Toaster OEE using MQTT and Arduino Uno WiFi Rev 2

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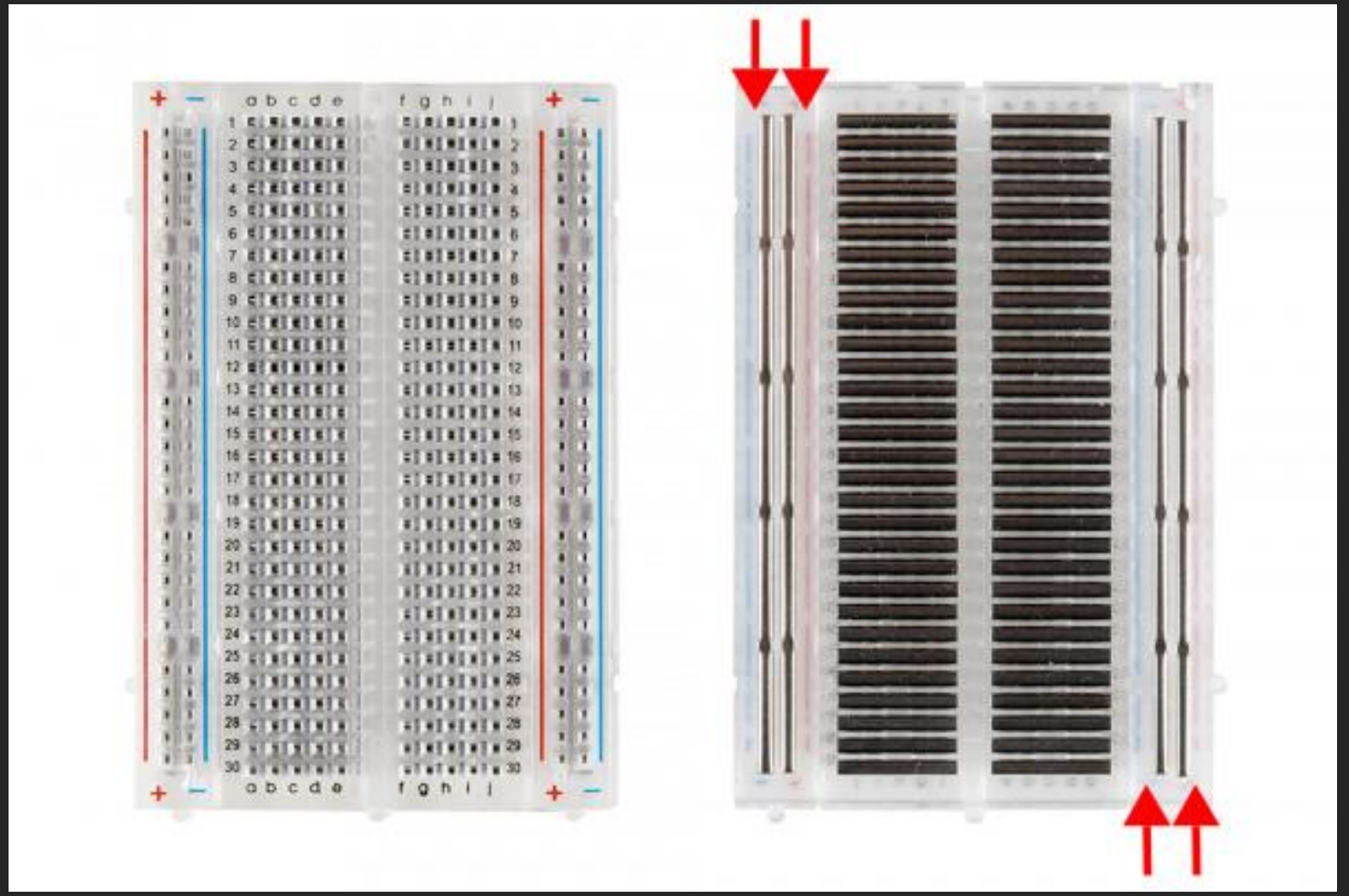
Agenda

- Motivation for project
- Architecture diagram of technology stack
- Electrical schematic for circuit connections
- Parts List
- Physical Wiring
- Code review
- Circuit design & code optimization
- Summary
- Github
  - https://github.com/enrimarini/toasteroee

