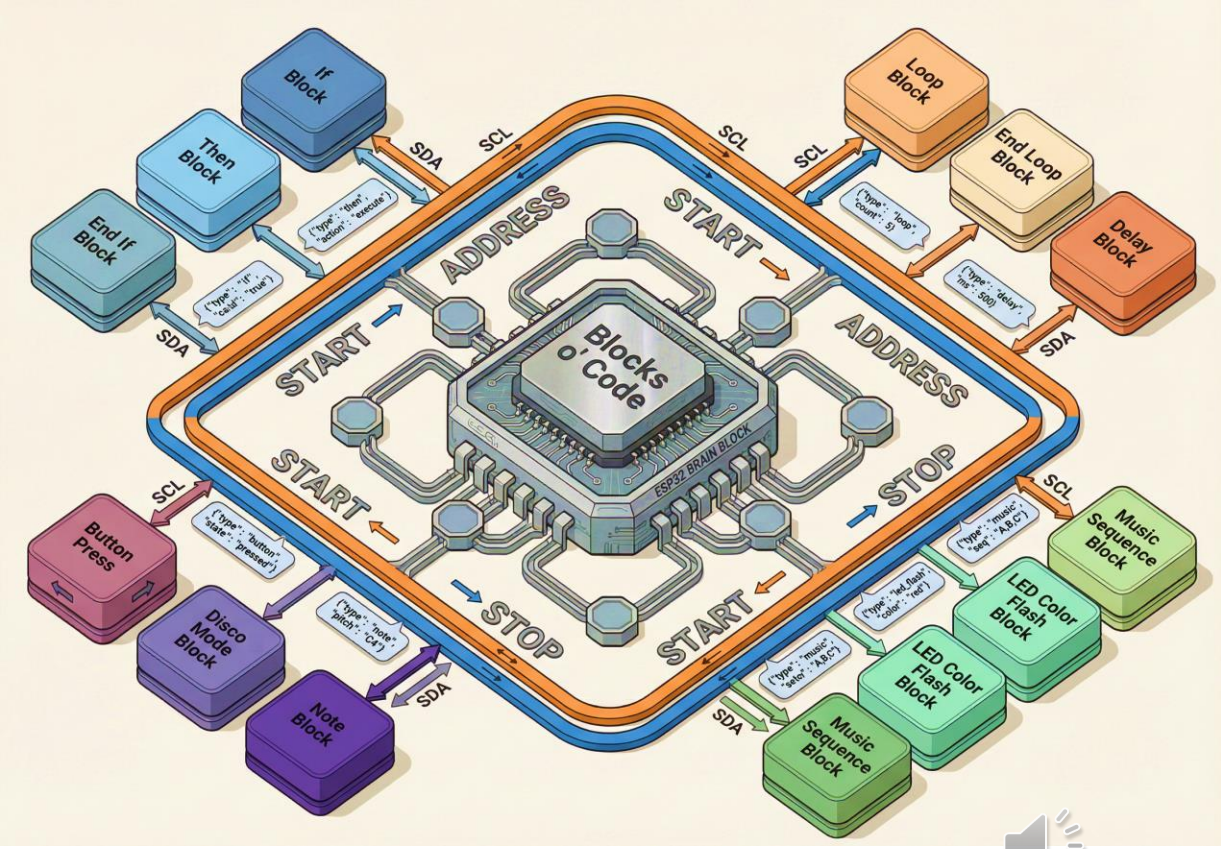
Option	Pros	Cons	Choice	Alternatives Reviewed
Board-to-board/header	Inexpensive, widely available, simple for prototyping	Exposed pins (not child-safe), bend easily, need precise alignment	No	Standard male/female headers, stacking headers, JST-style wired connectors
ADuM1201 (magnetic coupling)	Contactless, no exposed metal, touch-safe, dust-resistant	Higher cost and complexity, lower efficiency, tuning required	No	Other contactless coupling approaches, inductive coupling concepts, isolated magnetic data interfaces
Magnetic pogo-pin (Mill-Max 858-22-004-10-011101)	Snap alignment, power +data, compact, gold-plated for reliability	Alignment sensitive	Yes	Spring-loaded pogo connectors, other magnetic pogo-pin connector families, custom magnetic contact layouts

Software Selection

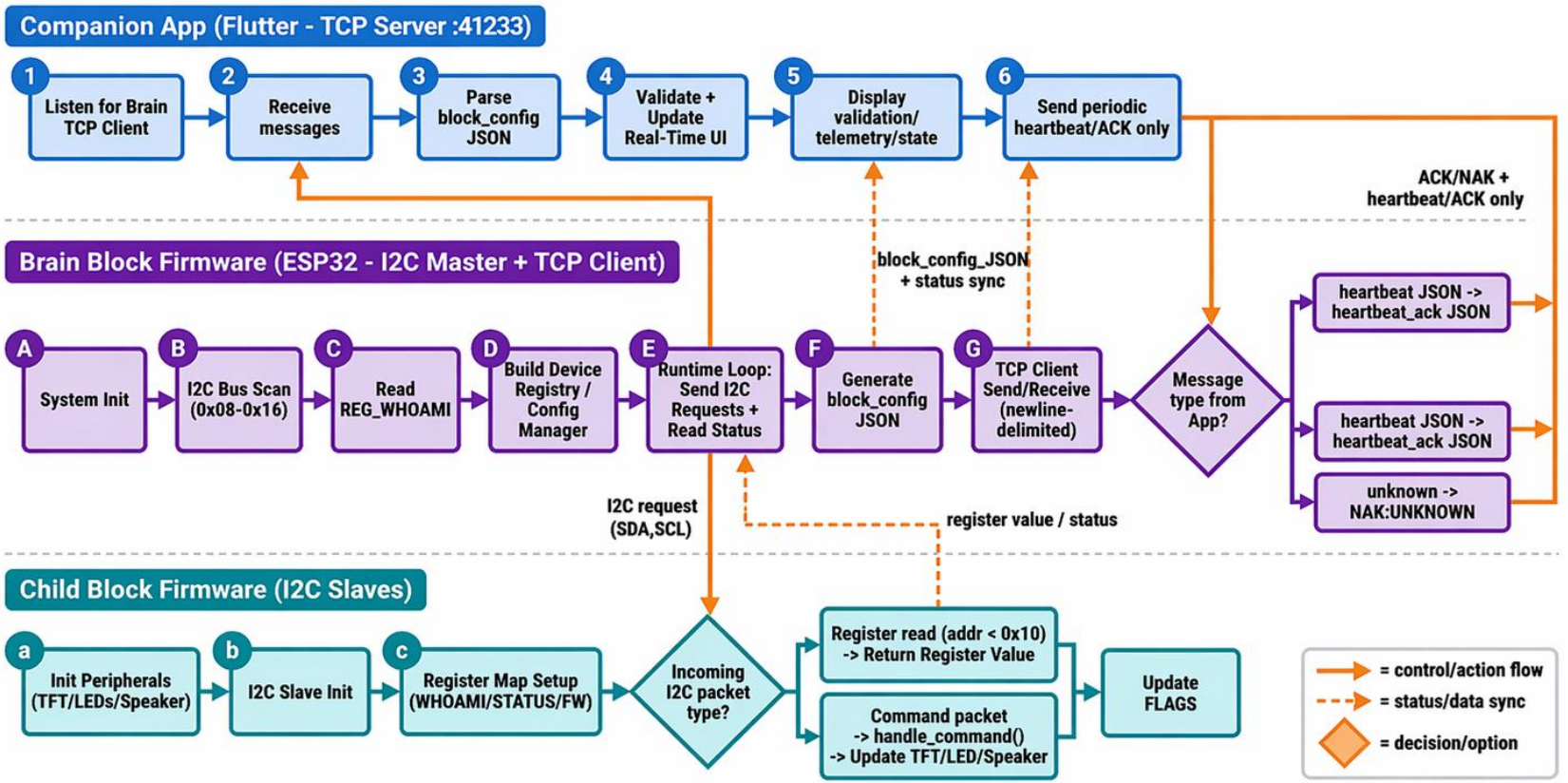
Layer	Selected Tool	Role	Justification	Alternatives Reviewed
Version Control System	Github	To host the project repository, manage branches for hardware and software teams, and track changes.	Enables collaborative development between group; provides a centralized "source of truth" for code and system diagrams.	**Bitbucket / GitLab:** Less community support and fewer integration tools for our specific workflow.
Embedded Framework	ESP-IDF	To develop the firmware for the ESP32-WROOM-32.	Provides full access to wireless connectivity, RTOS support, peripheral drivers	**Arduino IDE:** Lacks advanced multi-threading, less compatible with MCU, not great for real-time systems
Application Framework	Flutter	To build the Companion App that connects to the ESP32-WROOM-32.	Cross-platform performance, C-like programming language, good response time	**React Native:** Slower bridge performance for real-time data streaming **Unity:** Great for 3D visuals, but excessively high overhead.

Software Design

Layer	Role
Companion App	User interface. Design programs (block flow), see live state, send commands to the Brain. Connects via Wi-Fi.
Brain Block	Controller. Finds Child blocks over I^2C, runs programs, sends commands to blocks and status to the app.
Child Blocks	Peripherals. Execute actions (lights, sound, display) and report identity and status over I^2C.

