Smart Ball Milling Machine

Group 30

Sponsored by the Blair Research Group

The Team

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Project Motivation

- What is a ball milling machine?
  - Used to grind and blend materials
  - Stainless steel balls are placed in a canister with the substance
  - The milling machine vigorously shakes the canister

- What's wrong with the current machine?
  - Dr Blair's group often runs the mill for extended periods
  - The motor needs to be stopped every 30 minutes or so to cool down
  - The mill needs to be manually restarted

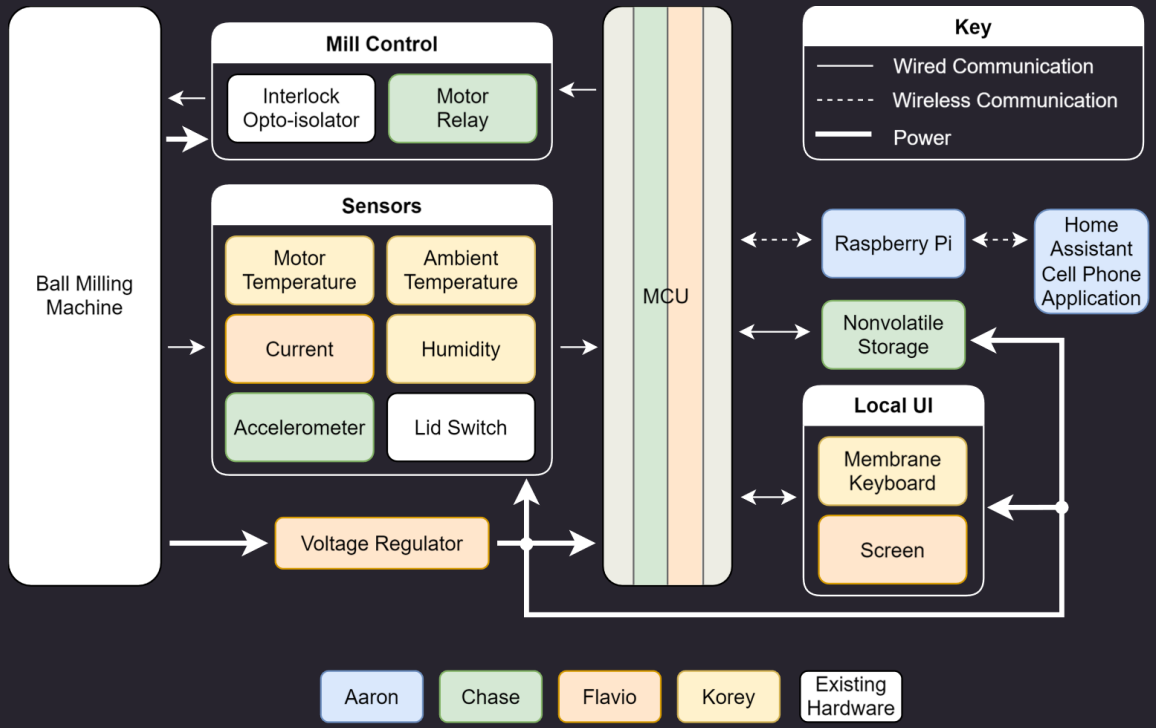
Project Goals

- Remote Operation and Automation
- Scheduled jobs with intermittent pauses for motor cooldown
- Sensory Capabilities and responses
  - Current Measurement
  - Motor Temperature Detection
  - Vibration Detection
- Customer Customization
  - Requested/Personalized UI

Engineering Requirements

Remote User input Delay	Less than 2 Seconds
Reboot Time	Less than 5 Seconds
Timer Error After Power Outage	Less than 5 Seconds
Timer Clock Drift	Less than .5% Error
Current Detection	Less than .5% Error
Environment Humidity Detection	Measure humidity between 5% and 95%
Motor Temperature Monitoring	Measure Temperature up to 150°C

Block Diagram



Parts

Microcontroller Selection

	ESP32-WROOM	ATmega328P	STM32WBA52
Core Clock	240MHz	16MHz	100 MHz
Cores	2	1	1
Flash	4 MB	32 kB	1 MB
SRAM	520 kB	2 kB	128 kB
GPIO Pins	26	23	35
Wireless Connectivity	Wifi, Bluetooth	No	Bluetooth
Price	$3.80	$2.80	$5.67
IDE Support	ESP-IDF, Arduino	Microchip Studio, Arduino	STM32CubeIDE

Sensors

Current:	Split Core CT
Humidity:	SHT
Temperature:	Thermistor
Accelerometer:	Bosch

Sensor Part Selections

- Current

Sensor	CR9580-10-M	SCT013-010	SCT-0400-010
Accuracy	±0.5%	±1%	±1%
Frequency Range	50 – 400Hz	50-1000 Hz	50-1000 Hz
Output Voltage	0-5 V (DC)	1 V (AC)	0.333 V (AC)
Rated/Max input	10A/24A	10A/35A	10A/12A
Burden impedance	1 Mega-ohm	Built in	Built in
Dimensions	49.57mm(W) x 25.42mm(D) x 50.84mm(H)	32.00mm(W) x 22.00mm(D) x 57.00mm(H)	24.00mm(W) x 27.00mm(D) x 40.00mm(H)
Opening Size	10.17mm	13mm	10.0mm
Cost	$50.39	$6.90	$26.00

Sensor Part Selections

- Humidity

Model	Minimum Reading	Maximum Reading	Resolution/Accuracy	Cost	Size in mm
SHT41	0% RH -40C	100% RH 125C	1.8% RH, 0.2C	3.12	1.5x1.5x0.5
SHT30	0% RH -40C	100% RH 125C	2% RH 0.2C	4.94	2.5x2.5x0.9
DHT22	0% RH -40C	100% RH 80C	2-5%RH 0.5C	9.95	1.05x2.32 x0.53
HDC1080	0% RH -40C	100% RH 125C	2% RH 0.2C	3.68	2x2x0.7
Phidgets 1125_0	10% RH -30C	95% RH 80C	5% RH 0.75C	74.33	35.56x50.8 X8.53
CHS-UPS	5% RH 0C	95% RH 60C	3% RH	77.17	9x6.5x3.7
Adafruit BME688	5% RH 0C	100% RH 80C	3% RH 1.0C	19.95	25.5x17.6 x4.6
SHT20	0% RH -40C	100% RH 125C	3% RH 0.3C	5.40	3.0x3.0x1.1

Sensor Part Selections

- Temperature

Model	Minimum Temp	Maximum Temp	Resolution	Cost	Size in M (Length)
P/N 1600-10K Thermistor	-80C	150C	±0.1C: When less than 70C	$20.00	0.152
1DC103J-EC	-40C	150C	±10% (Resistance Tolerance)	$3.03	0.038
A99CA-200C	-40C	120C	0.5C	$35.51	0.050
NTCLE100E3	-40C	125C	±5% (Resistance Tolerance)	$0.29	0.024
02-N103-1	-40C	125C	±10% (Resistance Tolerance)	$5.80	0.025
2152793605	-40C	135C	±1% (Resistance Tolerance)	$2.53	0.033

Sensor Part Selections

- Accelerometer

	STM IIS328DQ [27]	Memsic MXC6655XA [28]	Kionix KXTJ3-1057 [29]	Bosch BMA400 [41]
Supported Scales	±2g/±4g/±8g	±2g/±4g/±8g	±2g/±4g/±8g/±16g	±2g/±4g/±8g/±16g
Output Bit Width	16 bits	12 bits	8/12/14 bit modes	12 bits
Output Data Rate	0.5 Hz to 1 kHz	100 Hz	0.781 Hz to 1.6 kHz	125 to 800 Hz
Interface Type	SPI or I^2C	I^2C	I^2C	SPI or I^2C
Shock Survivability	10,000g	200,000g	10,000g	10,000g

