# Findings From Power Supply Testing

Aidan Williams

1/10/25 - 3/10/25

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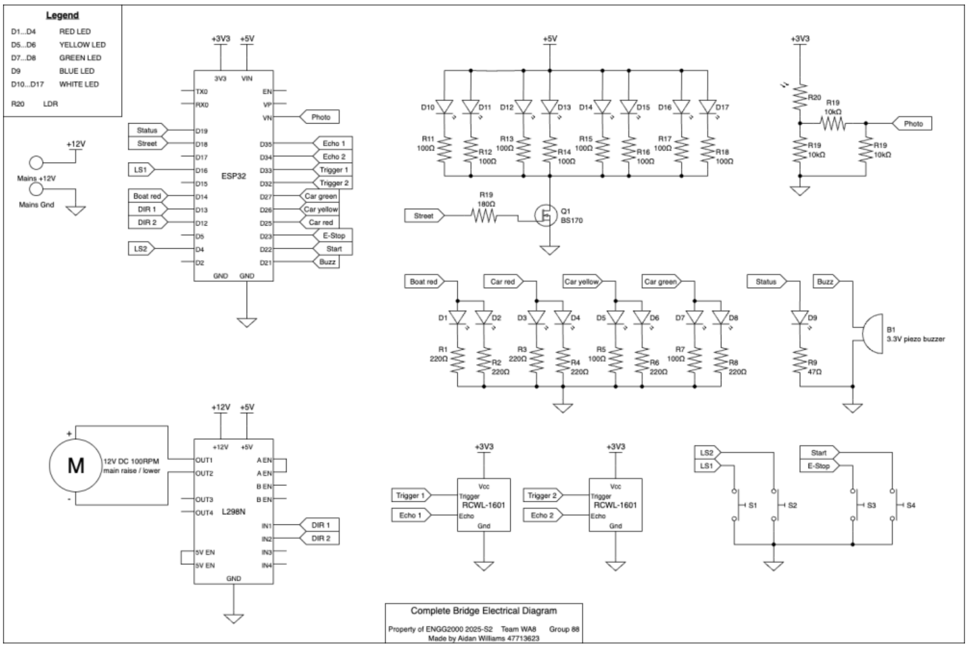
# Background

Electricity is passed throughout the electrical subsystem at three different DC voltages:

1. 12V provided by an external supply
2. 5V provided by the LM78M05 linear regulator integrated into the L298n DC motor driver board
3. 3.3V provided by a linear regulator onboard the ESP32 dev board




# Goals

1. Determine max current draw from the 3.3V & 5V supplies
2. Test the voltage output & temperature of the LM78M05 under maximum loading conditions
3. Test the maximum sustainable load on the LM78M05 for extended periods
4. Test that the 3.3V regulator can produce a stable voltage under the lowered voltage from the stressed LM78M05 under maximum load conditions

# Part 1 – Analysis of Maximum Required Load

## Method:

Using an excel spreadsheet, I went over all components in the electrical subsystem & recorded the following:

- What it was
- What voltage it required
- The maximum current the component could draw
- Whether the component would be inactive when other components were active
    - This analysis was really only necessary for the traffic lights
    - Since the difference that this made was only –40mA on the 3.3V rail, this step of the analysis went unused in later parts

| | | | Will not be on at same time as: | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Max Current (mA) | Voltage Stage (V) | ESP32 | 2x Ultrasonics | street lights | car red | car yellow | car green | boat red | status led | piezo buzzer | light sensor | raise motor |
| ESP32 | 250 | 3.3 | | | | | | | | | | | |
| 2x Ultrasonics | 6 | 3.3 | | | | | | | | | | | |
| street lights | 160 | 5 | | | | | | | | | | | |
| car red | 20 | 3.3 | | | | | | | | | | | |
| car yellow | 20 | 3.3 | | | | x | | | | | | | |
| car green | 20 | 3.3 | | | | x | x | | | | | | |
| boat red | 20 | 3.3 | | | | | | | | | | | |
| status led | 20 | 3.3 | | | | | | | | | | | |
| piezo buzzer | 5 | 3.3 | | | | | | | | | | | |
| light sensor | 0.275 | 3.3 | | | | | | | | | | | |
| raise motor | 2200 | 12 | | | | | | | | | | | |

| | Max Current Load per Voltage Stage (mA) | | |
|---|---|---|---|
| | 12V | 5V | 3.3V |
| Stage Subtotal | 2200 | 160 | 361.275 |
| Cascaded Total | 2721.275 | 521.275 | 361.275 |
| Disapated Power (W) | | 3.65 | 0.61 |
| Total System Current (A) | 2.722 | | |

**This Table can be found on the SharePoint at Systems/Electrical by Aidan/Current Budget.xlsx or at this link**

Using the summed current draw & the voltage dropped across the regulator, I worked out the power dissipated by each regulator under maximum loading conditions.

