UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Optimized Solar Charging Off Grid for Several Output Voltage Potentials

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Problem Statement

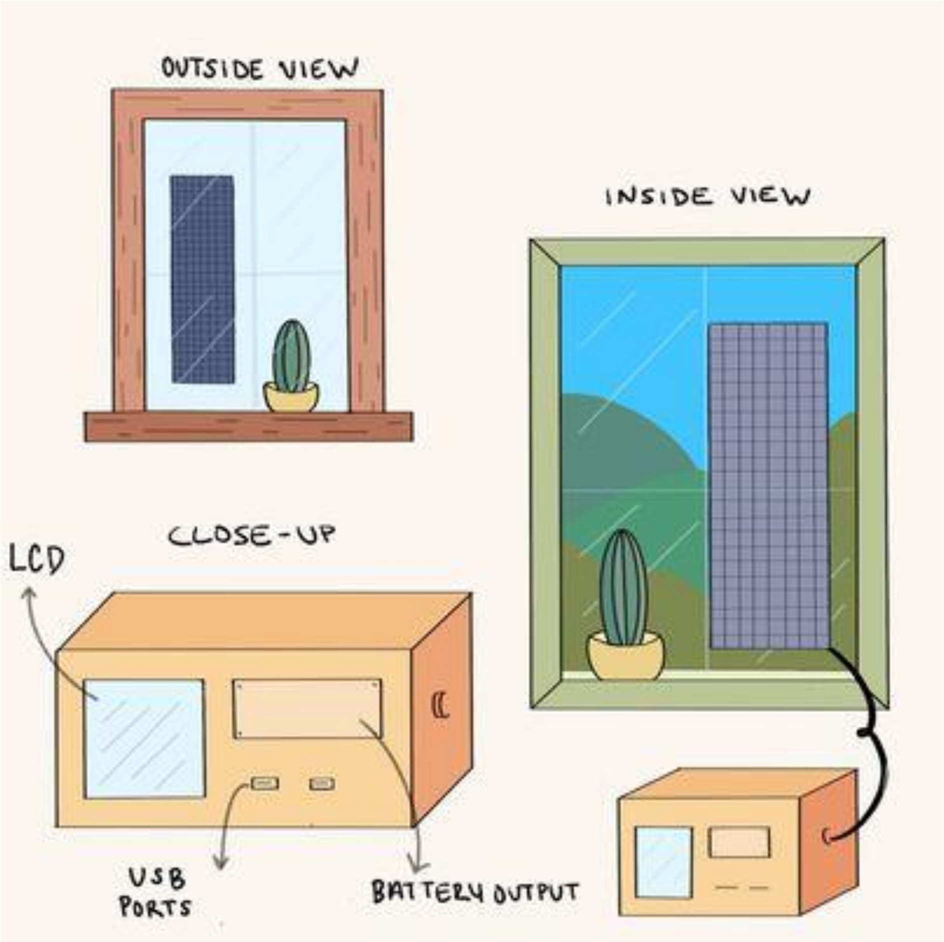
Need for Reliable Energy Source Isolated from the Grid

Problem: In the event of electricity going out for several days during a natural disaster, people are left with no way to charge their phones, flashlight batteries, or any other tools they may desperately need.

Essential Features:

- Provides an off-grid energy source
- Ability to charge electronic devices
- Can harvest energy from a renewable source
- Must be reliable within a wide range of conditions and environments
- Adhere to IEEE safety and ethics for battery charging
- Must be user friendly

Example Power Outage [1]