Relay Selection

	Coto 8L41-05	Coto 8L02-05	Littlefuse HE721C05	Standex-Meder SIL03
Coil Voltage	5 V	5 V	5 V	3V
Coil Current	25 mA	25 mA	25 mA	6 mA
Max Switching Voltage	100 VAC	200 VAC	120 VAC	200 VAC
Max Switching Current	0.25 A	0.5 A	0.35 A	0.5 A
Configuration	SPDT	DPST	SPDT	SPST
Price	$10.21	$4.48	$4.65	$4.48

Display Selection

OLED Display	Crystal Fontz CFAL12864K-Y	New Haven Display NHD-2.7-12864WDY3-M	Display Visions EA OLEDL128-6LGA
Resolution	128 x 64	128.64	102 x 64
Contrast Ratio	10,000:1	10,000:1	2,000:1
Brightness	80 cd/m2	80 cd/m2	100 cd/m2
Dimensions	73.0 (W) x 41.86 (H) x 2.15 (D)	82.0 (W) x 47.5 (H) x 6.4 (D)	39.0 (W) x 20.75 (H) x 2.6 (D)
Connector	Molex 31 pin connector	Molex 20 pin connector	20 pin header direct solder
Interface	8-Bit Parallel, SPI, I2C	8-Bit Parallel, SPI	SPI, I2C
Integrated Controller	Yes	Yes	Yes
Lifetime	50,000 hrs	100,000 hrs	50,000 hrs
Price	$38.85	$38.08	$30.42