Motivation for Project

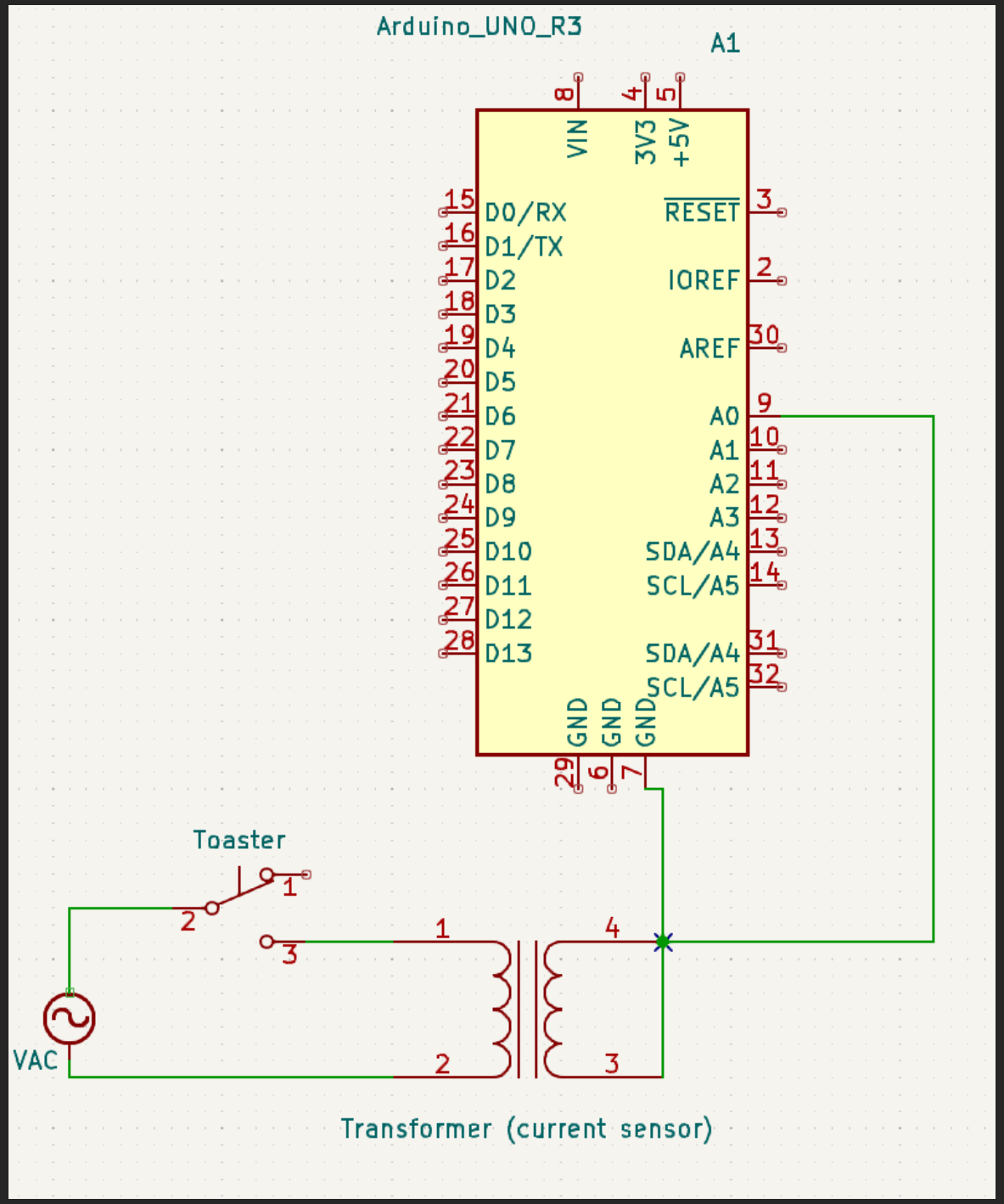
- Free Open-Source Alternative to using paid low-code as a platforms (LCAP) like Tulip.
- Countless FOSS platforms out there that offer almost exact copy of modules in Tulip, most use Python.
- Countless OEE tutorials available, most are terribly documented.
- Replace Tulip app front-end with Streamlit app using custom and pre-established Streamlit widgets.
- No backend necessary – publishing flat MQTT to free HiveMQ broker. Recommend using SQLalchemy to create database in future project.