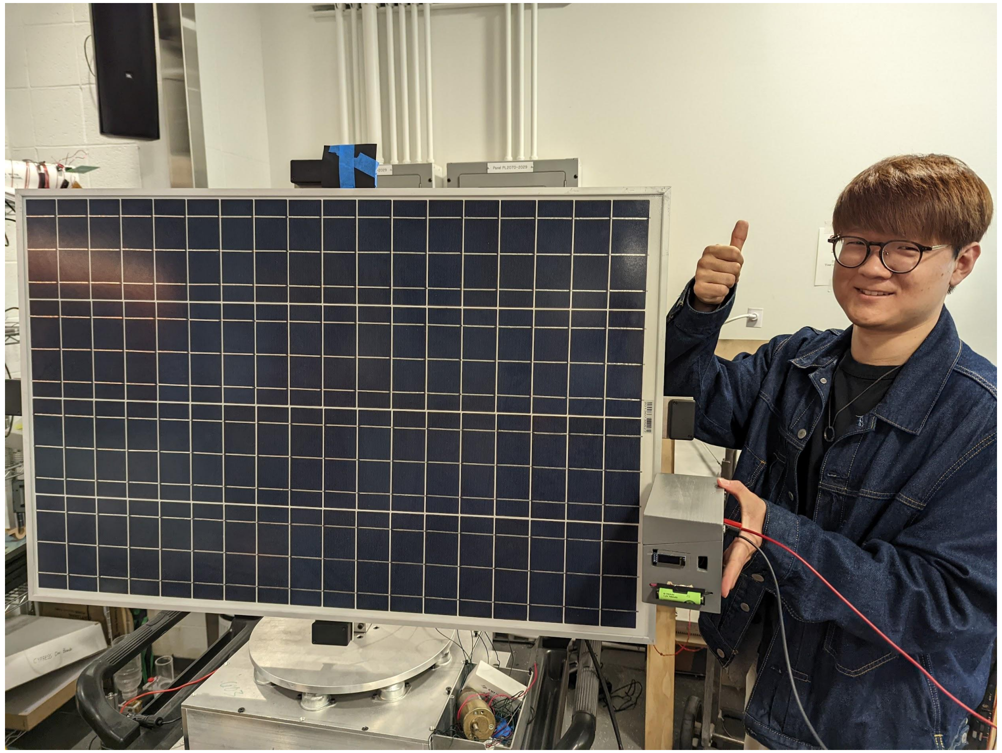
Solution:

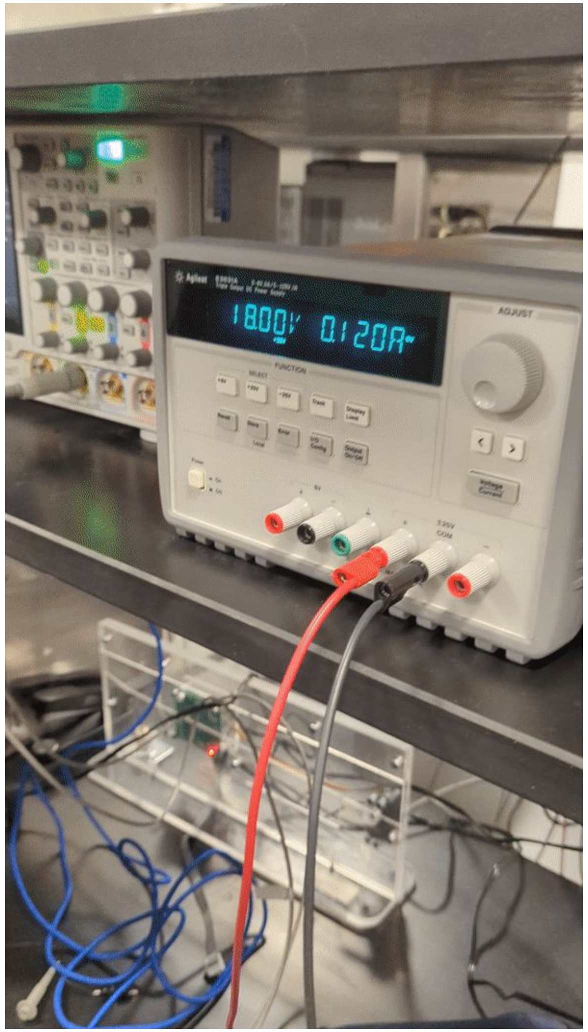
- Input Power Subsystem
- Microcontroller Subsystem
- Voltage and Current Regulation System
- User Interface