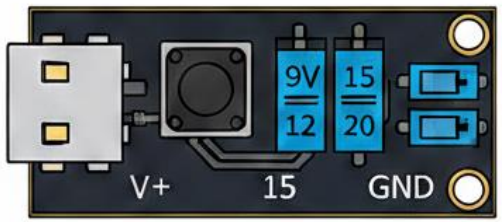


Software Block Diagram



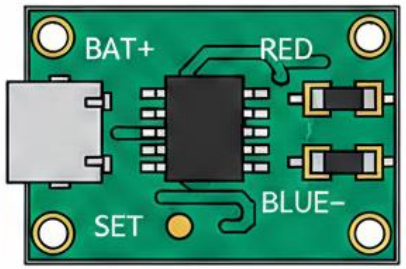
Power System Selection

PD trigger



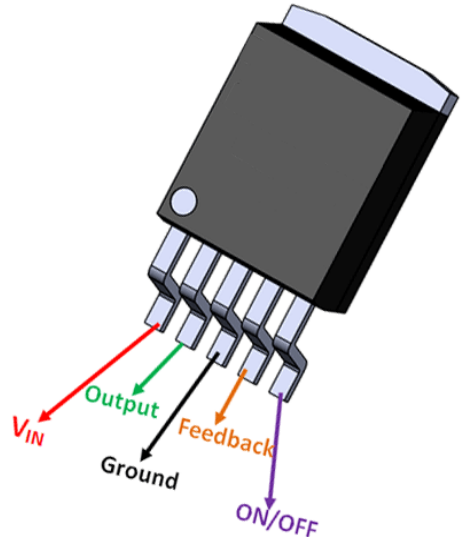
Provides safe and controlled CC/CV charging for our 2-cell lithium-ion battery pack.

TP5100



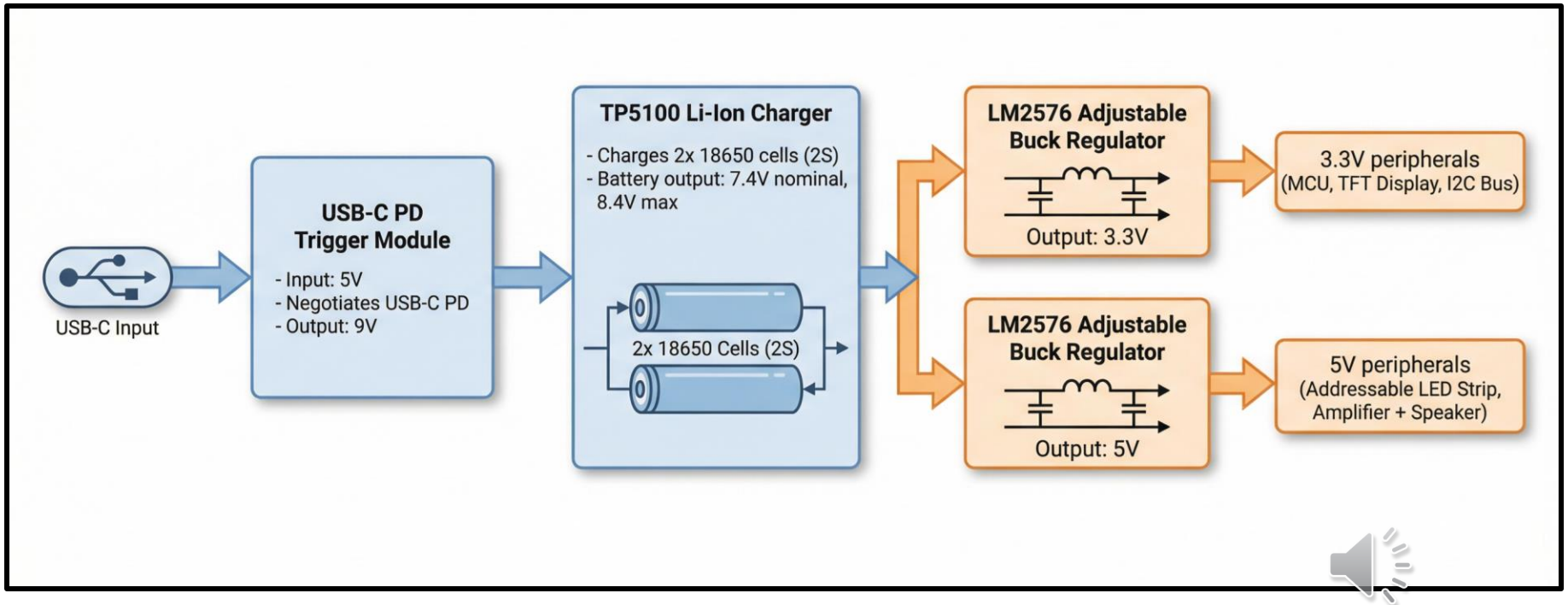
Negotiates 9V from a USB-C power adapter to supply sufficient voltage for 2S battery charging.

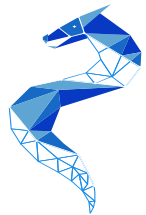
LM2576



Steps down and stabilizes the battery voltage to provide a consistent, safe supply for the system electronics.

Power Architecture





Power Budget

POWER BUDGET — Blocks-o-Code

2S 18650 Li-Ion (7.4V nominal, 8.4V max, 2,600 mAh, 19.24 Wh)

3.3 V RAIL (ESP32 + Display + I2C)				
Component	**Typ (mA)**	**Peak (mA)**	**Typ (mW)**	**Peak (mW)**
ESP32-WROOM-32	100	260	330	858
2.2″ TFT Controller	8	10	26	33
I2C Bus / misc	2	5	7	17
RAIL TOTAL	**110**	**275**	**363**	**908**

5 V RAIL (LEDs + Audio + Backlight)				
Component	**Typ (mA)**	**Peak (mA)**	**Typ (mW)**	**Peak (mW)**
30x WS2812B LEDs	600	1,800	3,000	9,000
4x4 LED Matrix (16 LEDs)	50	160	250	800
LM386 Amplifier + Speaker	30	100	150	500
2.2″ TFT Backlight	25	40	125	200
RAIL TOTAL	**705**	**2,100**	**3,525**	**10,500**

SYSTEM SUMMARY (LM2576 Buck Regulators, efficiency approx 82 percent)					
Scenario	**3.3V Load**	**5V Load**	**Total Load Power**	**Battery Current (at 7.4V)**	**Runtime**
Idle/Standby	40 mA	55 mA	0.41 W	68 mA	~38 hrs
Typical Demo	110 mA	705 mA	3.89 W	641 mA	~4.1 hrs
Peak/Worst Case	275 mA	2,100 mA	11.4 W	1,880 mA	~1.4 hrs

DESIGN RISKS

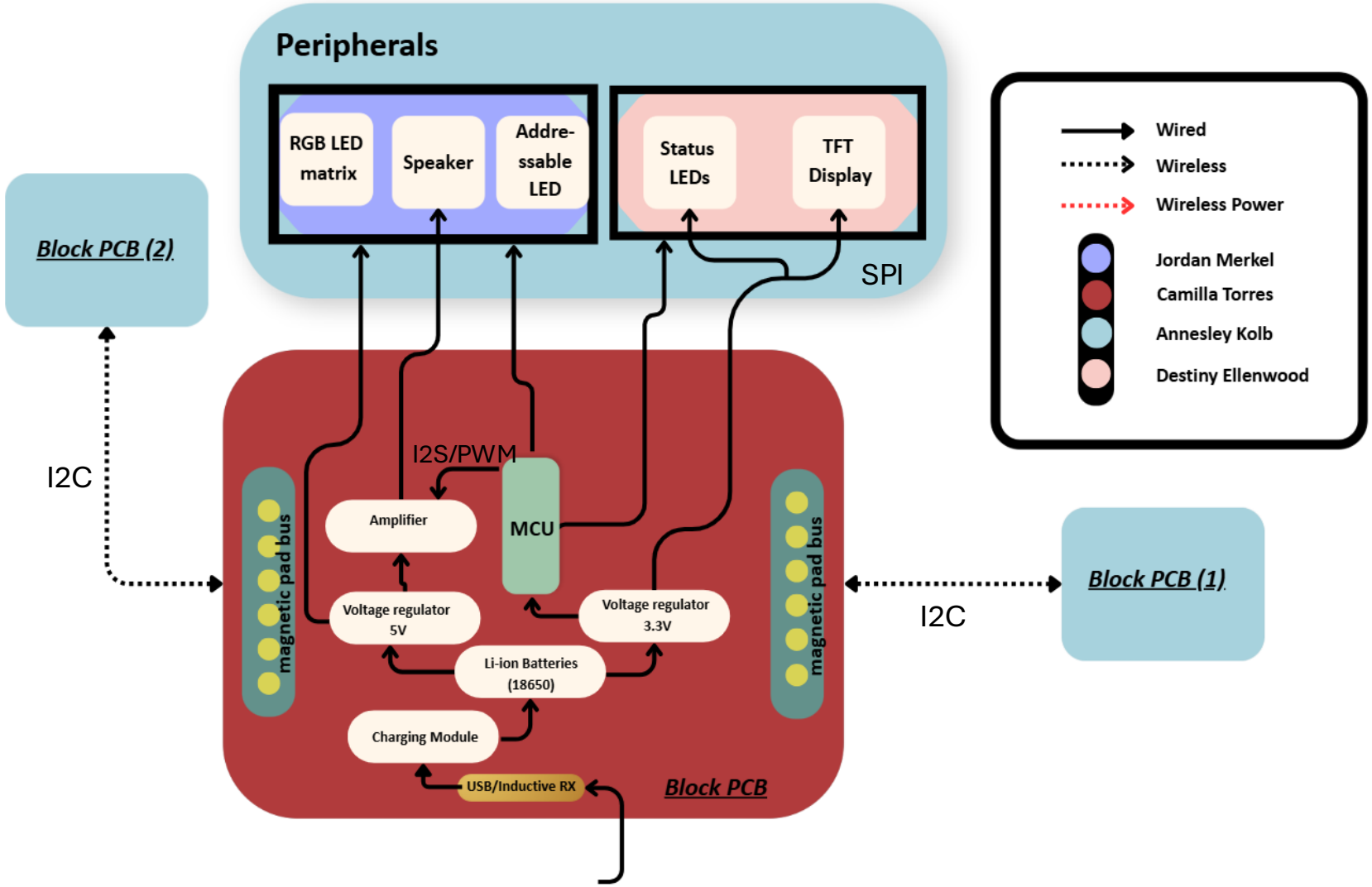
- WS2812B strip dominates — 9 W at full white
- LM2576 rated 3 A; cap LED brightness in firmware
- ESP32 WiFi bursts up to 260 mA — use bulk cap
- Low-voltage cutoff needed at 6.0 V battery