Electrical Schematic



Breadboard with adhesive backing removed, exposing metal strips that makeup the breadboard

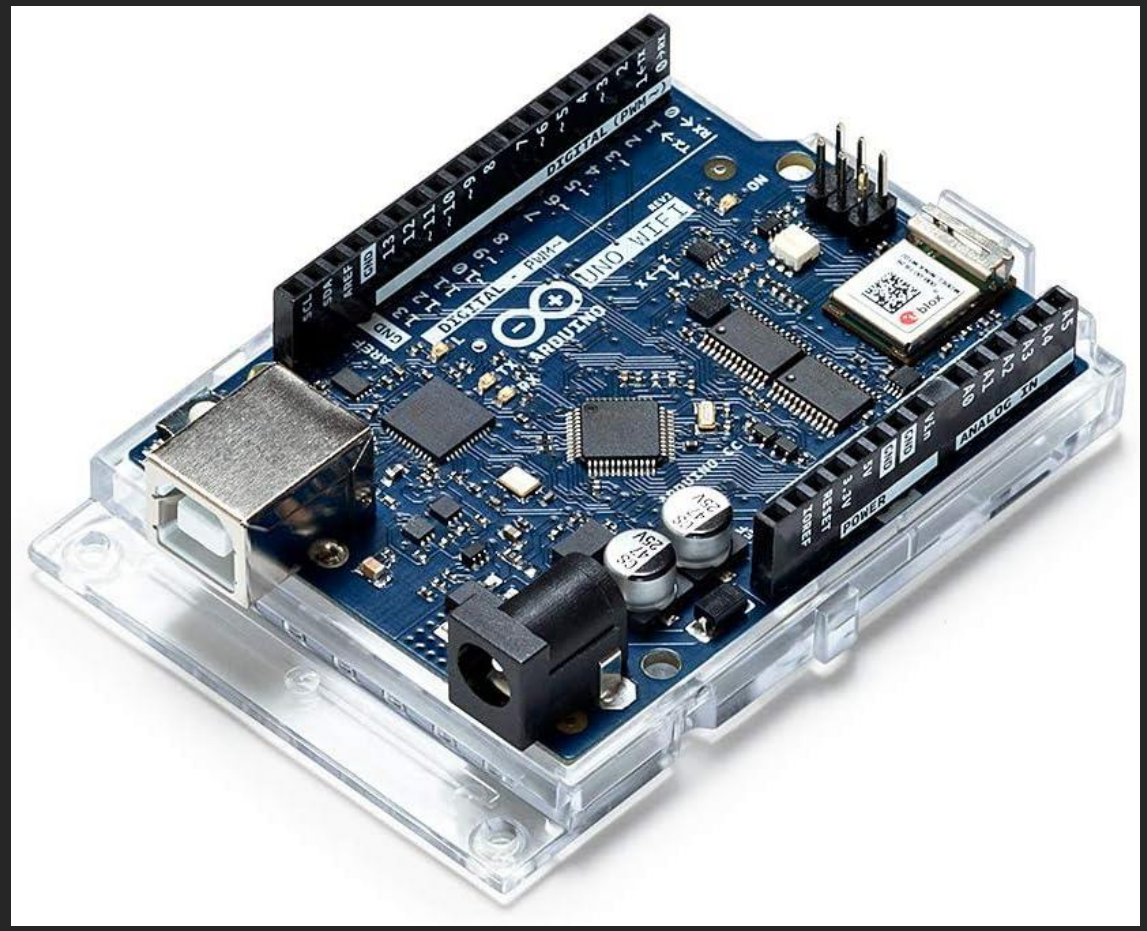
Electrical Schematic Part 2



Parts List

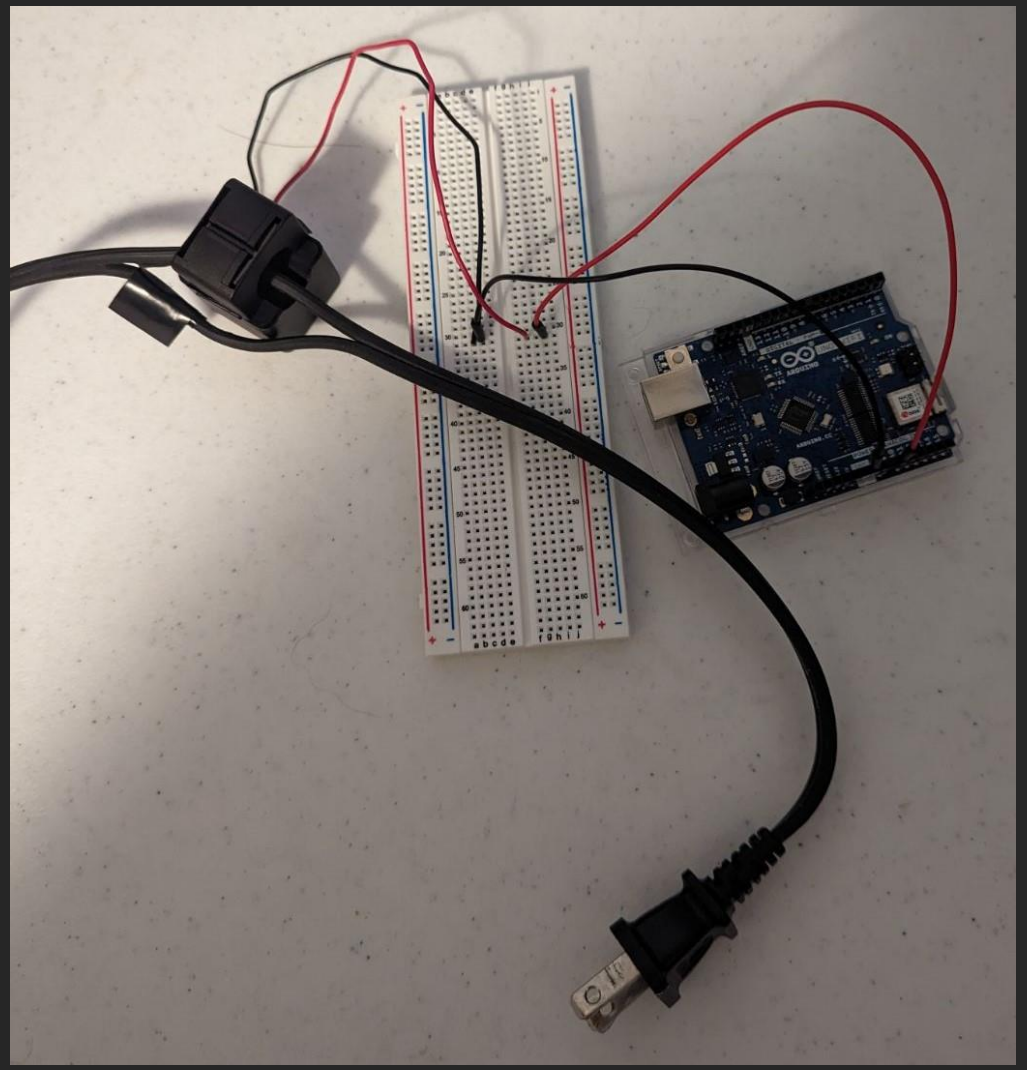
- Arduino UNO WiFi Rev2 microcontroller (x1)
- Manual switch-operated Toaster Oven (x1)
- Split-core current transformer (x1)
- Breadboard (x1)
- Jumper cables (x2)
- Male USB-B to male USB-A cord (x1)