Ethical Concerns:

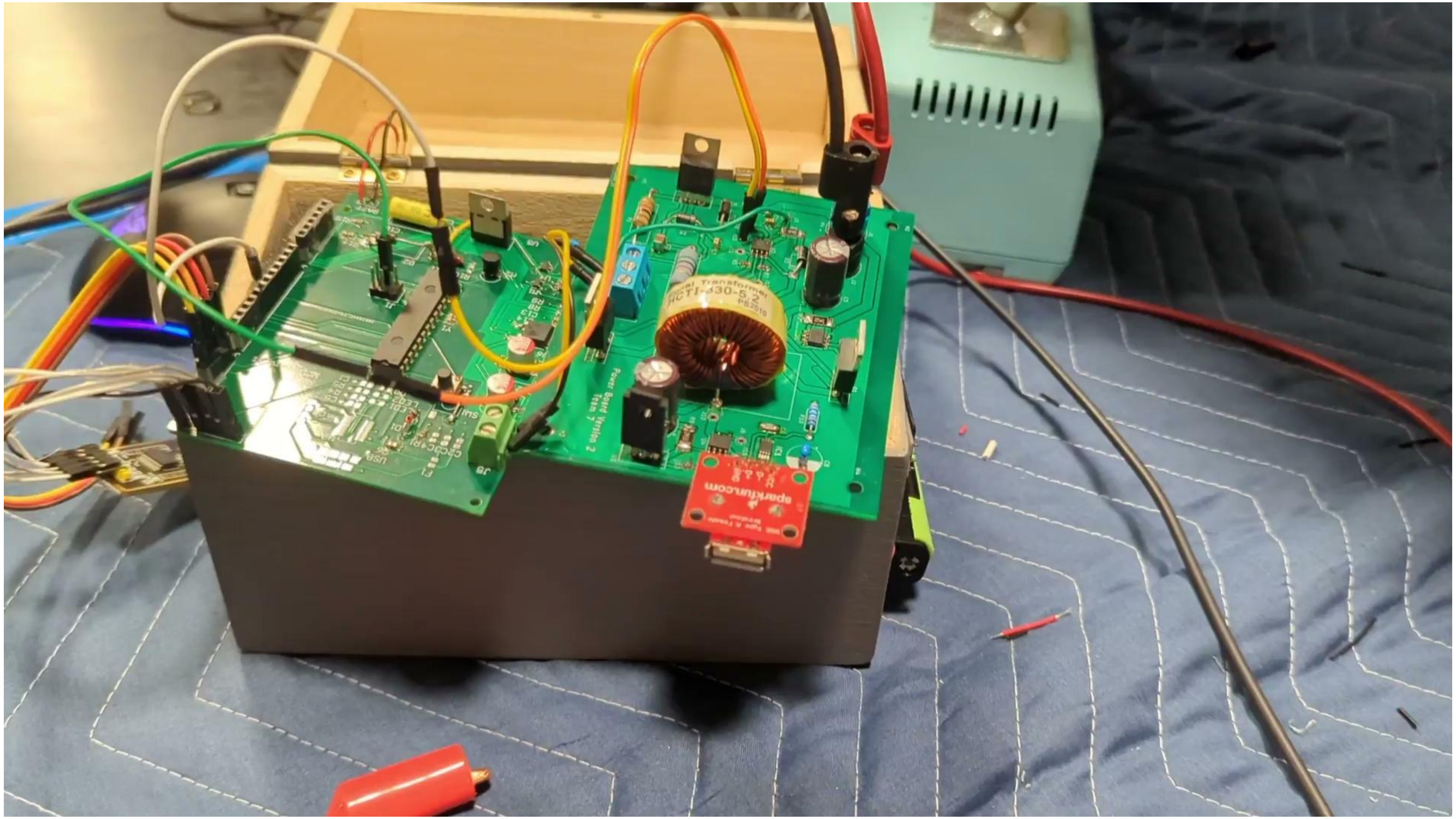
- Battery management safety
- Accuracy of measurement
- Reproducibility