## Findings:

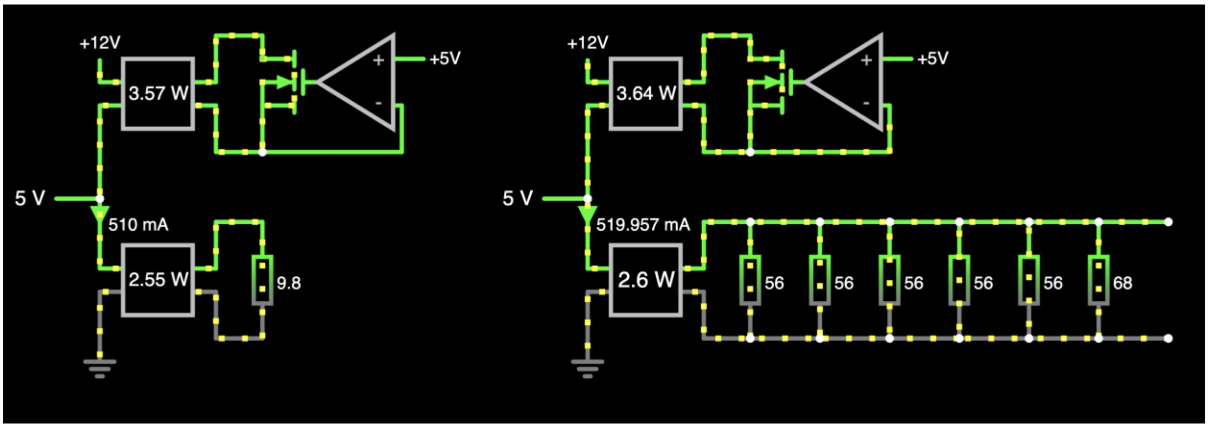
- The whole system falls well within the 5A limit for the external 12V supply
- The 3.3V regulator will likely handle maximum loading conditions without thermal issues
- The 5V regulator will probably not handle the maximum load conditions without thermal issues

# Part 2 – 5V Regulator Testing

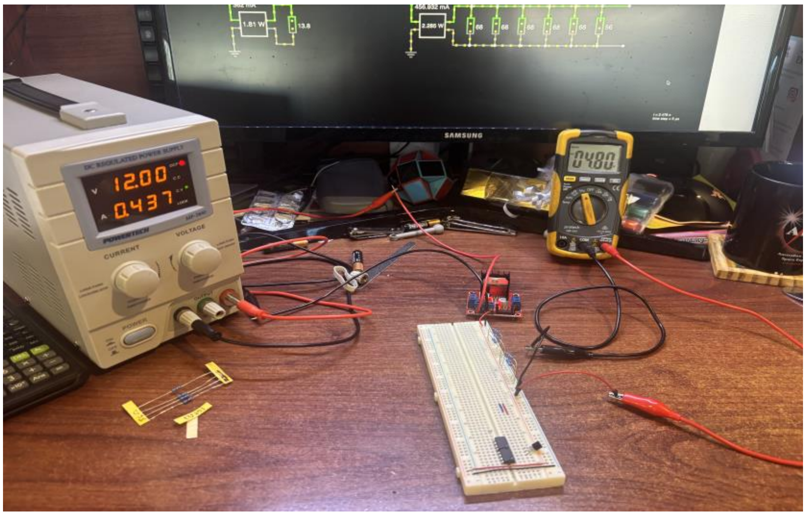
## Method:

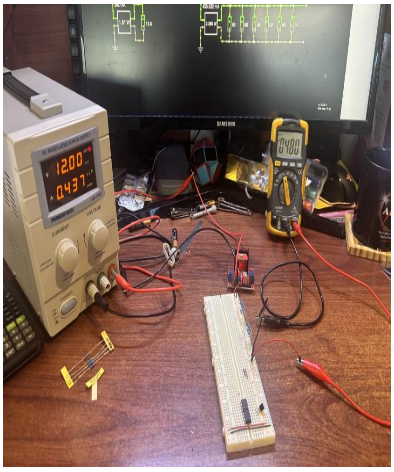
Using many resistors in parallel, I was able to produce a test load that drew a similar current to the maximum load conditions calculated previously. I used both the Desmos online graphing calculator & falstad.com circuit simulator to pick a set of resistors that such that each resistor would not exceed their individual 0.5W rating.