MITIGATIONS

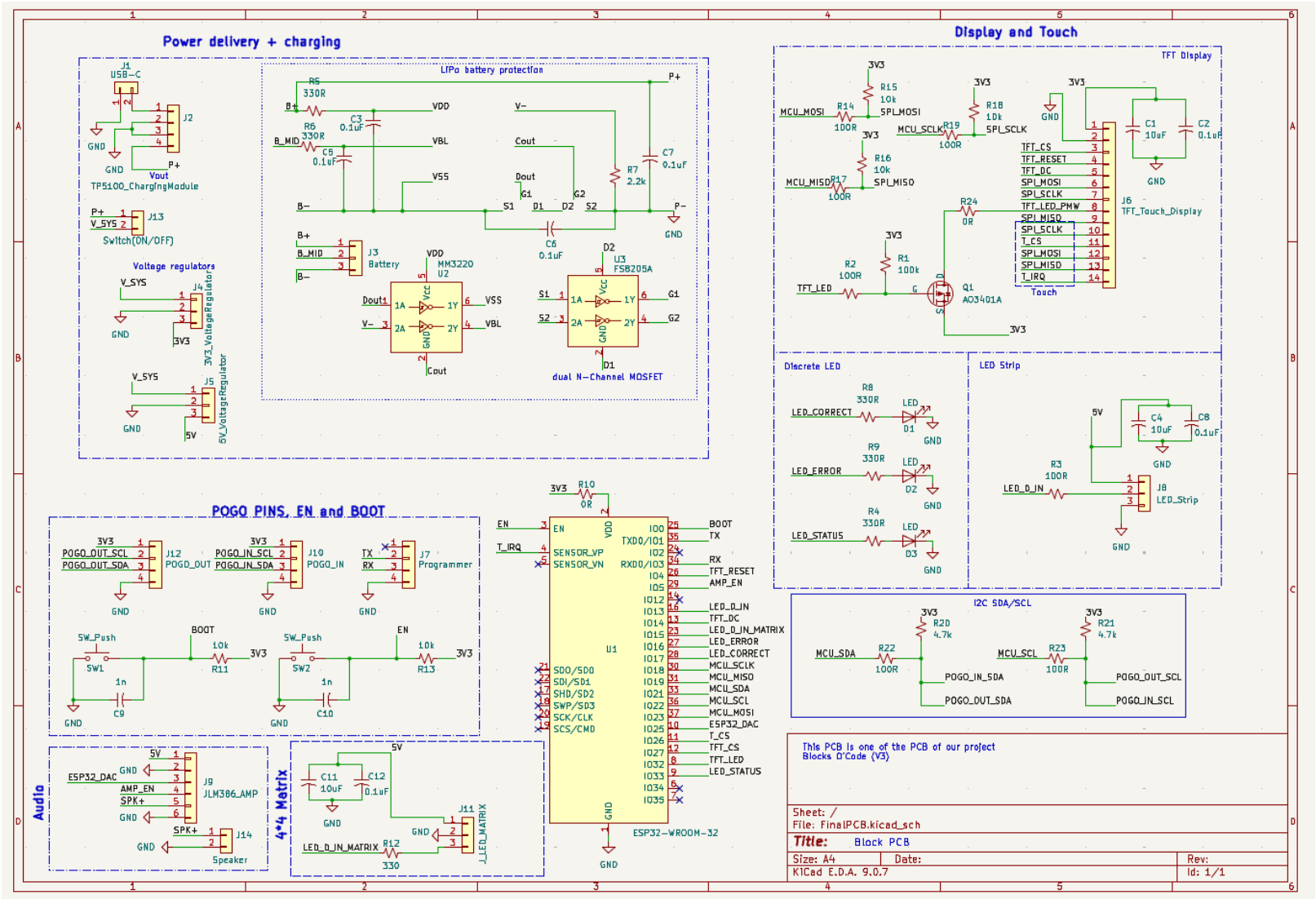
- Brightness capped at 50% → ~4 hr demo runtime
- 470 uF cap near ESP32 VCC
- Heatsink on 5V LM2576 (1.85 W dissipation)
- TP5100 provides over-discharge protection

All values from datasheets: Espressif ESP32-WROOM-32 section 5.4 | TI LM2576, LM386 | Worldsemi WS2812B | Adafruit ILI9341

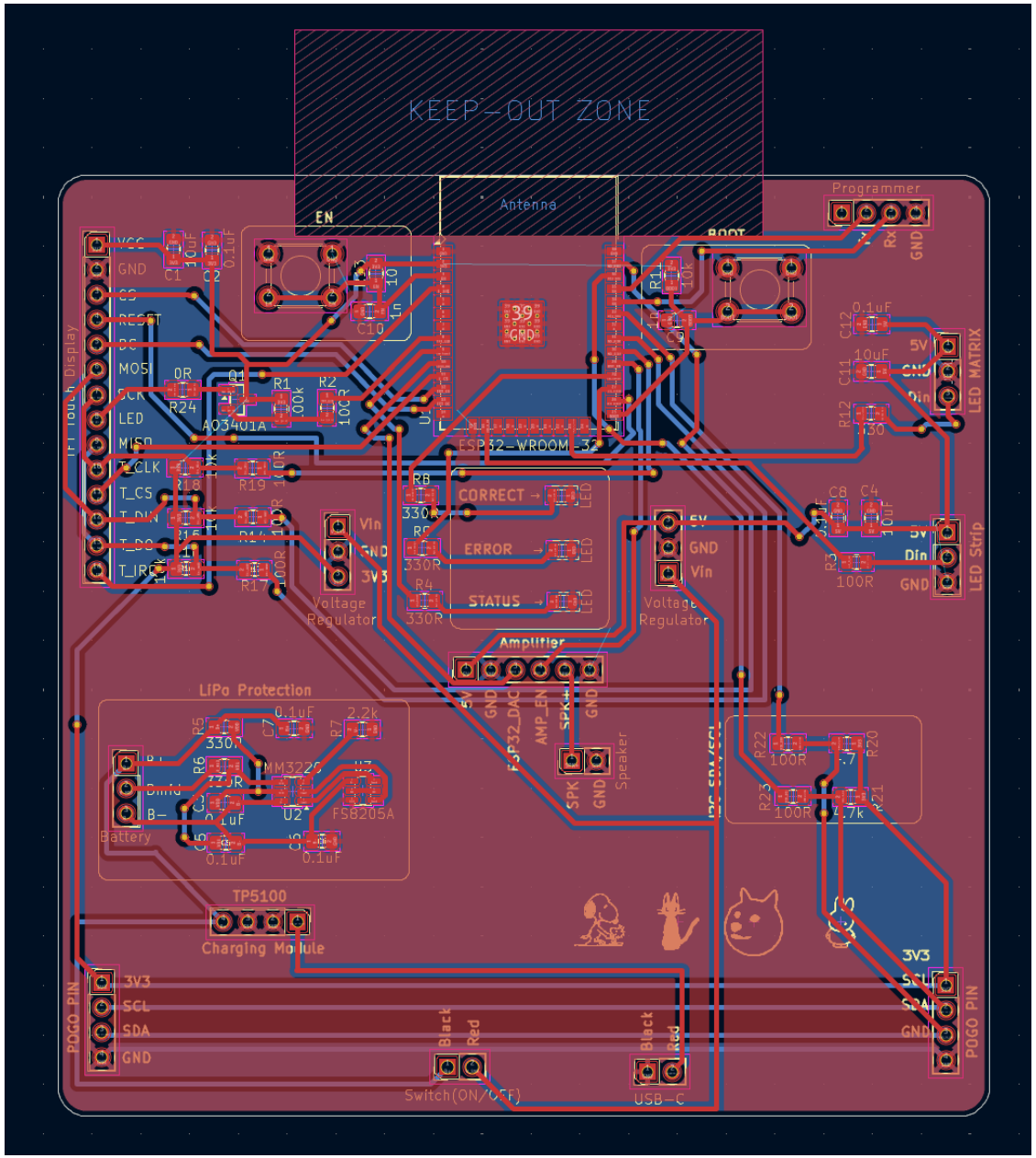
Hardware Block Diagram



Schematic

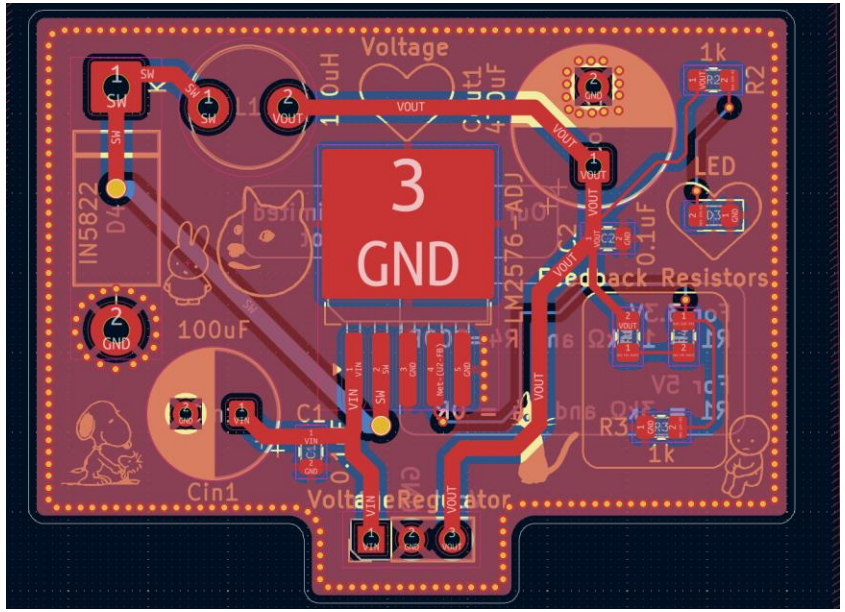

Power delivery + charging
LiPo battery protection
Display and Touch
TFT Display
Discrete LED
LED Strip
POGO PINS, EN and BOOT
I2C SDA/SCL
Audio
4*4 Matrix
TP5100_ChargingModule
Switch(ON/OFF)
Voltage regulators
3V3_VoltageRegulator
5V_VoltageRegulator
Battery
MM3220
FSB205A
dual N-Channel MOSFET
TFT_Touch_Display
Touch
Programmer
JLM386_AMP
Speaker
ESP32-WROOM-32
This PCB is one of the PCB of our project
Blocks O'Code (V3)
Sheet: /
File: FinalPCB.kicad_sch
Title: Block PCB
Size: A4
Date:
Rev:
KiCad E.D.A. 9.0.7
Id: 1/1