Our Solution



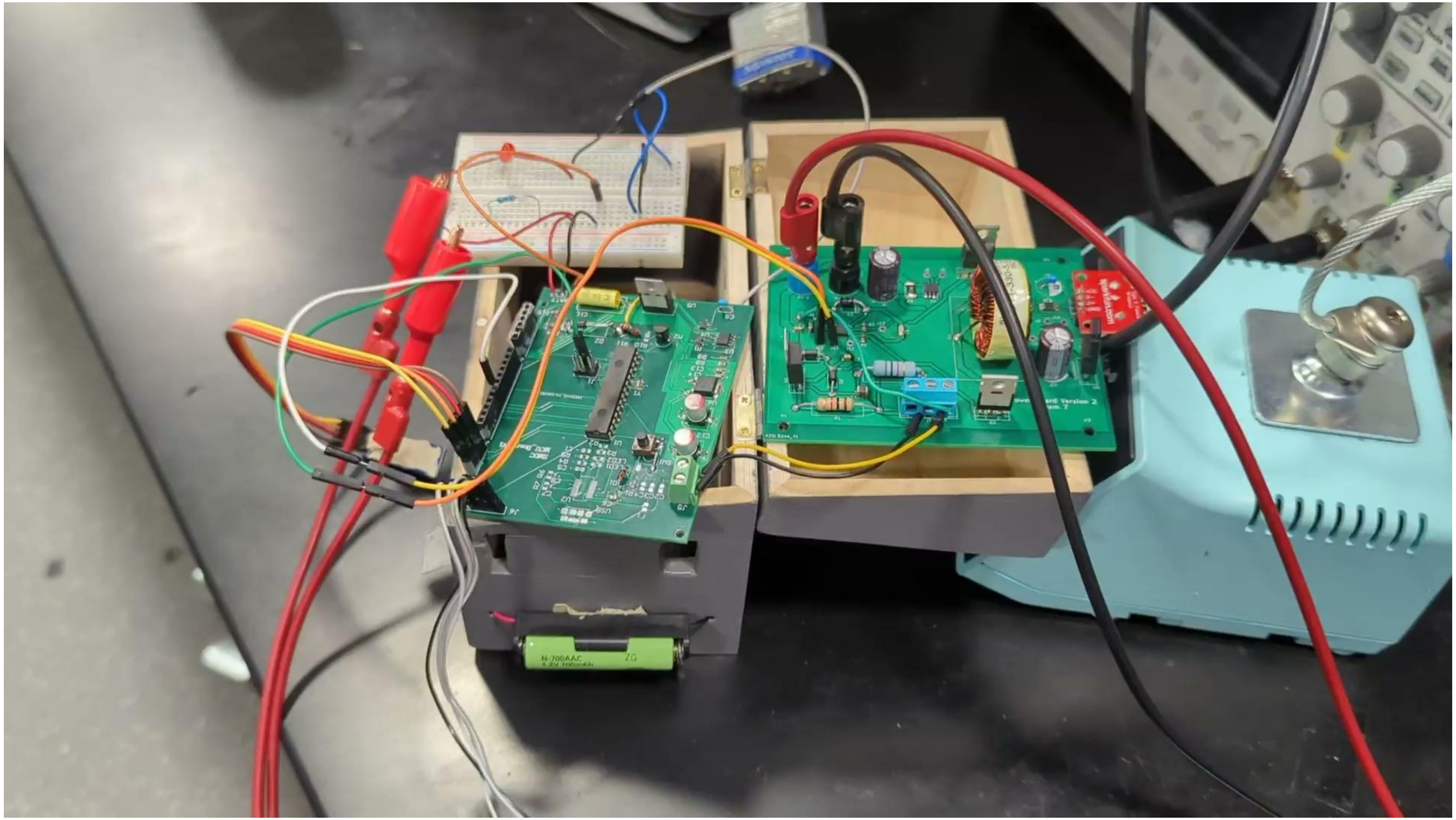


Video Demo - Final Product



Output for Solar Charging