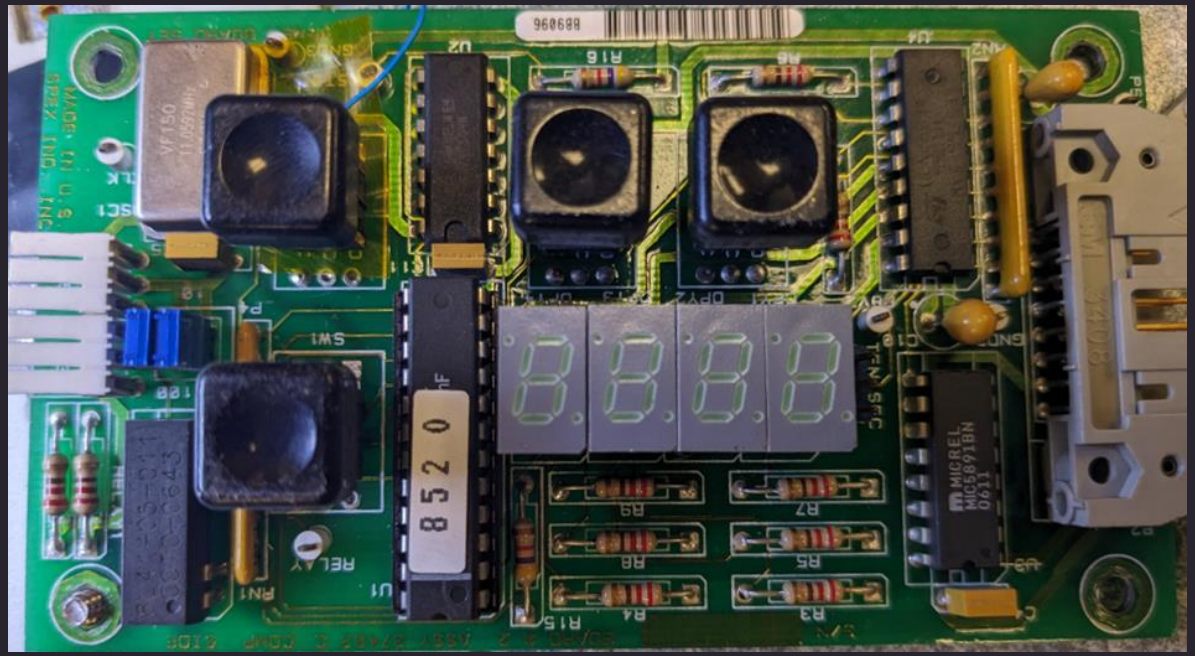
New Haven Display

47.5mm

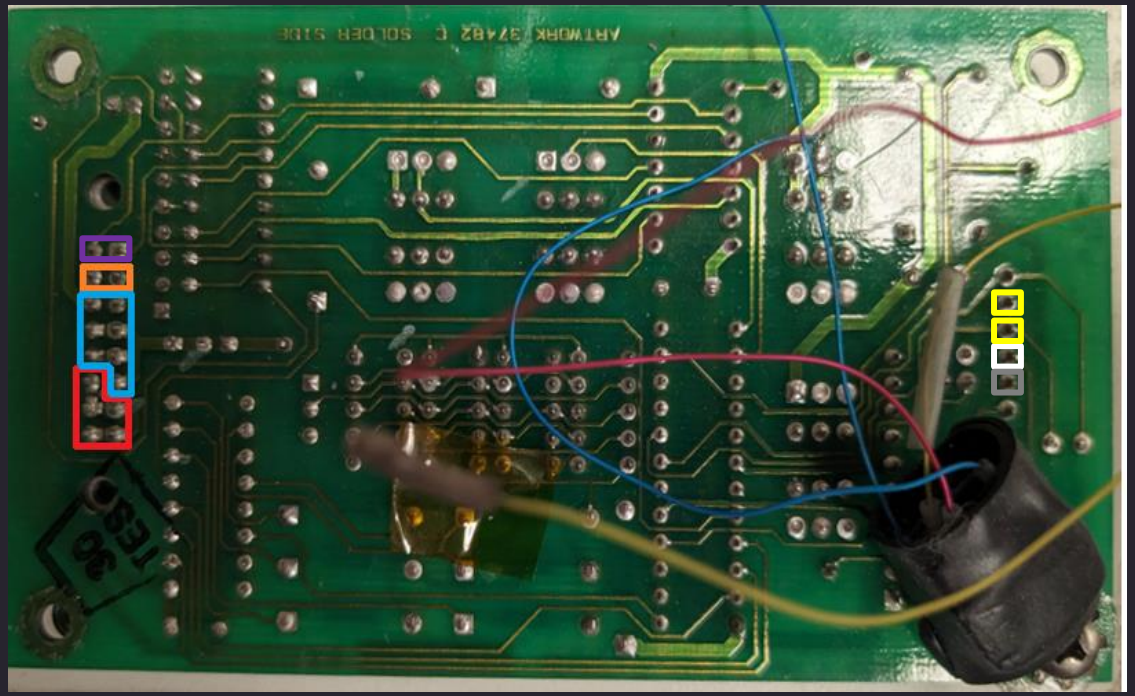
82mm

PCBs

The Existing Mill Controller

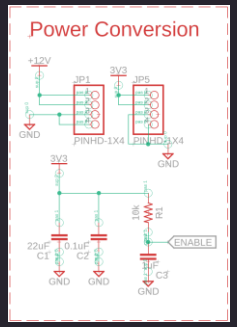


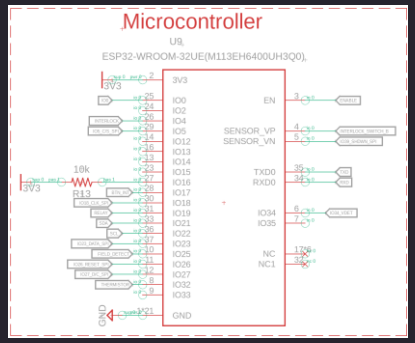
The Existing Mill Controller

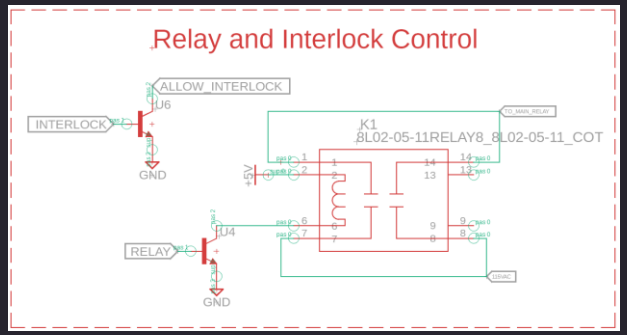


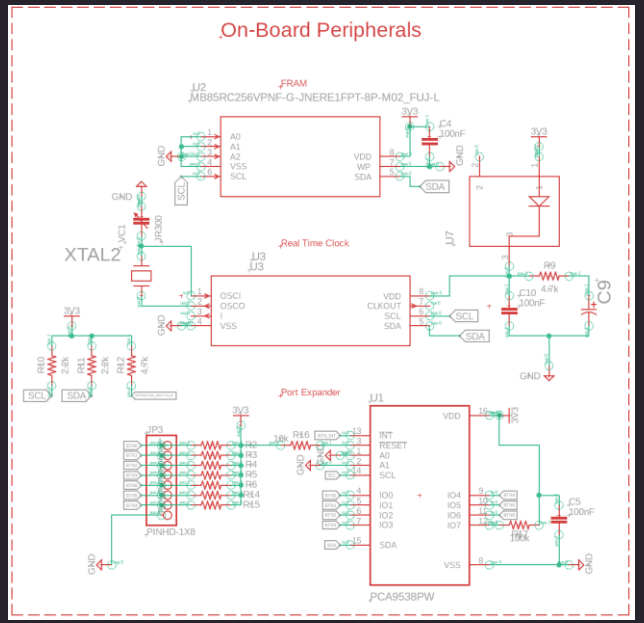
- Power Stable / Enable Interlock
- 5 V
- GND
- 12 V
- Interlock Switch
- 115 VAC
- External Relay