PCB Layout

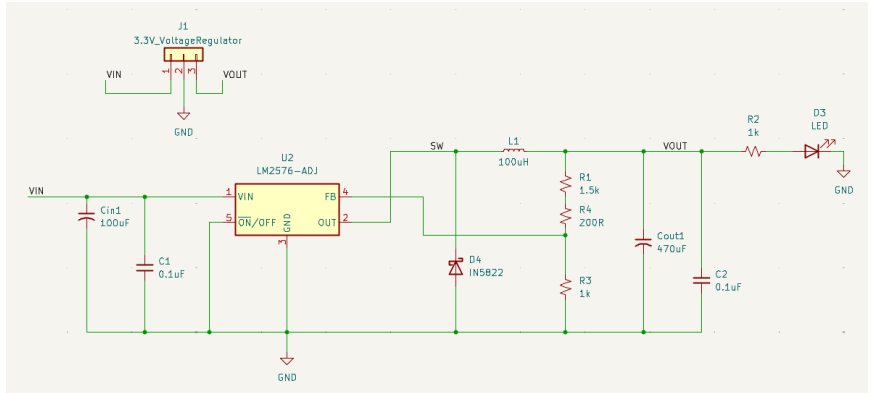

KEEP-OUT ZONE
Antenna
EN
BOOT
Programmer
TFT Touch Display
LED MATRIX
LED Strip
ESP32-WROOM-32
AO3401A
CORRECT
ERROR
STATUS
Voltage Regulator
Amplifier
Speaker
LiPo Protection
Battery
TP5100
Charging Module
FS8205A
MM3226
POGO PIN
Switch(ON/OFF)
USB-C
Black
Red