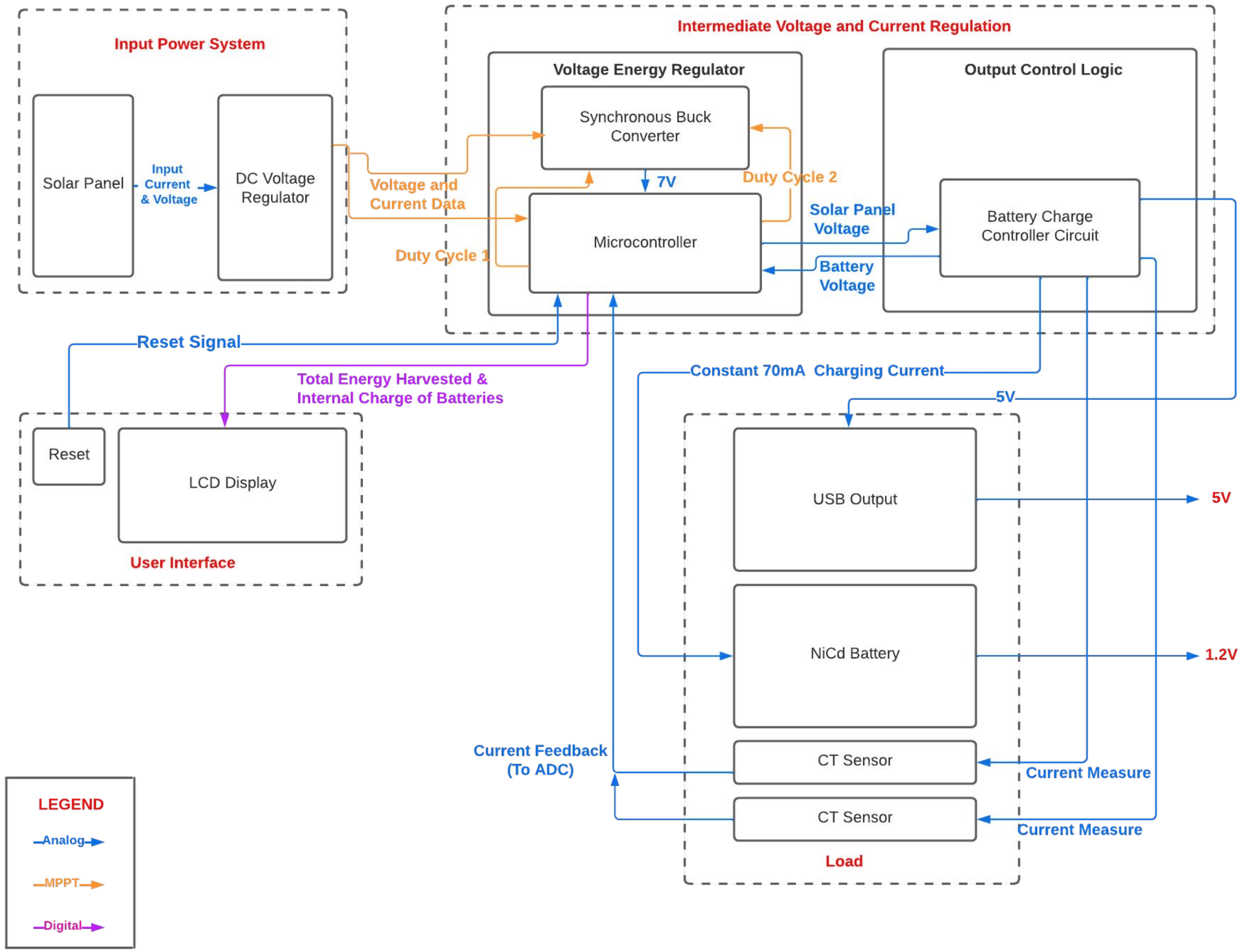
Video Demo - Final Product



NiCd battery charging (70 mA output)