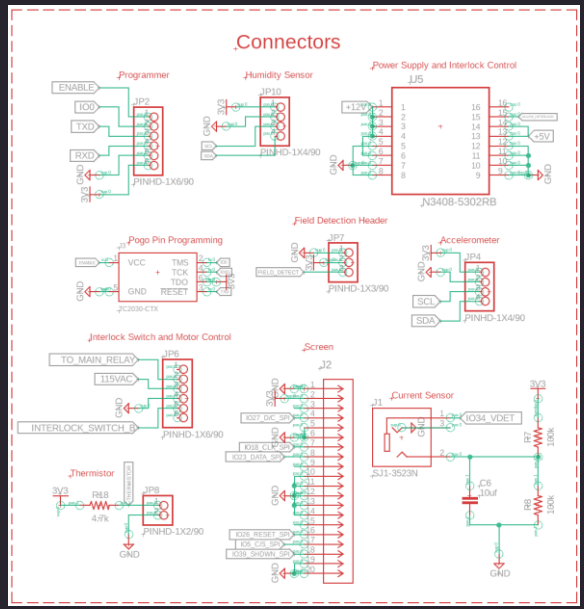
Main Board - Schematic



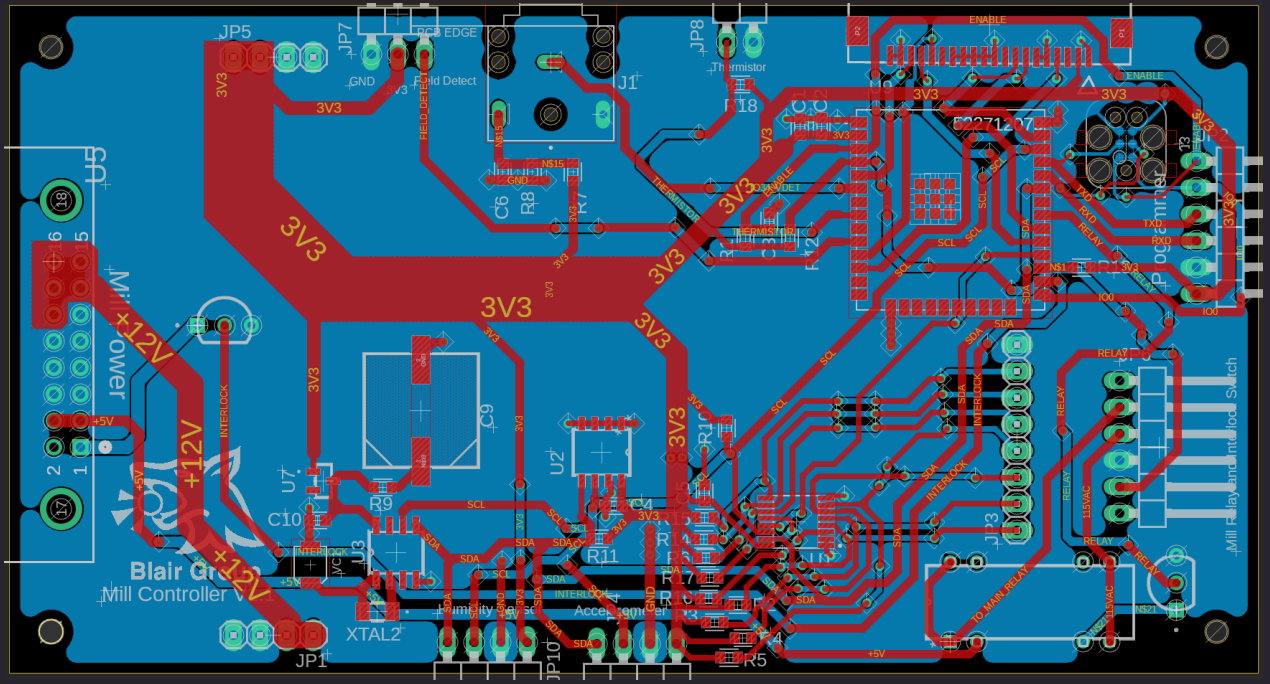








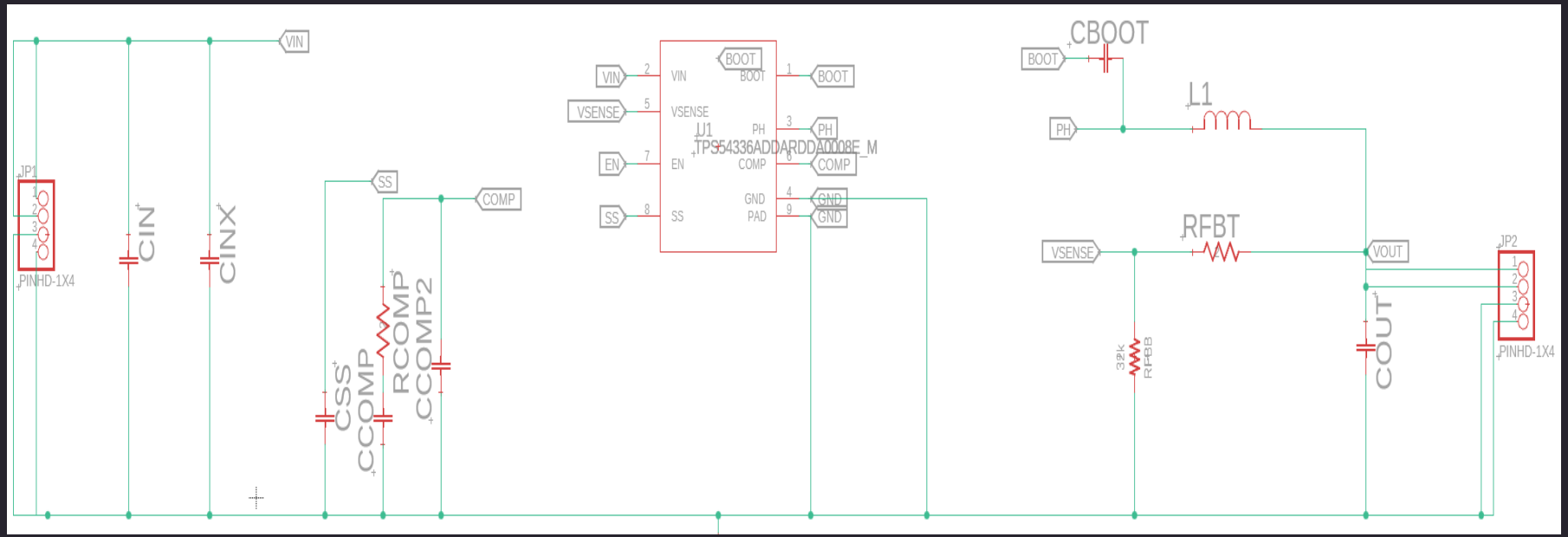
Main Board - Layout



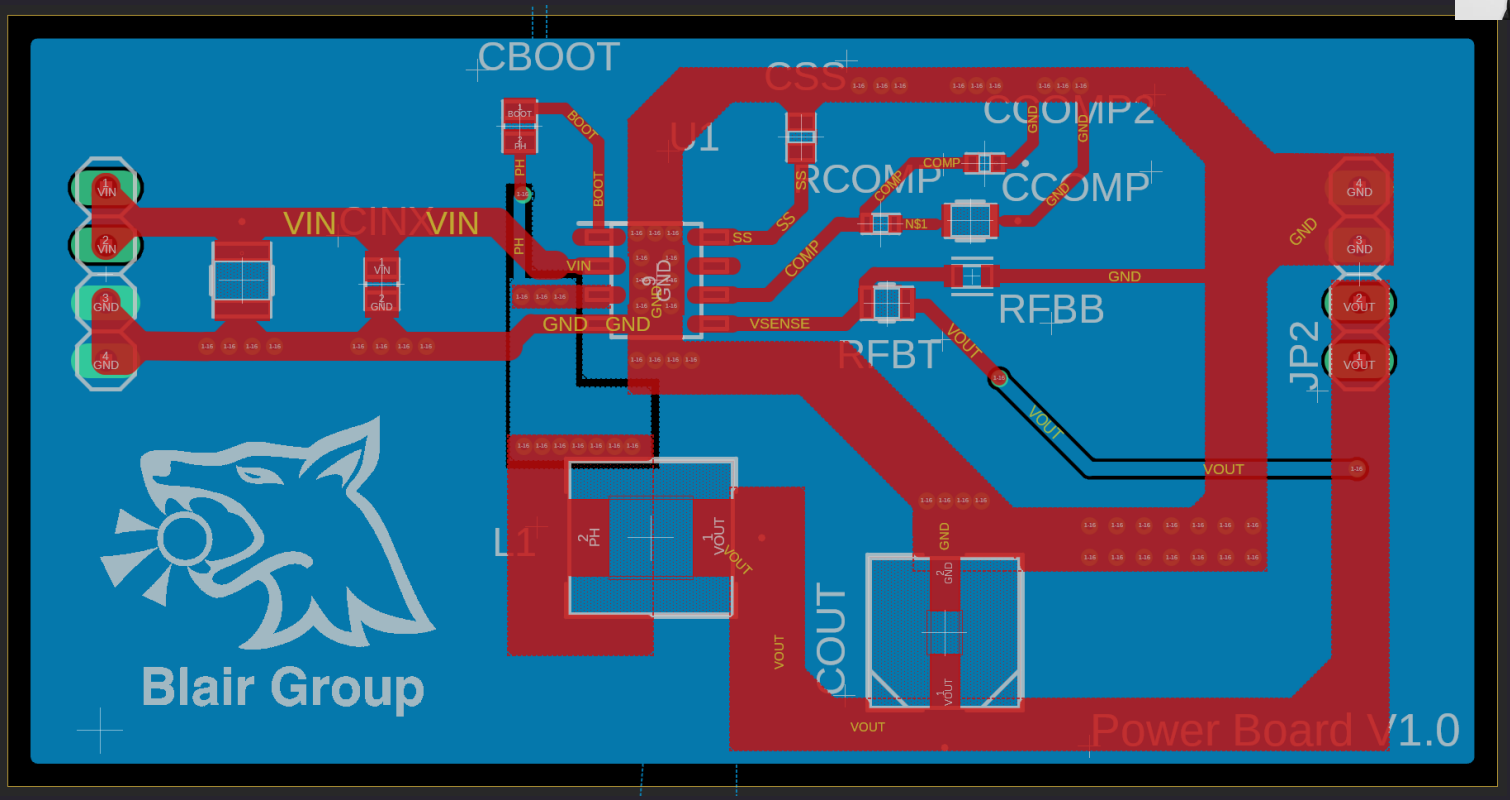
Switching Voltage Regulator

Model	LC78_2.0	R-78K-2.0	TSR 2-2433	TPS54336ADDAR
Accuracy	±3%	±3%	±2%	±2.35%
Efficiency	91%	85%	93%	88.6%
V in	4.5V – 28V DC	4.5V – 36V DC	4.75V – 36V DC	4.5V – 28V DC
Operating Temperature	-40C - +85C (Derating at 60C)	-40C - +90C	-40C - +85C	-40C - +150C
Dimension(mm)	11.6 x 7.5 x 10.2	11.5 x 8.5 x 17.5	10.1 x 7.5 x 14	10.1 x 7.5 x 14
Switching Frequency	600 kHz	400 kHz	410 kHz	340 kHz
Ripple + Noise	150mV	100mV	150mV	5 mV
Price	$11.62	$4.50	$11.75	$1.63

Switching Voltage Regulator

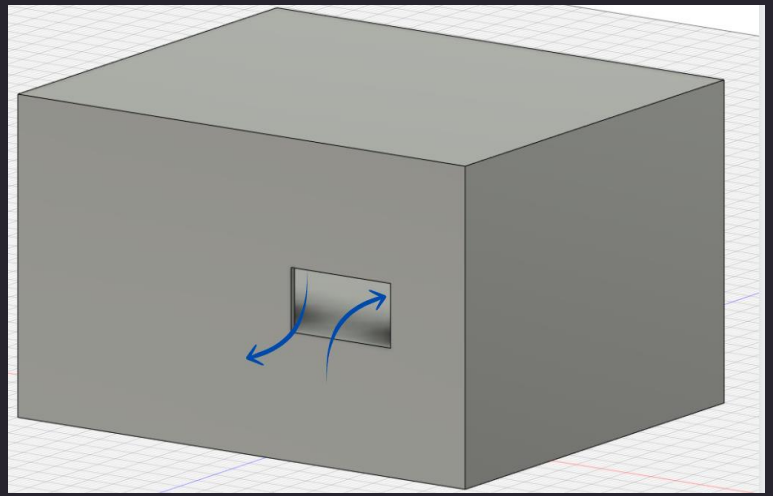


Voltage Regulator – PCB Layout



Faraday Cage Solution

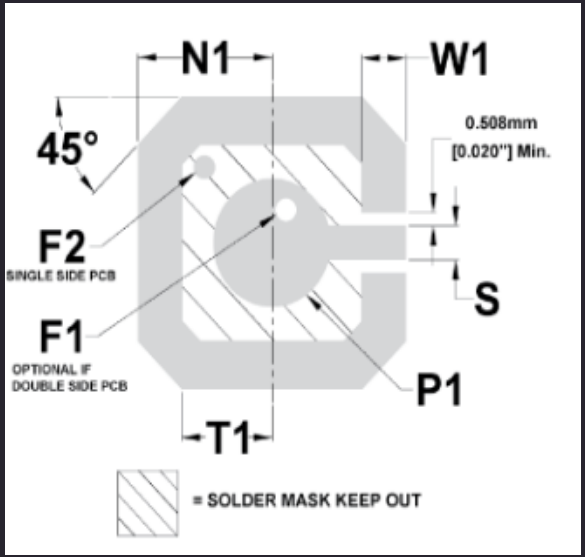
- Replace existing front panel with PCB designed keyboard to allow Wi-Fi signal both in and out of mill.