Voltage Regulators

Layout



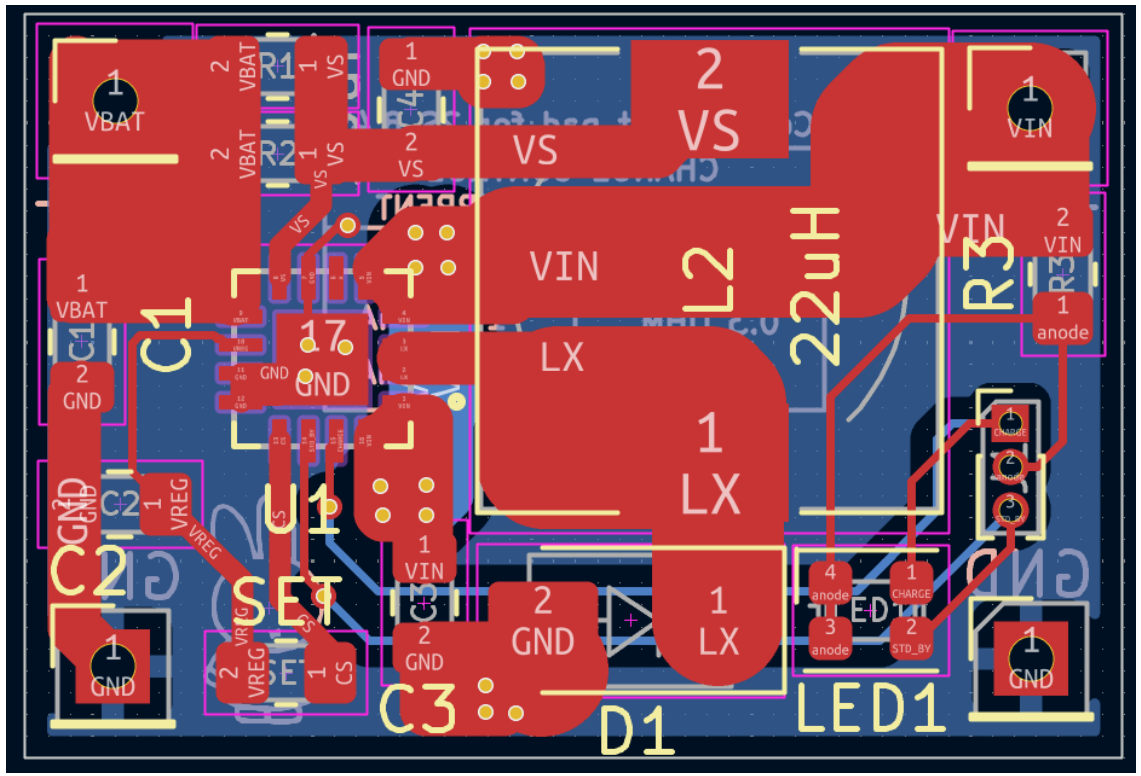
Schematic



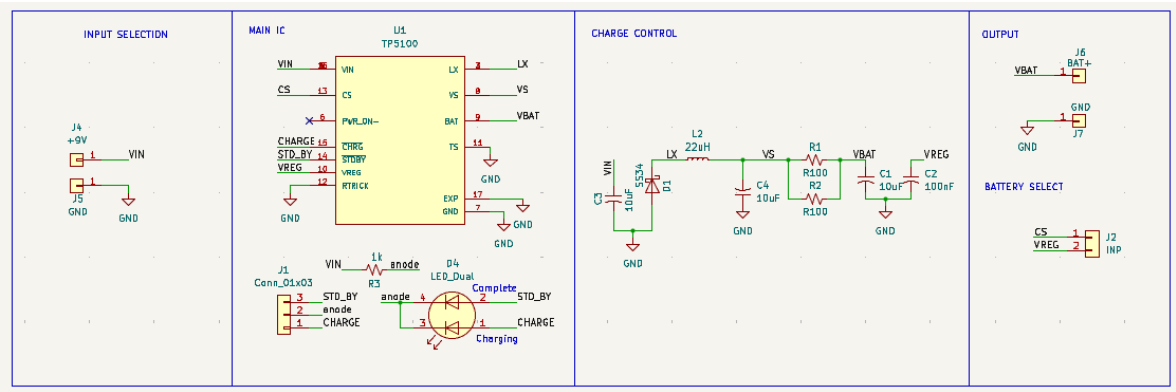
For 3.3V: R1 = 1.5kΩ and R4=200R

For 5V: R1 = 3kΩ and R4 = 0R

Charging Module

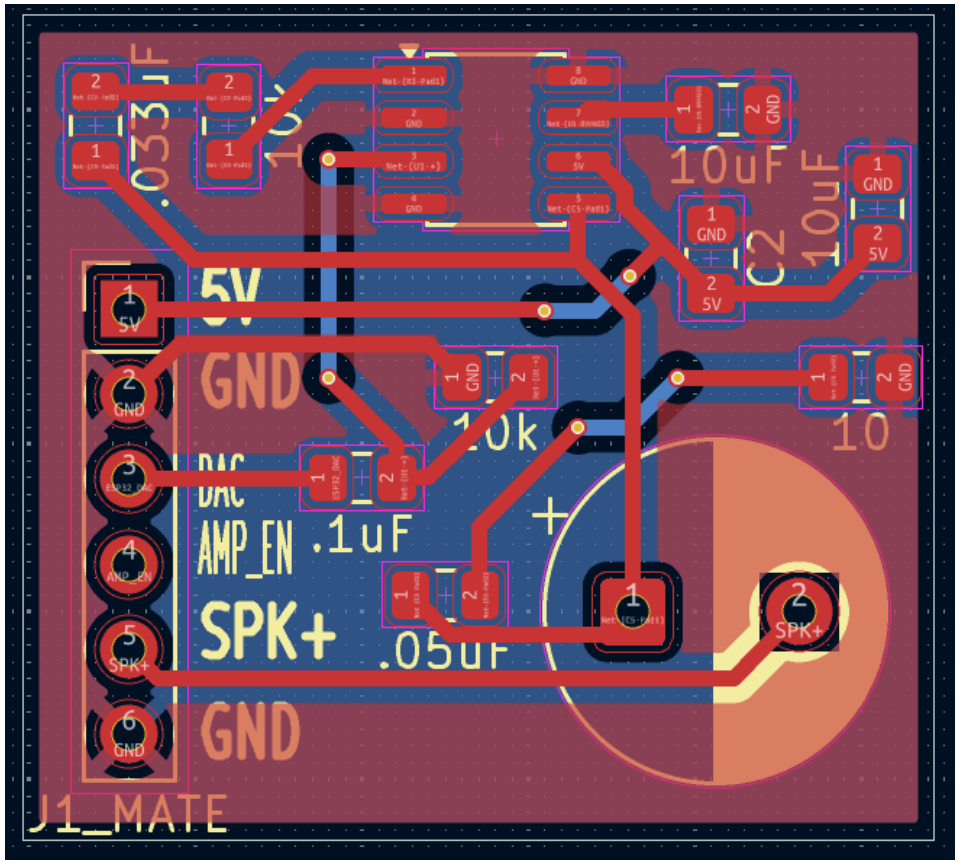


Layout

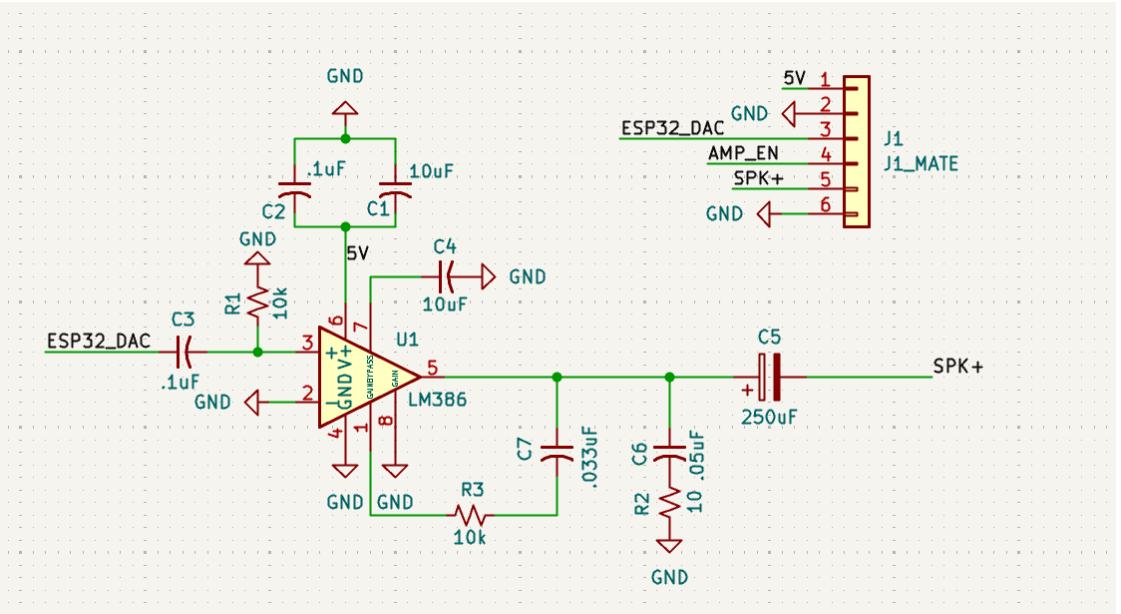


Schematic

Amplifier

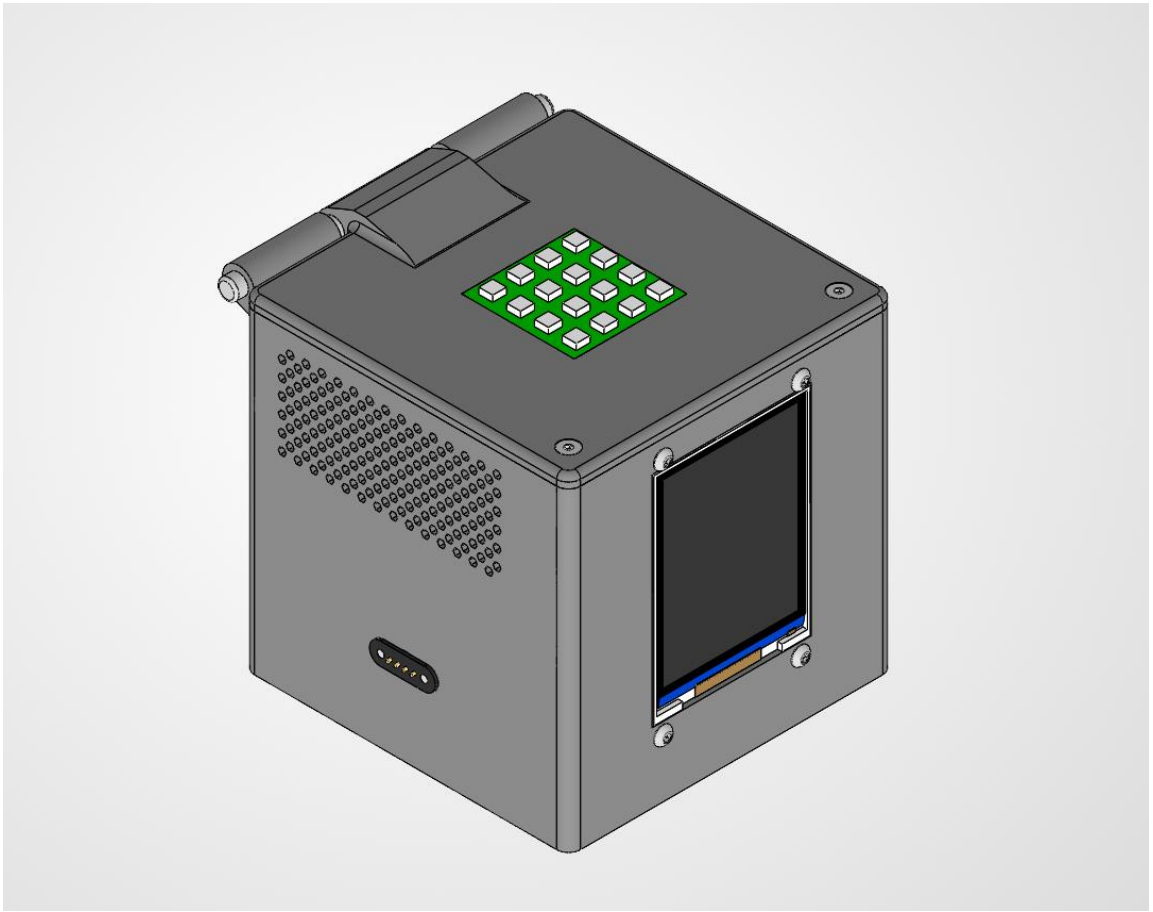


Layout

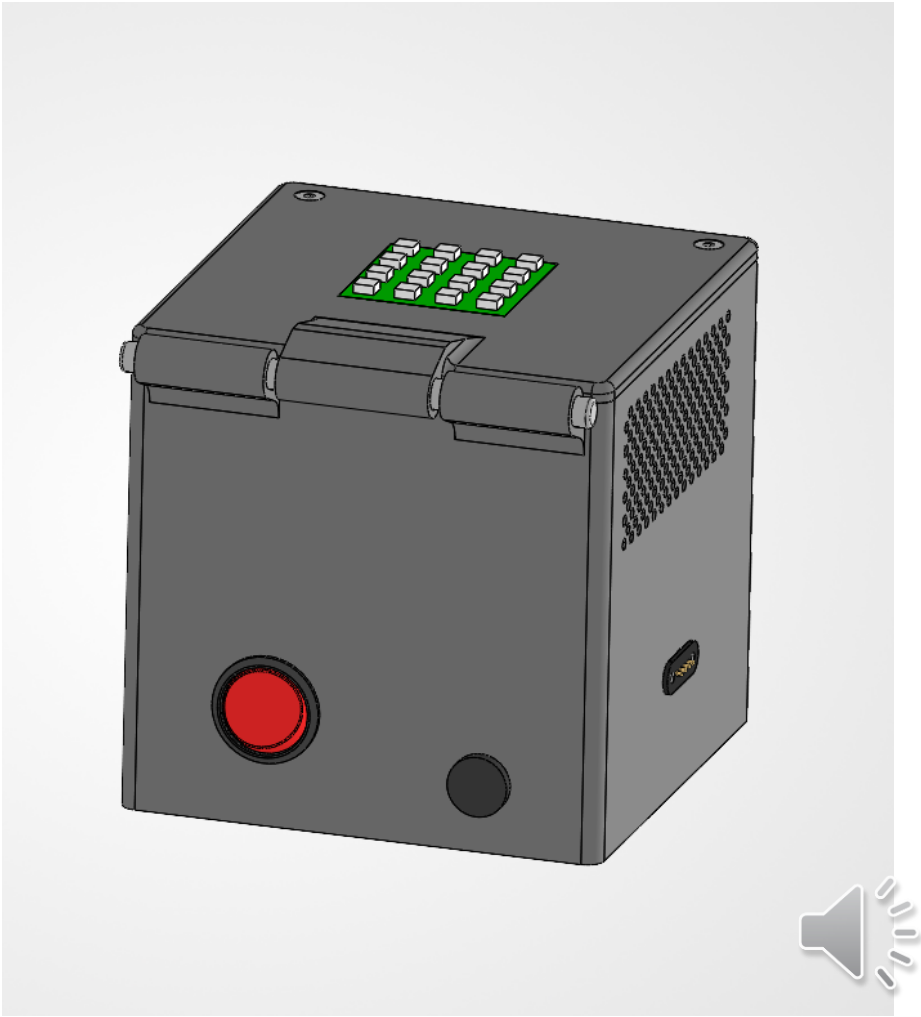