The circuit on the left depicts the ideal load resistor to simulate max loading , & the circuit on the right shows my approximation using 6 resistors in parallel. Both circuits also model the LM78M05 (the top half of each circuit)




Pictured on the left is the whole testing setup, including the 12V power supply which has an internal current sensor & display, the multimeter shows the voltage output by the LM78M05. The image on the right shows the parallel resistors forming the test load.





## Findings:

After 10-20 seconds of operation, the LM78M05 was incredibly to the touch & entered thermal regulation mode. When in thermal regulation mode, the LM78M05 reduces its output voltage in order to reduce total power draw & relieve the load on itself.

Due to the voltage sag, the load current was actually lower than the max current that will be drawn from the actual system. From these results, its very unlikely that the LM78M05 can supply the max rated current for very long, especially if enclosed within the bridge.

# Part 3 – LM78M05 Maximum Sustainable Load

## Method:

After letting the LM78M05 & resistors cool down, I started by only adding one load resistor and monitoring the output voltage & temperature. After waiting for a short period, I shut down the input 12V supply to let the LM78M05 & resistors cool before adding an additional load resistor & repeating.

I stopped adding load resistors once I reached approx. 362mA of load current, emulating the load if the streetlights from the 5V stage to the 12V stage.

## Findings:

At the ~362mA load, the LM78M05 output voltage dropped to 4.86V but was able to sustain the voltage for the duration of the test. It was still incredibly hot to the touch but did not enter thermal regulation, however whether or not it will overheat when enclosed is unknown. Additionally, I could only run the test for 30-40s max due to the load resistors overheating, so the long-term stability of the LM78M05 is still unknown.

# Part 4 – EPS 3.3V Regulator Tests

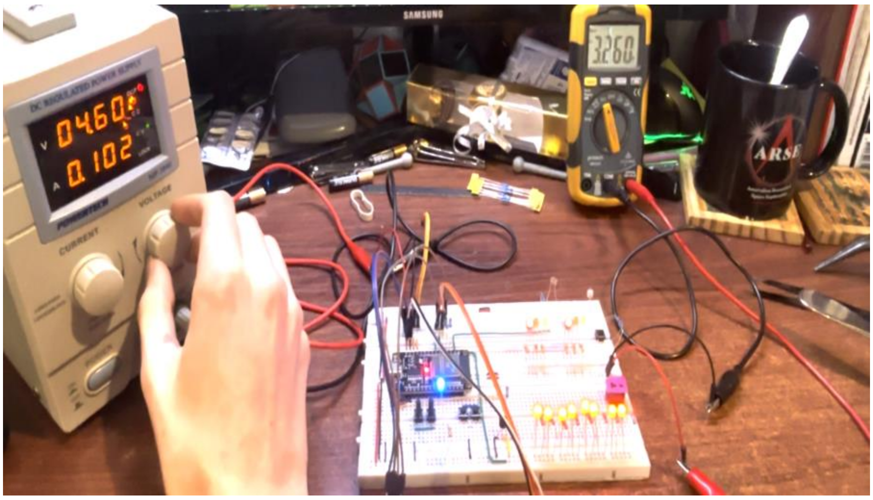
## Method:

Connected the ESP & prototype breadboard to my variable power supply set to 5.0V, the breadboard was modified in the following ways:

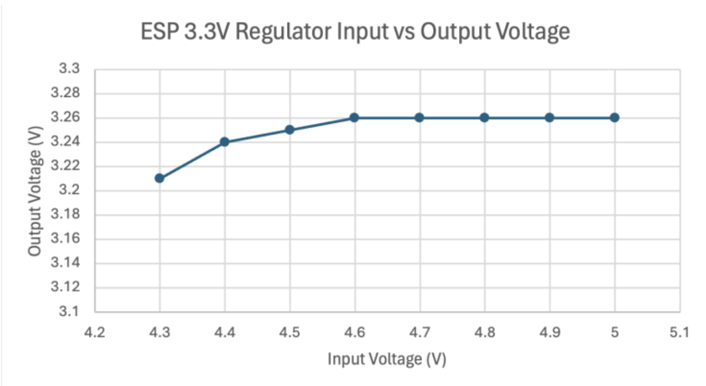
- The motor driver was removed & it's 5V regulator was replaced with my variable supply
- The light sensing circuit was modified to always trigger the streetlights
- The piezo was connected to the status light to constantly draw current

The code running on the ESP was unmodified from the prototype integration test as I didn't have a proper coding environment set up to upload new firmware.