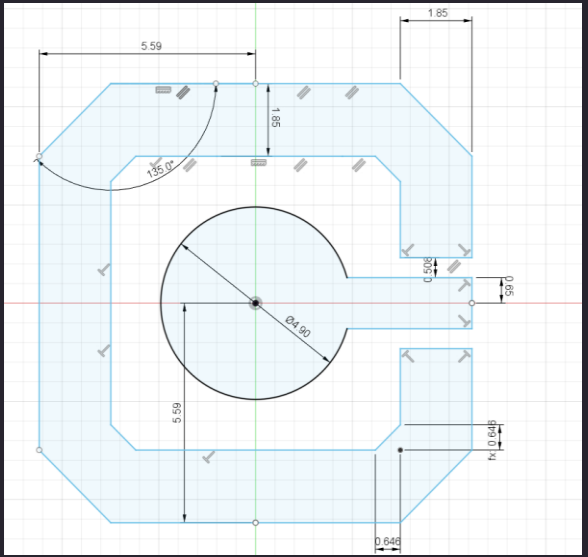


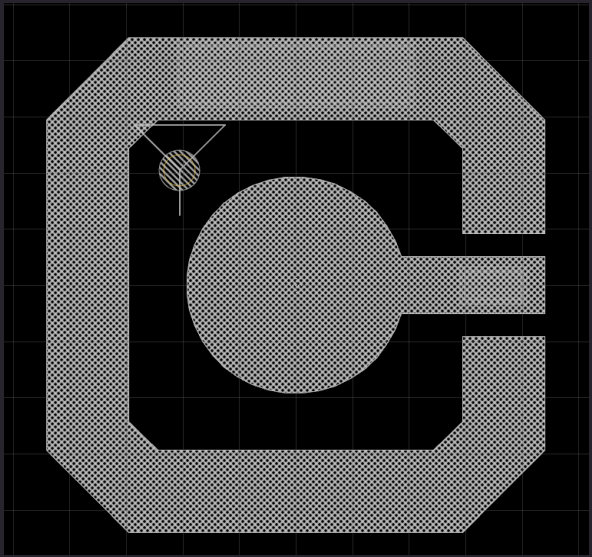
Snaptron Buttons

- Snaptron Single-sided Pads

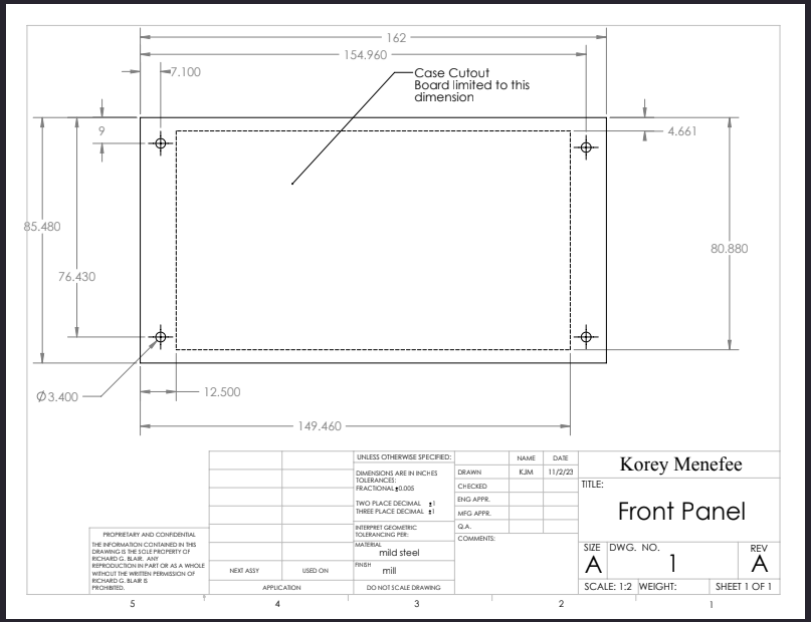
Diameter	P1	N1	T1	W1	S	F1/F2
4mm	1.60	2.10	1.25	0.97	0.30	0.32
5mm/5.3mm	2.03	2.59	1.67	1.04	0.38	0.41
6mm/6.3mm	2.45	2.96	1.96	1.09	0.64	0.41
7mm	2.86	3.45	2.28	1.27	0.76	0.60
8.5mm	3.48	4.19	2.77	1.55	0.92	0.89
10mm	4.08	4.67	3.15	1.55	1.10	0.89
11mm	4.50	5.23	3.45	1.70	1.20	0.89
12mm	4.90	5.59	3.76	1.85	1.30	0.89