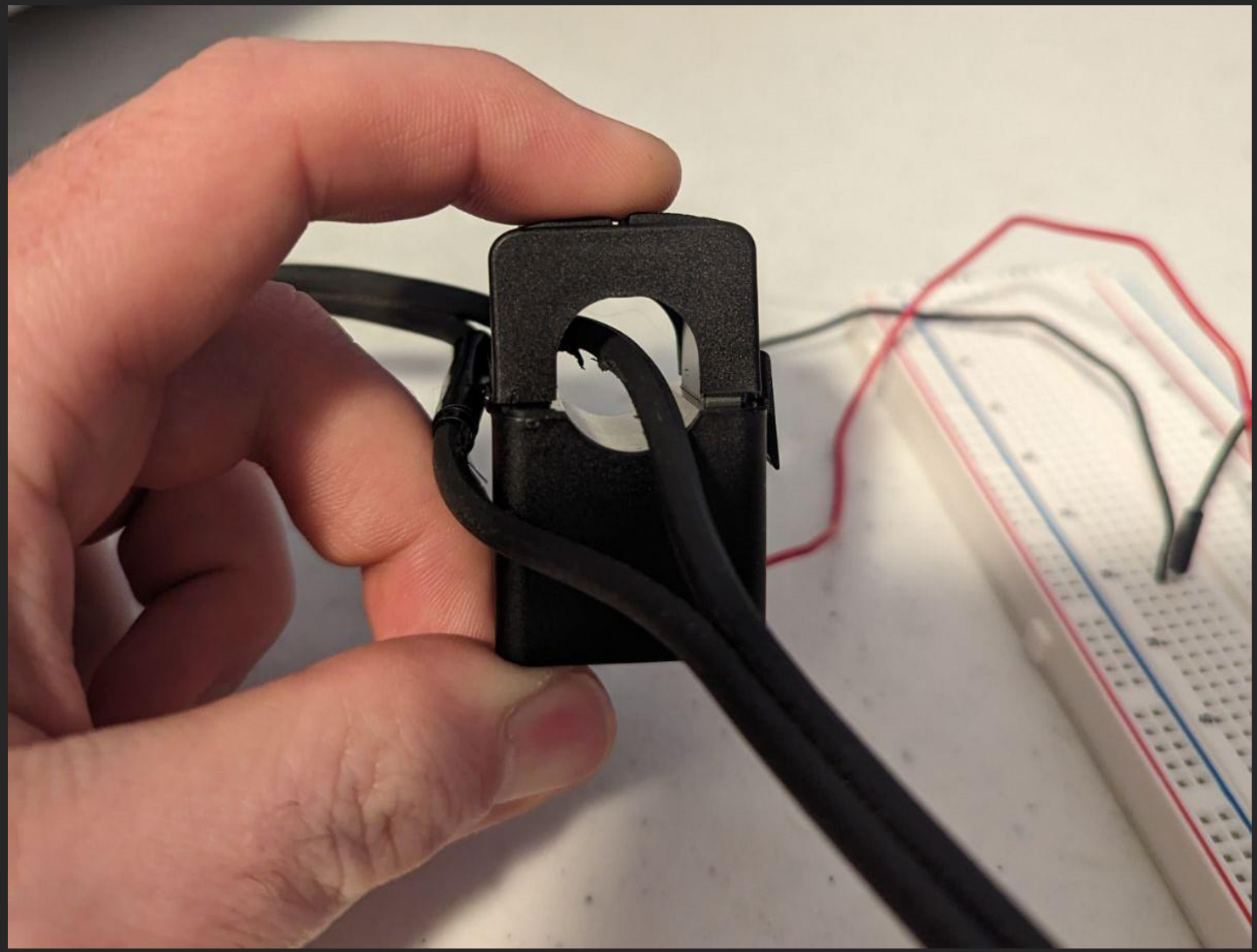
Physical Wiring



Physical Wiring Part 2

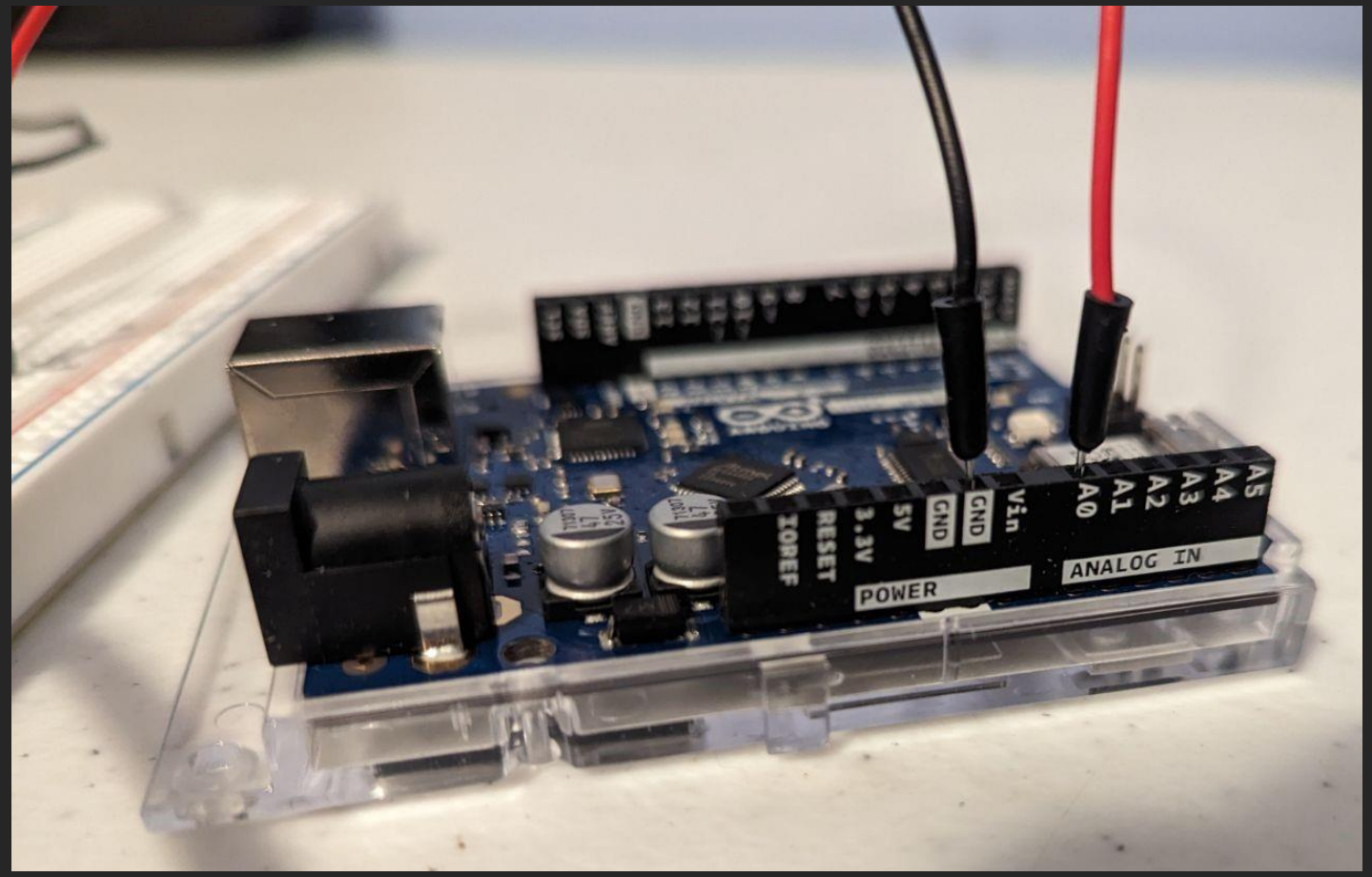
Physical Wiring Part 3