The input voltage was lowered from 5.0V in steps of 0.1V & the output voltage was recorded using a multimeter set to voltage mode.



## Findings:




I couldn't pull the full 316mA expected max current, only able to pull approx. 120mA. However, I was still able to observe that the output 3.3V will begin to lower at input voltages lower than 4.6V. Given that the LM78M05 only dropped to 4.86V under max current conditions, it is likely that the ESP will handle the heavily loaded LM78M05 conditions without issue.

# Suggestions

Given the results of these tests, the current setup for electrical distribution will overload the LM78M05 (5V regulator) under maximum load conditions. In order to remedy this, I propose two possible solutions to power distribution:

1. Offload all possible components from the LM78M05 either onto the ESPs regulator or the 12V stage
2. Replace the LM78M05 with a standalone buck converter

Both of these options have drawbacks & will be further outlined below.

## Option 1 – Offload the 5V Regulator

While the current load on the 5V regulator is too high, by shifting the streetlights to the 12V stage 160mA could be removed, dropping the total load to 362mA. Additionally, accounting for the component interactions discarded earlier in the study, an extra 40mA will not be present, lowering the total to 322mA. This would prevent thermal regulation & would likely work well, even when the L298n board is enclosed inside the bridge structure. However, the regulator would still be laboured, dropping to 4.8V but this would not affect the 3.3V stage or ESP operation.

Another issue with this approach is that there is no remaining overhead in the 5V regulator for additional components or features. This option will freeze the design & feature set of the bridge as-is.

However, the key benefit of this change is that the overall structure of electrical subsystem will not be changed substantially, & no extra components will need to be purchased.

## Option 2 – Buck Converter

A more flexible alternative is to replace the 5V regulator on the L298n with an external buck converter module. This more efficient converter would negate all of the overheating issues in the current electrical subsystem, meaning no further changes would be necessary.

An additional benefit would be a significantly higher maximum current capacity, raising the ~500mA (minus capacity lost to thermal regulation) limit on the L298n's regulator up to 2.5A (with this module).

However, such converters are far noisier than the current 5V regulator which may cause the following issues:

- Reduced range for Wi-Fi control connectivity
- Reduced accuracy & increased jitter in light level measurements

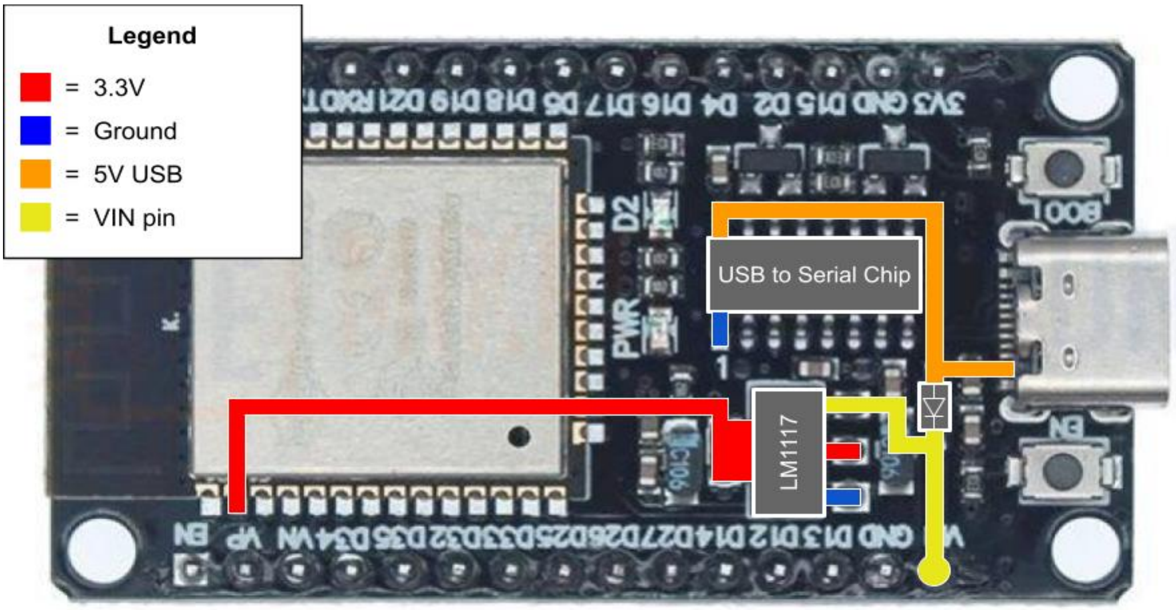
Additionally, switching to such a converter would require a new purchase & add another component to the BOM.