Schematic

Exterior Enclosure

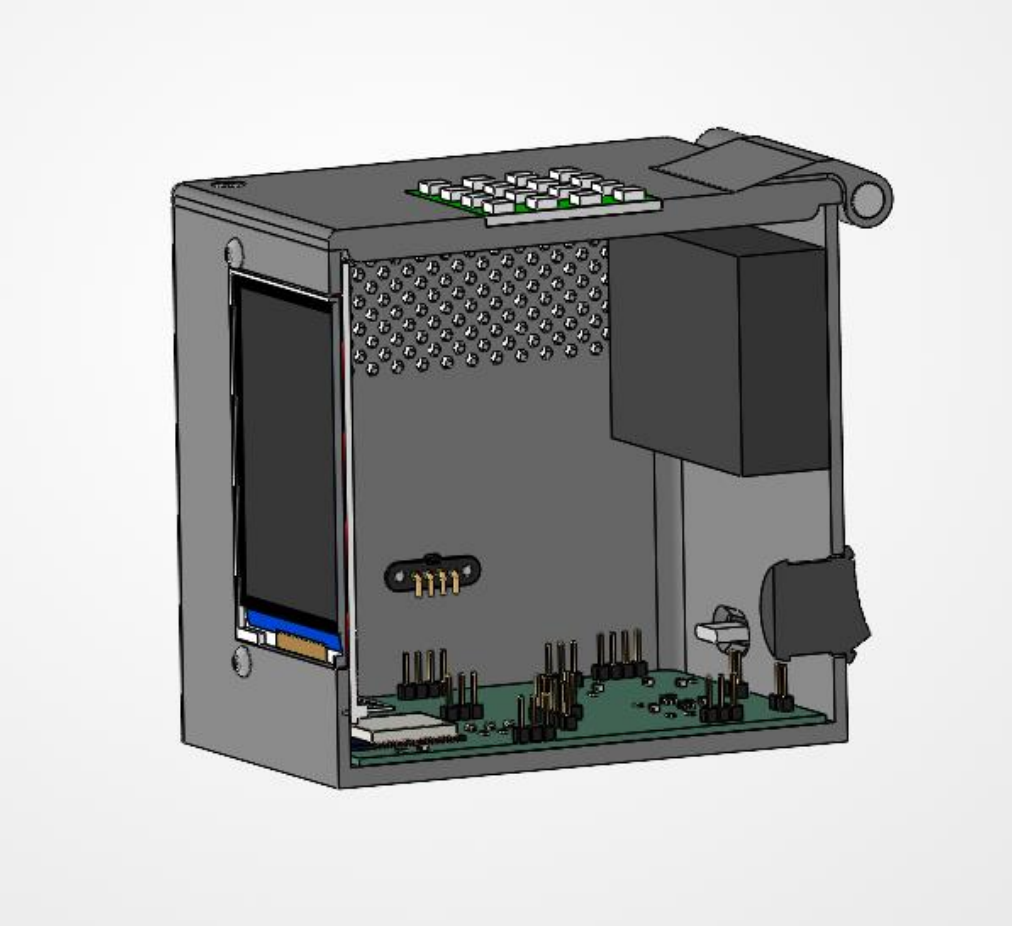


Front View

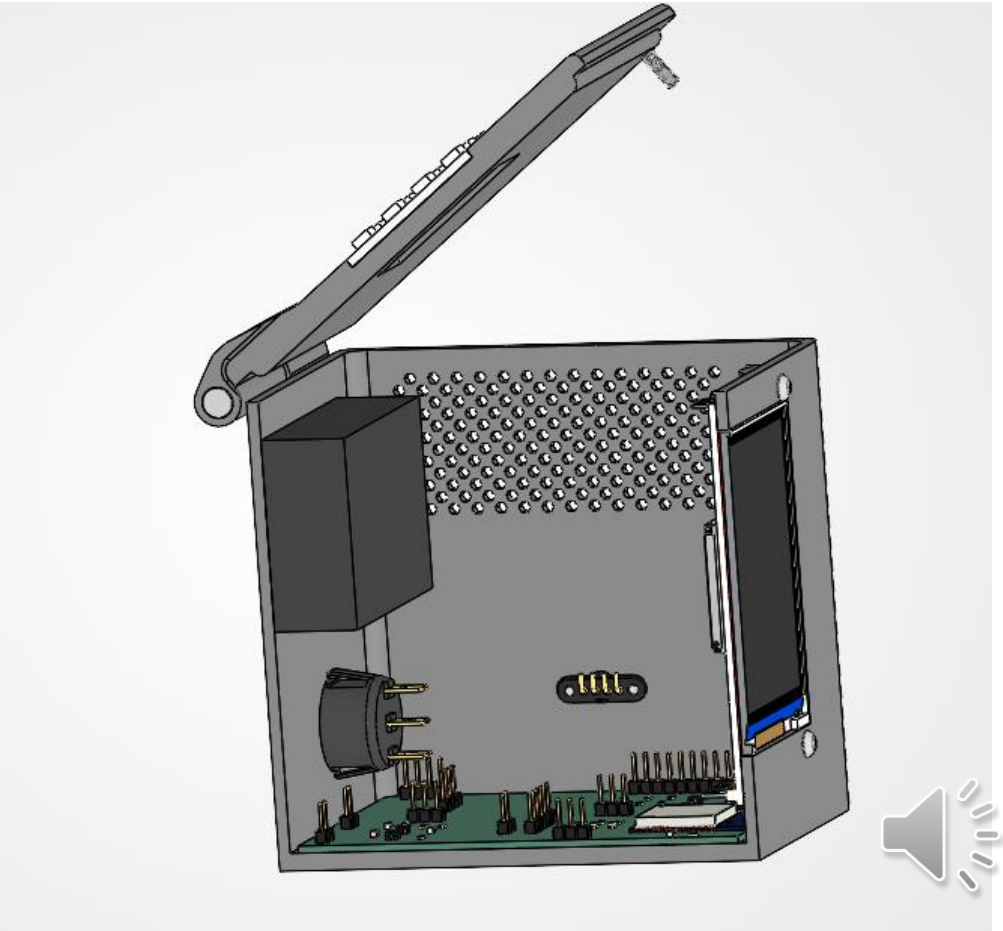


Back View

Interior Enclosure

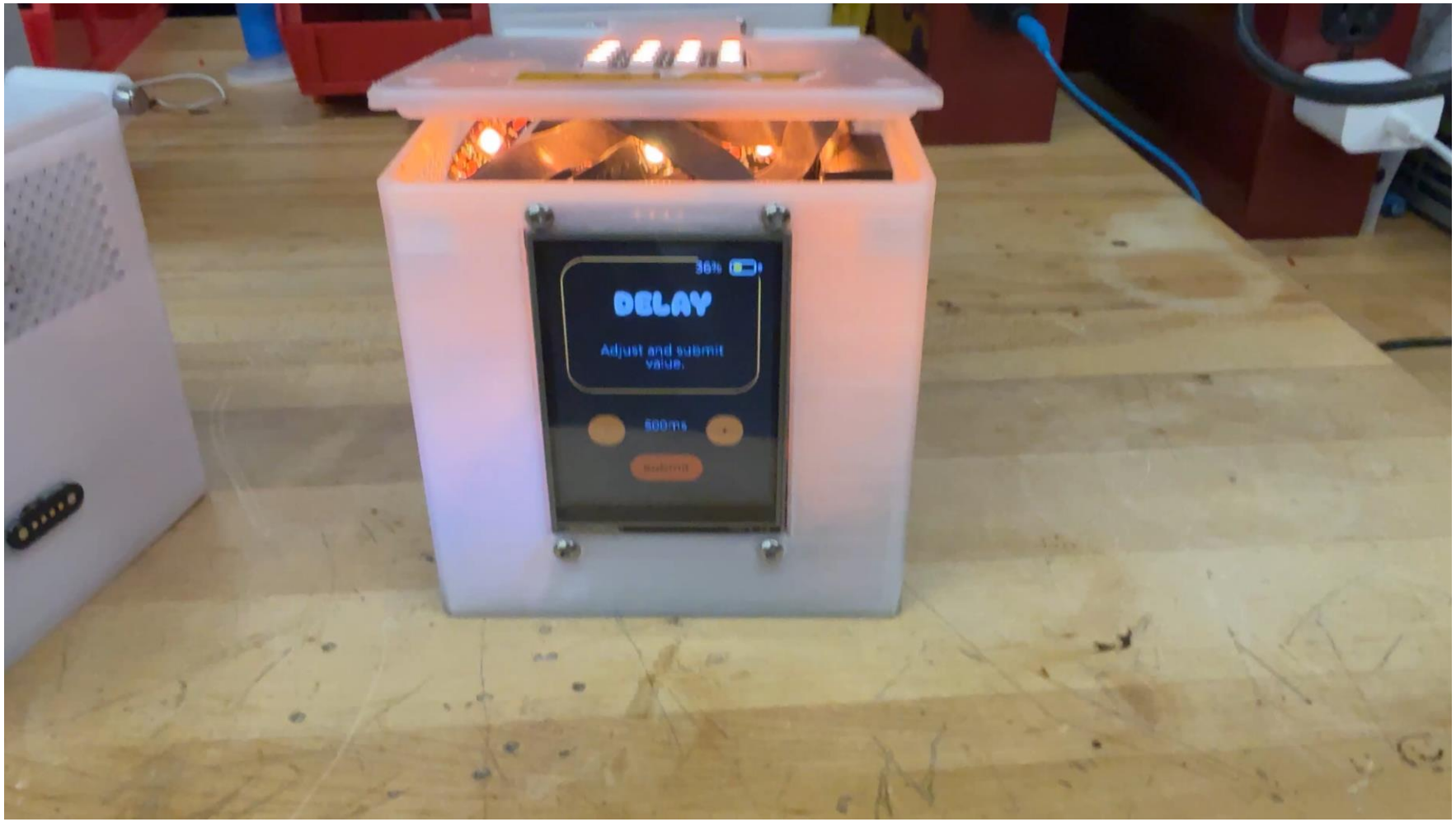


Left Side View



Right Side View

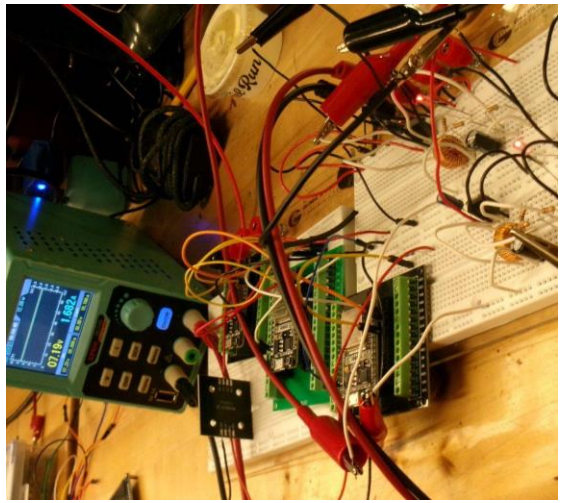
Complete Enclosure

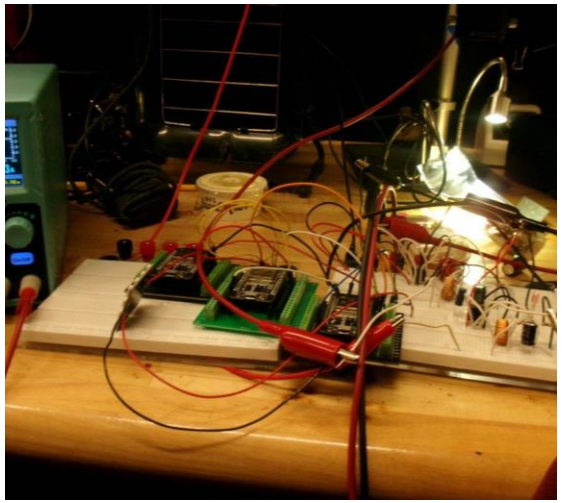


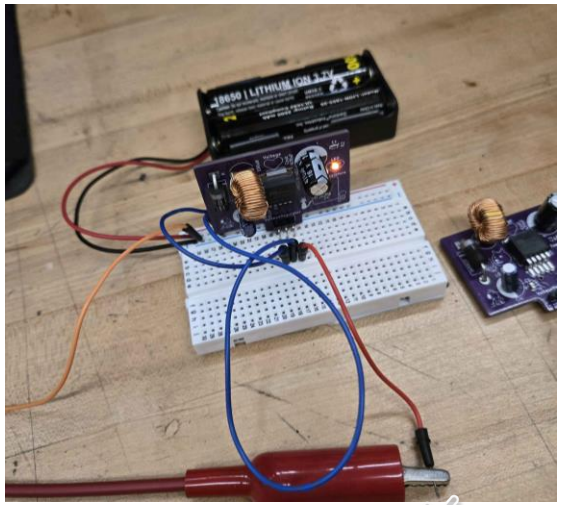
Testing -Regulators

Tested with:

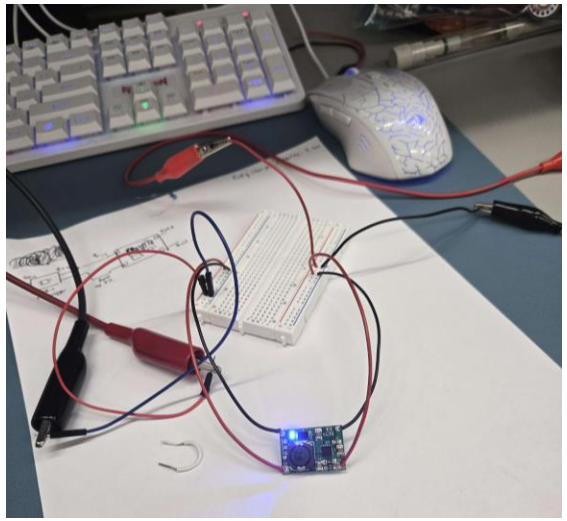
- Electronic Load
- Power supply and 18650 batteries

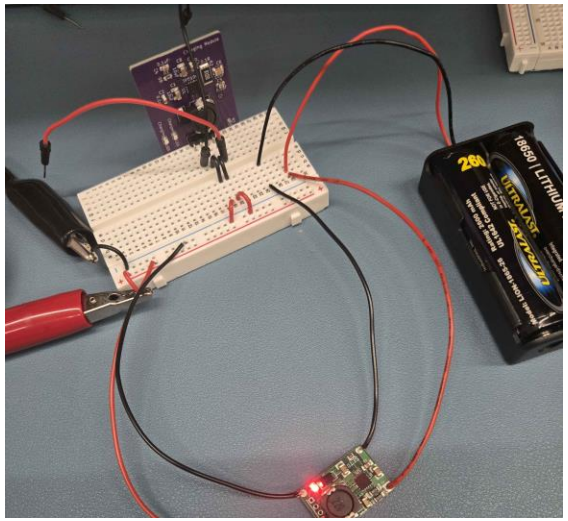




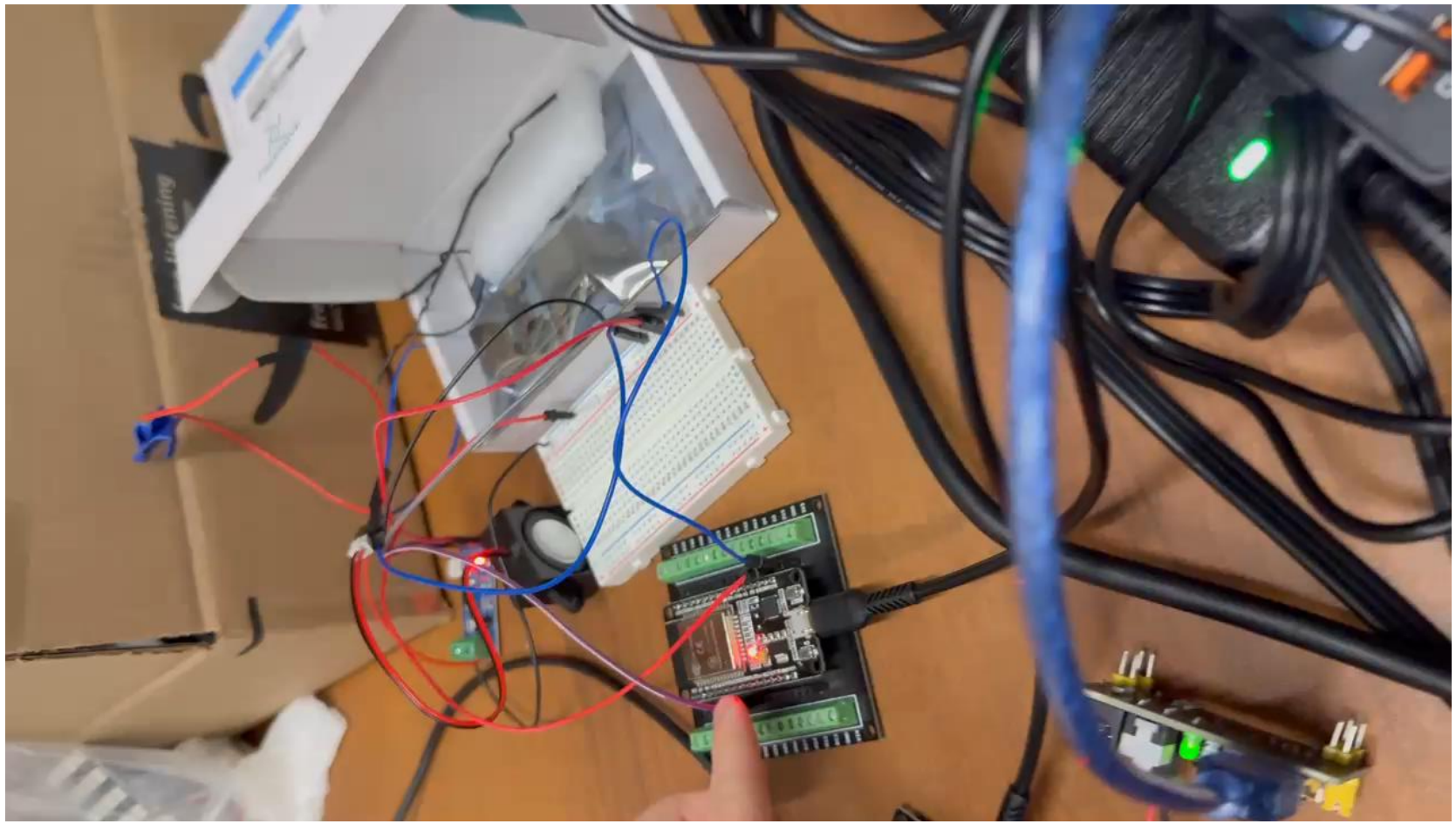


Testing - Charging





Testing – amplifier + speaker



Impedance: 8 ohms
Current: 3 Watts

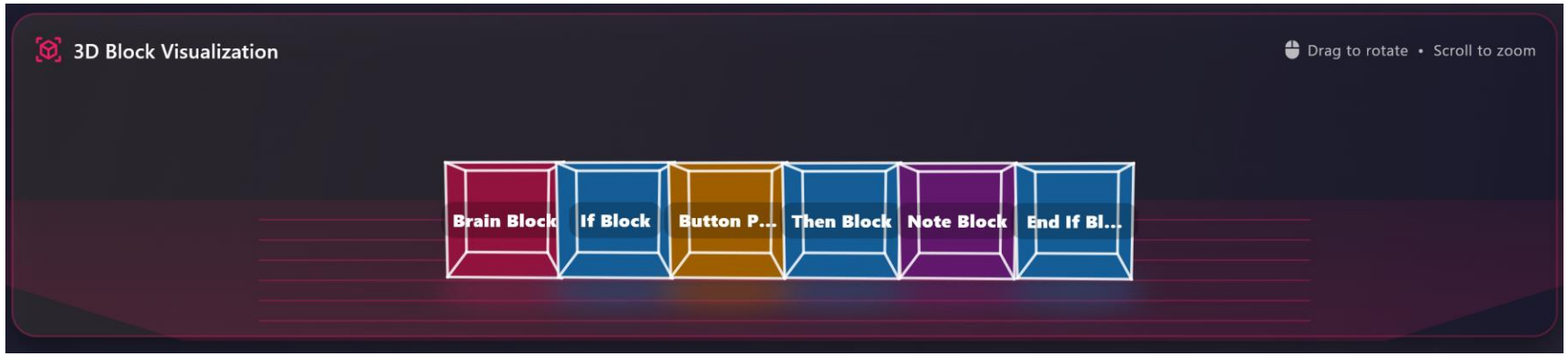
Testing – Wi-fi Connection + Integrity

Stress Test:

- App sends packets at a fixed rate (10 msg/s)
- Packet includes timestamp, sequence number, and payload to simulate network traffic
- Ran for 1 minute