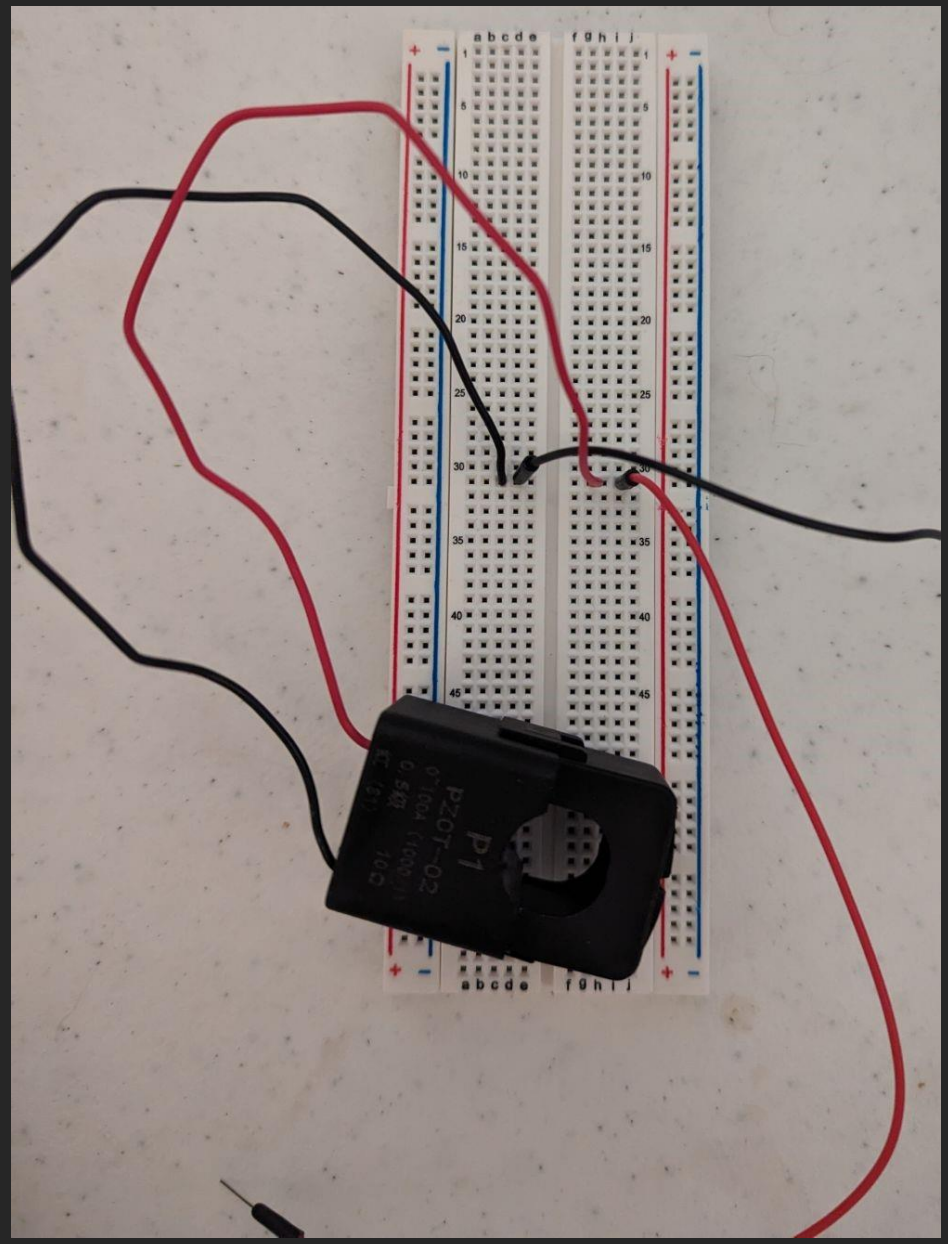




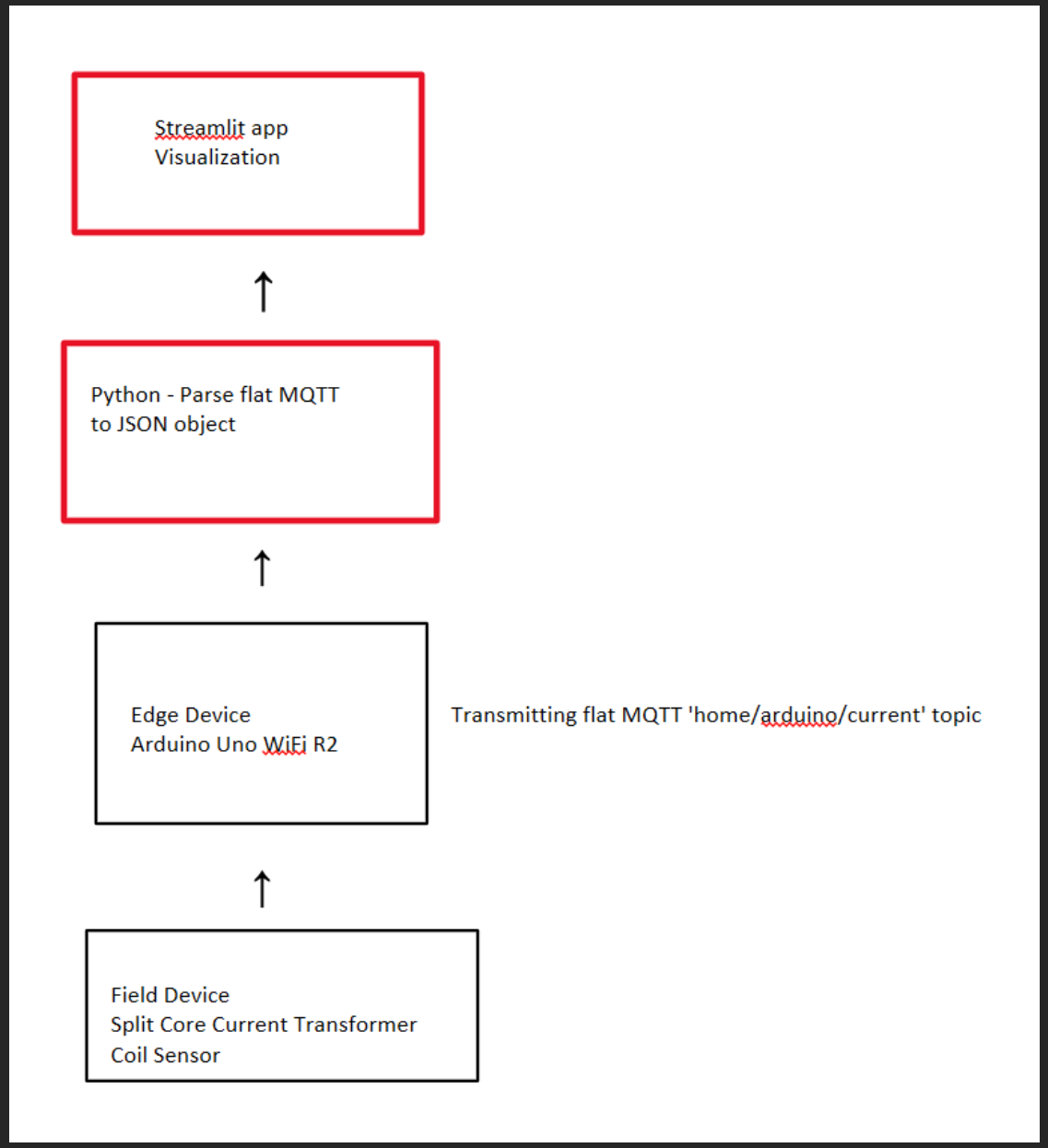
Black ground jumper: GND on Arduino, D31 on breadboard. Red jumper: A0 (analog input) on Arduino, I31 on breadboard
Red transformer lead: G31 breadboard. Black transformer lead: C31 breadboard.