## Option 2.5 - Buck Converter + New Motor

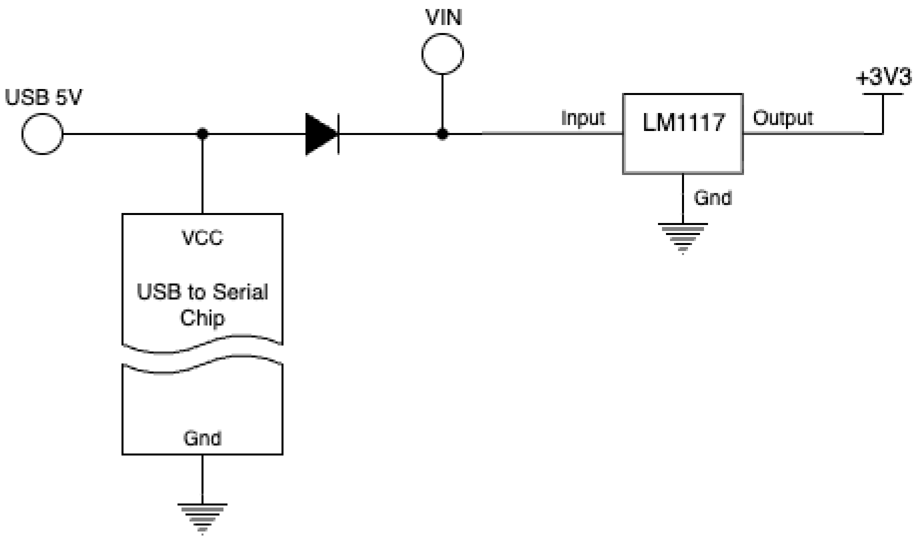
Using both the findings in the next section "ESP Regulator Hack", & the Structure teams revised torque specifications, the buck converter has one major advantage over the regulator. The buck converter can be adjusted to output 6V instead of 5V, which can still be safely sent to the VIN pin on the ESP32. By switching to a 6V stage, the entire L298n board & DC motor could be replaced by a single continuous servo motor.

# ESP Regulator Hack

Using the datasheet for the ESP32's onboard 3.3V regulator (the LM1117) & probing the dev board with a multimeter. I was able to reverse engineer the internal connections & come up with a plan that allows even greater flexibility for the buck converter solution.




**The reverse engineered connections on the dev board**




**A simplified schematic of the VIN pin, the 5V from the USB port, & the 3.3V regulator on the ESP32 dev board. Showing the protection diode between the USB port & the VIN pin.**

From this schematic, I realised that a higher voltage can be applied to the VIN pin of the dev board (say 6V) without any risk of damage to the USB to serial chip. Additionally, the USB port can still be in use at the same time as the VIN pin without any damage to any components involved.

## Summary

Through testing the 5V regulator on the L298n driver board & the 3.3V regulator on the ESP32 dev board, I have determined that we are overloading the 5V regulator to the point of shutdown. Through additional testing I propose 2 options to remedy this issue:

1. Offload the current regulator
    - Move the streetlights from 5V to 12V w/ bigger resistors
    - Pros:
        - No extra components need to be purchased
        - No extra noise to mess up Wi-Fi & light sensor
    - Cons:
        - Still may overheat when put in a sealed box
        - Absolutely no room for adding more features/functions
2. Replace the regulator with a better converter
    - Bypass the regulator on the L298n board with a more efficient converter
    - Pros:
        - No overheating issues, even when in a sealed box
        - Plenty of room for adding extra features/functions
        - Can be changed to 6V to replace the driver board & motor with a single (& cheaper) servo
    - Cons:
        - Need to buy a new component
        - Converter noise may interfere with Wi-Fi range & light level sensor