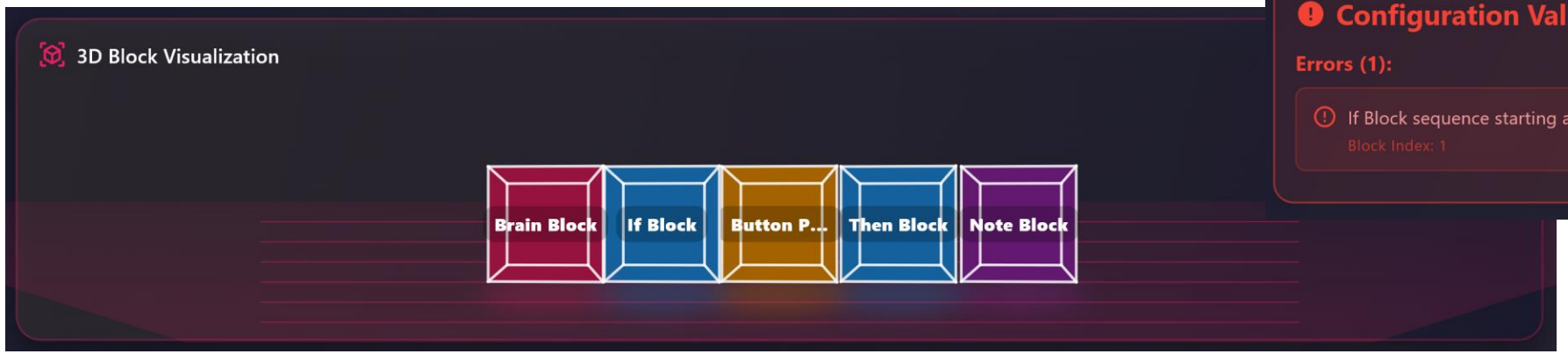
Metric	Result
Sent	542 (10/s)
Received	542 (10/s)
Errors	0
Loss % (Sent-Received)/Sent*100	0%

Testing – JSON Generation + Parsing



End to end latency: 50ms

Remove 1 block



Performance Evaluation and Results -

All subsystems met or exceeded design specifications **under full system operation with a 15-block chain**.

Category	Metric / Test Description	Requirement / Spec	Measured Result	Status
Hardware	**Regulated Power Rail Stability**	Stable under load	Validated under load	PASS
	Charging Path Operation	Stable charge/discharge	Confirmed stable	PASS
	Audio System (Amp + Speaker)	Functional output	Verified working	PASS
	Peripheral Integration (TFT, LEDs, Matrices)	Functional	Verified working	PASS
Firmware	**I²C Communication** (Master ↔ Slaves, 15-Block Chain)	Reliable communication	Validated	PASS
	Device Identification (REG_WHOAMI)	Correct detection	Verified	PASS
	Command Handling (LED/Audio/Display Control)	Correct execution	Verified	PASS
	JSON Generation + Synchronization	Valid JSON + Sync	Verified	PASS
	Real-Time Command/Response Flow	Stable updates	Verified	PASS
Companion App	**TCP Communication**	Successful messaging	Validated	PASS
	JSON Parsing + Configuration Validation	Correct parsing	Verified	PASS
	UI Updates (Real-Time State & Config)	Live updates	Confirmed	PASS
	Stress Test (1-Minute, Fixed Packet Rate)	0 errors	0 errors	PASS
System (Spec)	**JSON End-to-End Latency** (15-Block Chain)	**≤ 50 ms**	**50 ms**	PASS

Pre-Fabrication User Testing

Post-Fabrication User Testing

Difficulty, Problem, and Proposed Solution -

DIFFICULTY

- PCB interconnection
- Distributed status communication across connected blocks
- Coordinating concurrent event handling and execution logic
- Stable MCU power delivery and preventing resets during booting operation

PROBLEM

- Pogo pin connections
- Status flags from child blocks were not always transmitted or interpreted consistently by the Brain Block
- Race conditions occurred between the Brain event handler and executor
- The MCU constantly restarted because its power was not being held in a safe operating range

PROPOSED SOLUTION

- Applied a uniform and secure connection and verified continuity
- Added buffer flushing so stale or partial status bytes were cleared before new data was processed
- Added mutex protection for shared variables to prevent simultaneous access conflicts
- Reworked parts of the flow to be non-blocking, reducing stalls between the event handler and executor
- Added a power guard to stabilize MCU power conditions

Budget - Prototype

Item	Qty	Manufacturer	MPN	Supplier	Supplier P/N	Unit Price (USD)	Ext. Price
ESP32-WROOM-32 (MCU)	15	Espressif Systems	ESP32-WROOM-32-N4	Digi-key	B0CDRLRYJB	$6.56	$98.04
18650 lithium-ion cell batteries	30	Ultralast	N/A	Ace Hardware	UL1865-26-2P	$19.99	$299.85
TP5100 (charging module)	15	DKARDU	JK-US-386	Amazon	B09TKNFB3W	$9.99	$29.97
Type-C Female Chassis	20	Coliao	687117711298	Amazon	B0D813FX3J	$8.99	$8.99
SPI TFT LCD Display Touch Panel	1	HiLetgo	3-01-1433	Amazon	B073R7BH1B	$16.39	$16.39
4x4 RGB WS2812B LED Matrix (5 Pcs)	2	GODIYMODULES	N/A	Amazon	B0F59HC7PT	$10.99	$21.98
0.96" SSD1306 128X64 OLED SPI LCD Display	10	HiLetgo	3-01-1234-YB-AU-1PC	Amazon	B01N0KIXJ6	$6.99	$69.99
1602 I2C LCD Display	5	Hosyond	N/A	Amazon	B0BWTFN9WF	$11.99	$23.98
WS2812B IC RGB Addressable LEDs (300 ft)	2	BTF-LIGHTING Technology Co., Limited	WS2812B5M60LW67	Amazon	B01CDTEID0	$29.99	$59.98
Discrete LED 0805 (Red)	15	ams-OSRAM USA INC.	LS R976-NR-1-0-20-R18	Digi-Key	475-LSR976-NR-1CT-ND	$0.15	$2.25
Discrete LED 0805 (Blue)	15	Würth Elektronik	150080BS75000	Digi-Key	732-4982-1-ND	$0.19	$2.85
Discrete LED 0805 (Green)	15	ams-OSRAM USA INC.	LG R971-KN-1-0-20-R18	Digi-Key	475-LGR971-KN-1CT-ND	$0.15	$2.25
Same Sky (CUI) CMS-2580-05SP (speakers)	4	Same-Sky	CMS-2850-058SP	Digi-Key	2223-CMS-2850-058SP-ND	$2.13	$8.52
PAM8302A (Amplifier)	5	JESSINIE	PAM8302	Amazon	B0BG2F3LMP	$9.95	$9.95
MAX98357A (Amplifier)	4	GODIYMODULES	MAX98357A	Amazon	B0DPJRLMDJ	$6.88	$13.76
Adafruit I²S MEMS Microphone (SPH0645LM4H)	3-4	Adafruit	SPH0645LM4H	Adafruit	SPH0645LM4H	$6.95	$27.80
Mill-Max 858-22-004-10-011101 (POGO pins)	15	Mill-Max Manufacturing Corp.	858-22-004-10-011101	Digi-Key	ED11072-ND	$8.49	$127.35
						Total:	$823.90

Budget – Manufacturer Level

Item	Qty	Manufacturer	MPN	Supplier	Supplier P/N	Unit Price (USD)	Ext. Price
ESP32-WROOM-32 (MCU)	30	Espressif Systems	ESP32-WROOM-32-N4	Digi-key	B0CDRLRYJB	$6.56	$196.80
18650 lithium-ion cell batteries	30	Ultralast	N/A	Ace Hardware	UL1865-26-2P	$19.99	$599.70
TP5100 (charging module)	30	DKARDU	JK-US-386	Amazon	B09TKNFB3W	$9.99	$299.70
Type-C Female Chassis	40	Coliao	687117711298	Amazon	B0D813FX3J	$8.99	$359.60
SPI TFT LCD Display Touch Panel	15	HiLetgo	3-01-1433	Amazon	B073R7BH1B	$16.39	$245.85
4x4 RGB WS2812B LED Matrix (5 Pcs)	20	GODIYMODULES	N/A	Amazon	B0F59HC7PT	$10.99	$219.80
WS2812B IC RGB Addressable LEDs (300 ft)	4	BTF-LIGHTING Technology Co., Limited	WS2812B5M60LW67	Amazon	B01CDTEID0	$29.99	$119.96
0805 SMD Book	2	SMT Books and Assortment	N/A	Amazon	B0B2WZ9XD7	$34.90	$69.80
Same Sky (CUI) CMS-2580-05SP (speakers)	15	Same-Sky	CMS-2850-058SP	Digi-Key	2223-CMS-2850-058SP-ND	$2.13	$31.95
LM386 (Amplifier)	10	Texas Instruments	LM386MMX-1/NOPB	Mouser	926-LM386MMX-1/NOPB	$9.95	$99.50
Mill-Max 858-22-004-10-011101 (POGO pins)	30	Mill-Max Manufacturing Corp.	858-22-004-10-011101	Digi-Key	ED11072-ND	$8.49	$254.70
Filament for 3d printing (transparent)(	5	TECBEARS	JWDE-PETG-TP-1KG	Amazon	JWUS-PETG-TP-1KG-TB	$13.99	$69.95
						Total:	$2,567.31

PROJECT DELIVERY & FUTURE WORK

DELIVERY (Completed Milestones)

- **Core Hardware Delivered:** Production and full functionality check of the first 15 standard modules
- **Basic Visual App released:** First version of the grammar-correct block-chain visualizer
- **Initial Pilot Tests Complete:** Preliminary data collected from a controlled group of participants

FUTURE WORK (Planned Refinements & Validation)

USER & EDUCATION FOCUS

- **Classroom Integration** — Pilot tests in K-5 CS environments
- **Deeper User Testing** — Analyzing how children perceive grammar rules
- **Expanded Tutorials** — More complex logic puzzles in-app with new programming concepts
- **3D Educational Play** — Vertical and multi-edge rotation to teach spatial logic
- **Block Configurability** — Blocks not specific to one function, but can be configured to be any block type

- **15 Identical Modules** — Scalable, consistent hadware peformance
- **Grammar-Correct App** — Fully functimal block-chain visualizn & modeler
- **Stres-Tested Bus** — Reliable electrical timing under maximum designload
- **Eductional UI** — Guided tutorials bridge physical play and logic concepts

Thank You!

Questions?