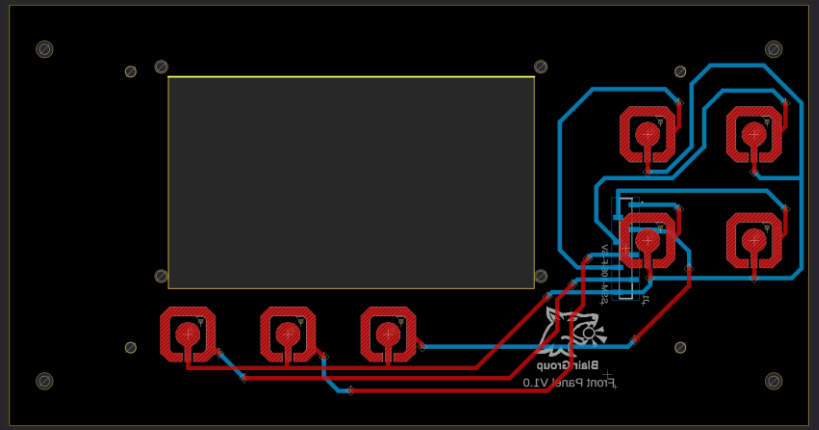




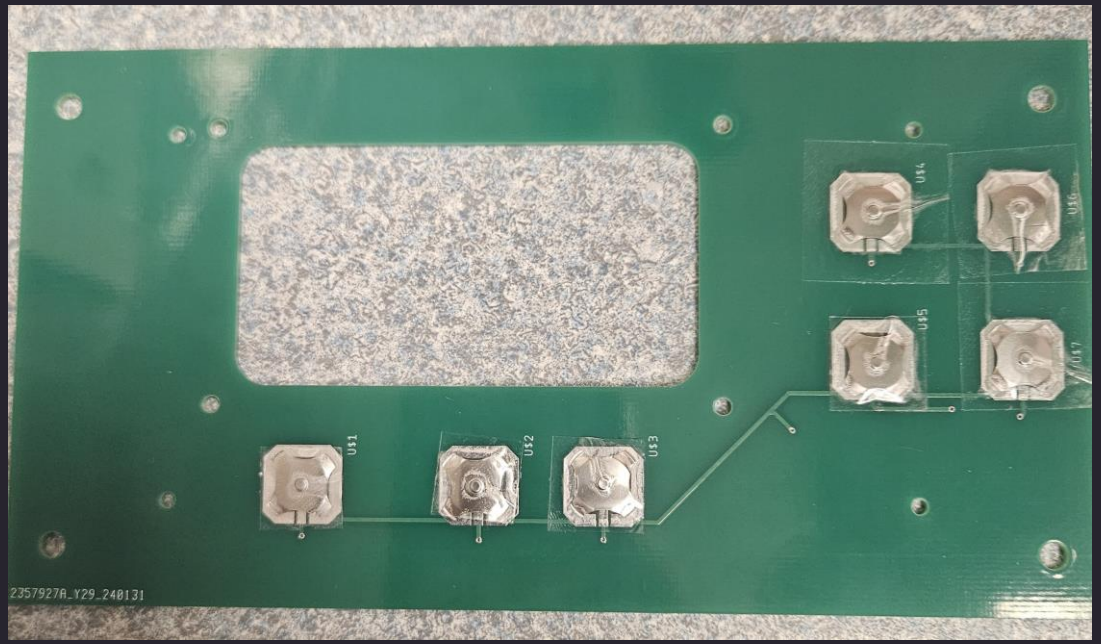


Front Panel – Early Layout and Footprint

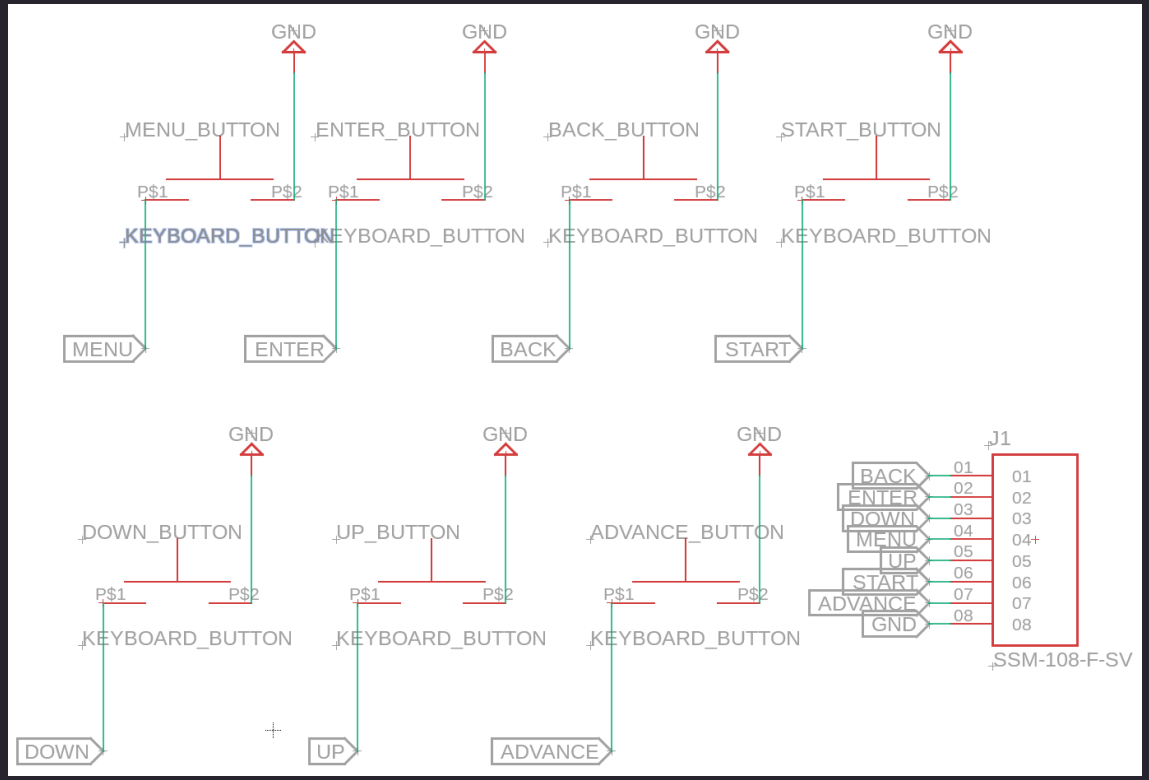




Front Panel - Prototype



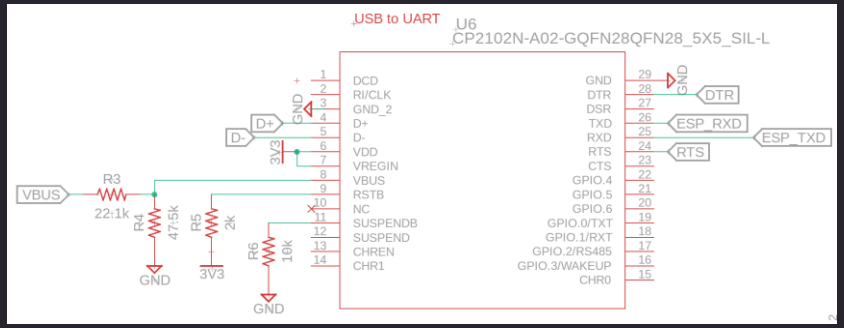
Front Panel - Schematic

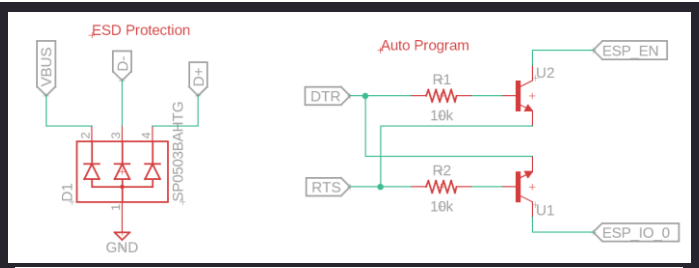


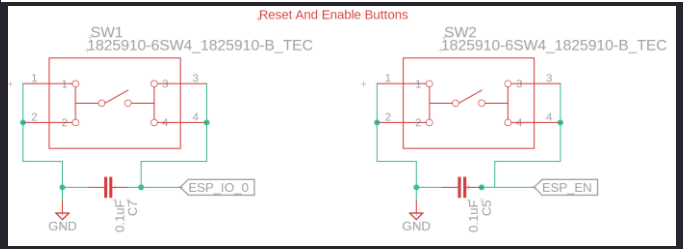
Programming Board

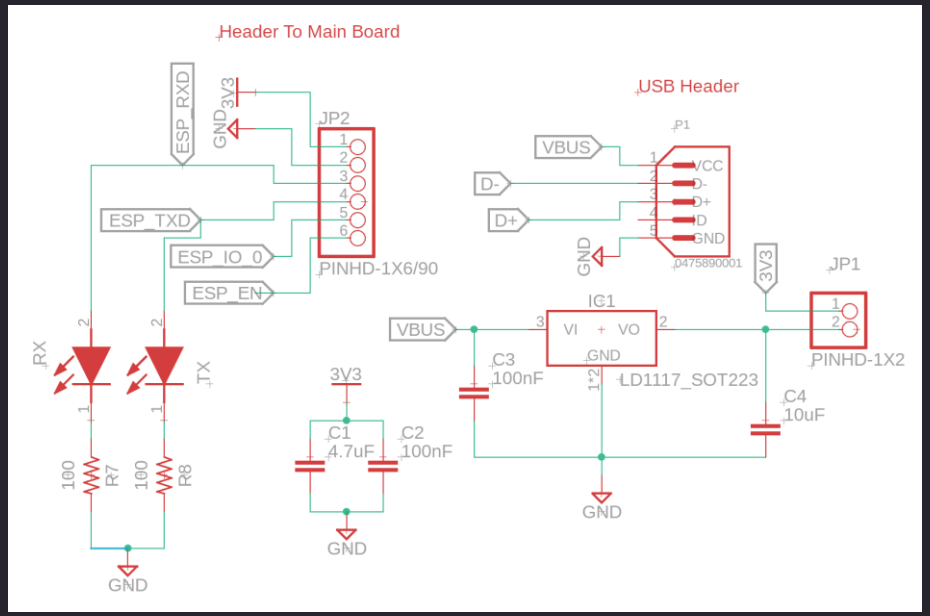
- Moves the Micro-USB header off of the main board
    - Removes a failure point from the main board
    - Allows the programming buttons to be outside of the mill
- Allows for easy debugging of the hardware
- Automatically causes the ESP32 to enter programming mode using signals from the USB-UART bridge
- Linear regulator can optionally power the ESP32 while flashing new firmware