Physical Wiring Part 4





Architecture Diagram



Equipment specs

- Toaster Electrical Characteristics
  - 120V AC, 60Hz, 1500W
  - I = P / V → draws 12.5A of current
  - Assuming steady-state operation, meaning the values we are publishing to MQTT broker do not consider startup or shutdown phases. 12.5A of current is being assumed to be drawn constantly if toaster is on and operating.
  - Start-up, shutdown, and the path towards achieving steady-state would require transient circuit analysis using calculus integration to give an accurate model of toaster operation during these periods.
- Split Core Transformer
  - Environment temperature: -40℃~+85℃
  - Relative humidity: ≤ 90%(40℃)
  - Working frequency: 50Hz~60Hz
  - Insulation endurance grade: B grade (130℃)
  - Insulation resistance: >1000MΩ normally
  - Dielectric strength: can afford power frequency 1000V/1minute
  - Flame resistance: Conform to UL94-Vo grade
  - Internal resistance: 10Ω
  - Measuring range: 0-100A

Assumptions

- Assuming voltage from transformer can be scaled to known range that does not exceed 0-5V ADC.
- Assuming only linear transformer behavior
  - 60Hz frequency of toaster is low
  - Resistive heating elements hold constant resistance, therefore insignificant nonlinearity is present
  - 120V AC is within range of transformer
- Max current from toaster will only ever be 12.5A

Physics

- How transformers work
  - Provide current output, Primary winding is passed through by current to be measured. Secondary winding generates proportional current
  - Current reading then converted to voltage using burden resistor
  - Calibration needed depending on transformer’s sensitivity and chosen burden resistor
- Ideal transformer behavior
  - Relationship between primary and secondary voltages and currents is linear and follows the turns ratio
  - No hysteresis or magnetic saturation in the core material
- Non ideal behavior
  - Iron core becomes magnetically saturated due to high magnetic flux densities, therefore non-linear input & output voltage
  - Hysteresis losses due to higher operating frequencies (cyclic magnetization & demagnetization)
  - Eddy currents pronounced at higher frequencies
  - Temperature affect iron core permeability
  - Changing load conditions causes output

Arduino Setup

- Analog inputs use built-in analog-to-digital (ADC) converter, 10-bit resolution, represents analog voltages as digital values 0-1023. Conversion is based on the principle of proportionality: the ADC reading is proportional to the physical measurement it represents.
- Does not read current values natively, therefore the current that can be measured using the analog input of Arduino depends on circuitry to convert the current into voltage.
- Analog input takes voltages 0-5V

Calculation: The current is calculated by first normalizing the ADC value (dividing by `maxADCReading`) to get a fraction between 0 and 1. This fraction is then multiplied by `maxCurrent` to scale the value to the actual current range.

Arduino Code

String Conversion for MQTT Publishing: Since MQTT deals with messages in a string format, the floating-point current value needs to be converted into a string.

- **Character Array (`currentStr[16]`)**: This is a buffer to store the string representation of the current. The size 16 is chosen to ensure there is enough space for the characters of the float, including the decimal point, digits, and potential negative sign.
- **`dtostrf` Function**: This stands for 'double to string format'. It's used here to convert the floating-point number (`current`) into a string (`currentStr`). The parameters `6` and `2` specify the width and precision of the floating-point number. In this case, it means the string will have a total of 6 characters including the decimal point, with 2 digits after the decimal.

Python Code

- Pure python using Streamlit to do front-end plotting
- Horizontal single bar chart shows timestamp of first downtime recorded after a series of ‘ON’ condition. Captures events only for the last 1 hour, can be modified but not recommended to go above 3-6 hours.
- Better ways to view downtime than a horizontal bar.
- Pie chart aggregates ON/OFF percentages for all time.
- Motivation – own the solution and directly change visuals as you see fit instead of messing with drop-downs and menus.

Future Upgrades

- More robust error handling at edge device
  - Network reconnection
  - Broker reconnection
- Dedicated burden resistor circuit to convert to volts
- Streamlit app
  - Additional MQTT topics, auto-discovery
  - Broker reconnection
  - Ensuring app continues to run over long period (containerization)