Programming Board - Schematic

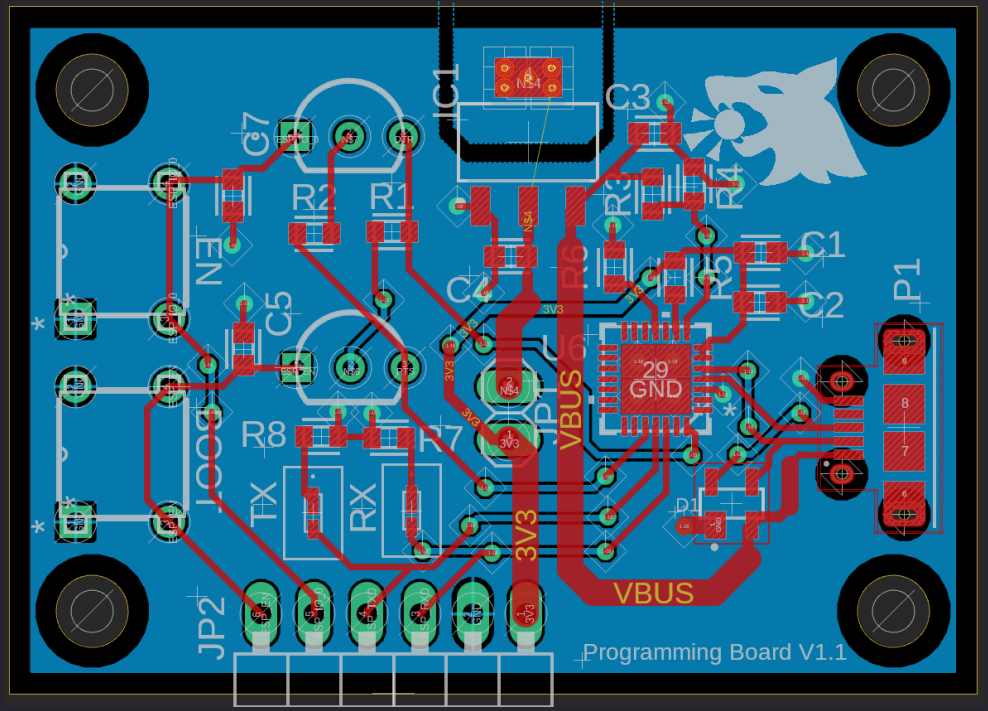








Programming Board - Layout

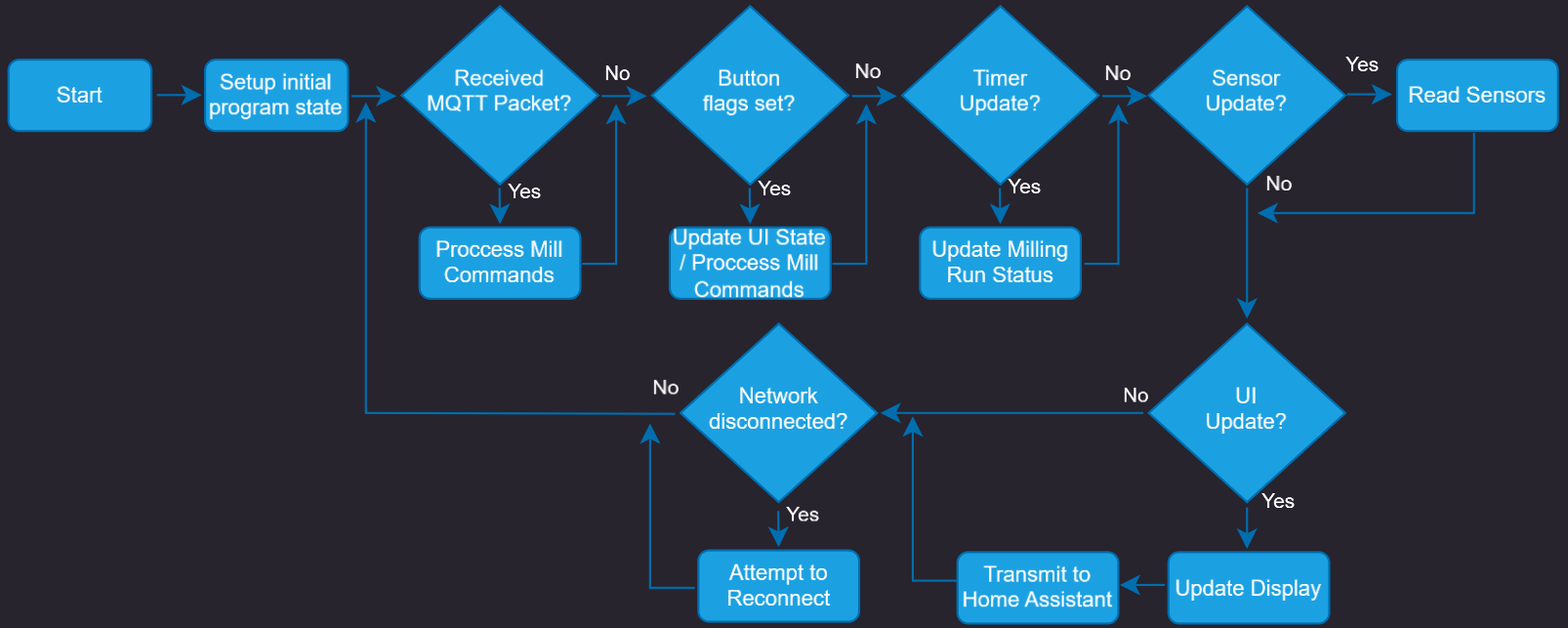


Software

Software Requirements

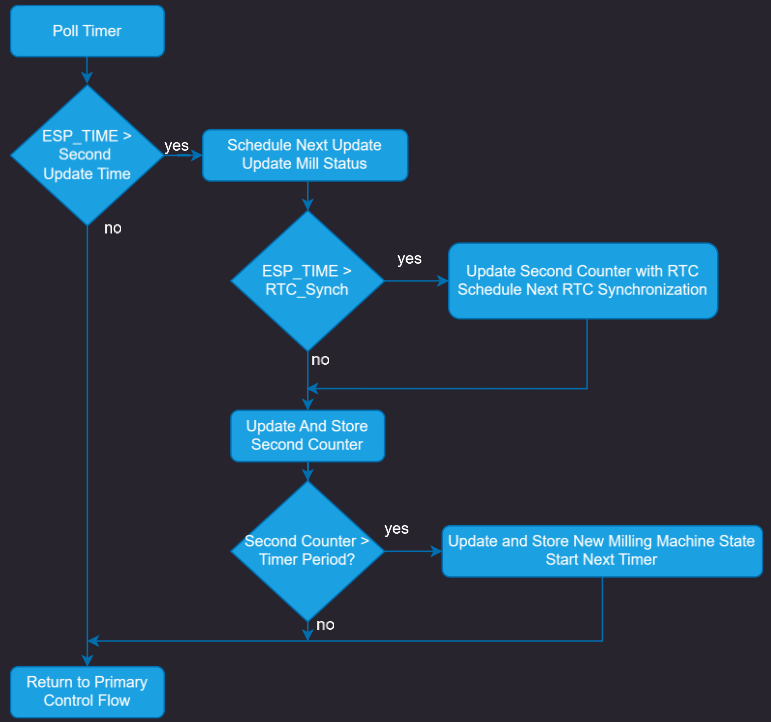
- Accurate Timekeeping
- State saving
    - Recovery from power disruptions
- Control through local UI or Home Assistant
- Machine status available locally and online
- Sensor readings

Software Overview



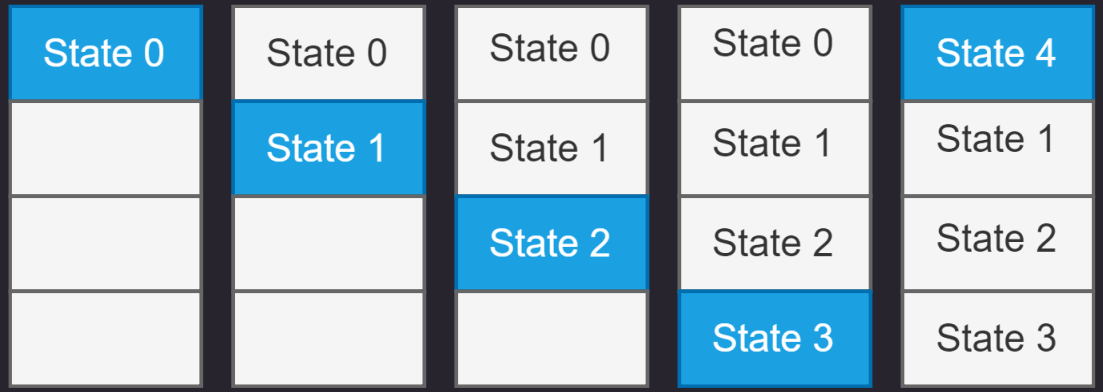
Timing Subsystem

- Two Levels
  - ESP32 built-in timer
  - Real time clock module



State Saving and Retrieval

- State is written to a ring buffer in non-volatile memory
- Tagged with sequence number
- Retrieval looks for smallest sequence number, then highest sequential write from that point
- A power outage during the write won't destroy the previous states



Wireless UI Requirements

- Intuitive UI with few interactive main elements not hidden in menus
- Same or similar functionality as local UI
- Ability to display sensor readings from MCU
- Ability to show messages from MCU
- Compatible with phone and browser
- Guaranteed delivery of messages (soft requirement)

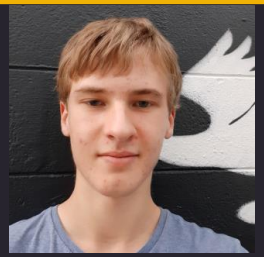
Communication Protocol Selection

	Bluetooth	BLE	Wi-Fi
Speed (Mbps)	1 / 2 / 3	0.125 / 0.5 / 1 / 2	1 to 150
RSSI (dBm)	-70	-82 / -75 / -70	-30 to - 80
Home Assistant Support	Yes	Yes	Yes
MQTT support	Depends	Depends	Yes

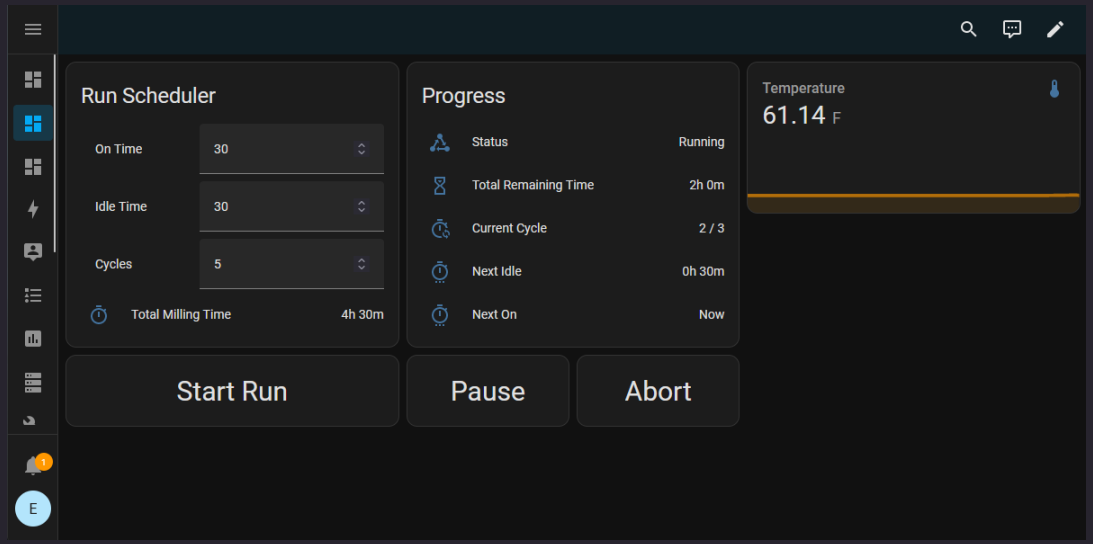
MQTT Topic Flow Chart

- A topic acts a channel
- Code and network activity is easier to understand
- Allows for more mills to be added to the network

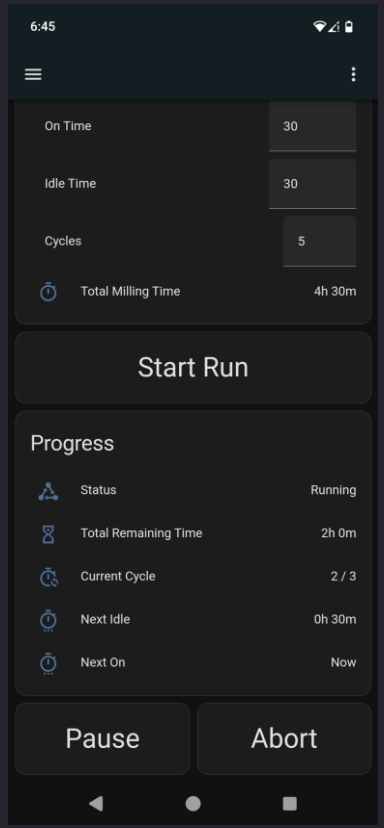
Home Assistant



Desktop View



Phone View



GUI

We chose the u8g2 open-source display library to program the display due to its simple one-line configuration and it being supported by Lopaka graphics editor and image converter. This allowed to easily generate and position the images on the display.

The initial start-up screen allows the user to operate the mill in traditional mode. This lets the user input the desired runtime in minutes with the addition of allowing them to enter the number of cycles .

The menu allows the user to adjust the mill settings such as the rest time between runs and access various information such as total running time, Sensor readings and network connection status.

Budget

ESP32 Devkit (x4)	$40
Component Breakout Boards (for prototyping)	$40
OLED Display	$50
Raspberry Pi	$0, already owned
Programmer Board Stencil, PCB (x5)	$11
Power Board Stencil, PCB (x5)	$9
Control Board Stencil, PCB (x5)	$34
Front Panel PCB (x5)	$16
Accelerometer board, assembly (x5)	$30
Components, all boards (x5)	$350
Board Revisions	$60
Total	$650

Work Distribution

Task	Primary
Power System Reverse Engineering	Chase
UI Design	Flavio
Membrane Keyboard Design	Korey
Controller PCB Design	Korey
Power Supply	Flavio
Microcontroller Main Loop	Chase
MCU Wifi and MQTT Programming	Aaron
Raspberry Pi Home Assistant Setup and Programming	Aaron

Thank You