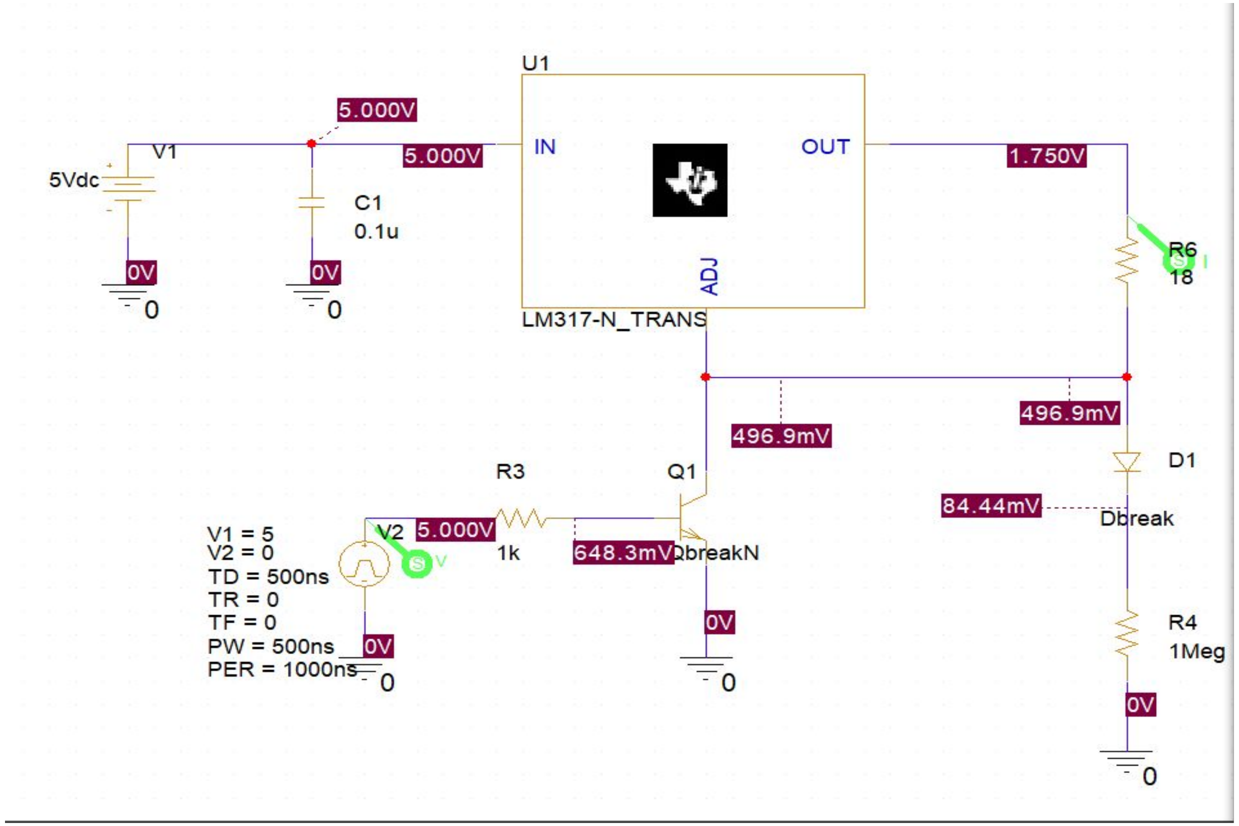
Design and Considerations

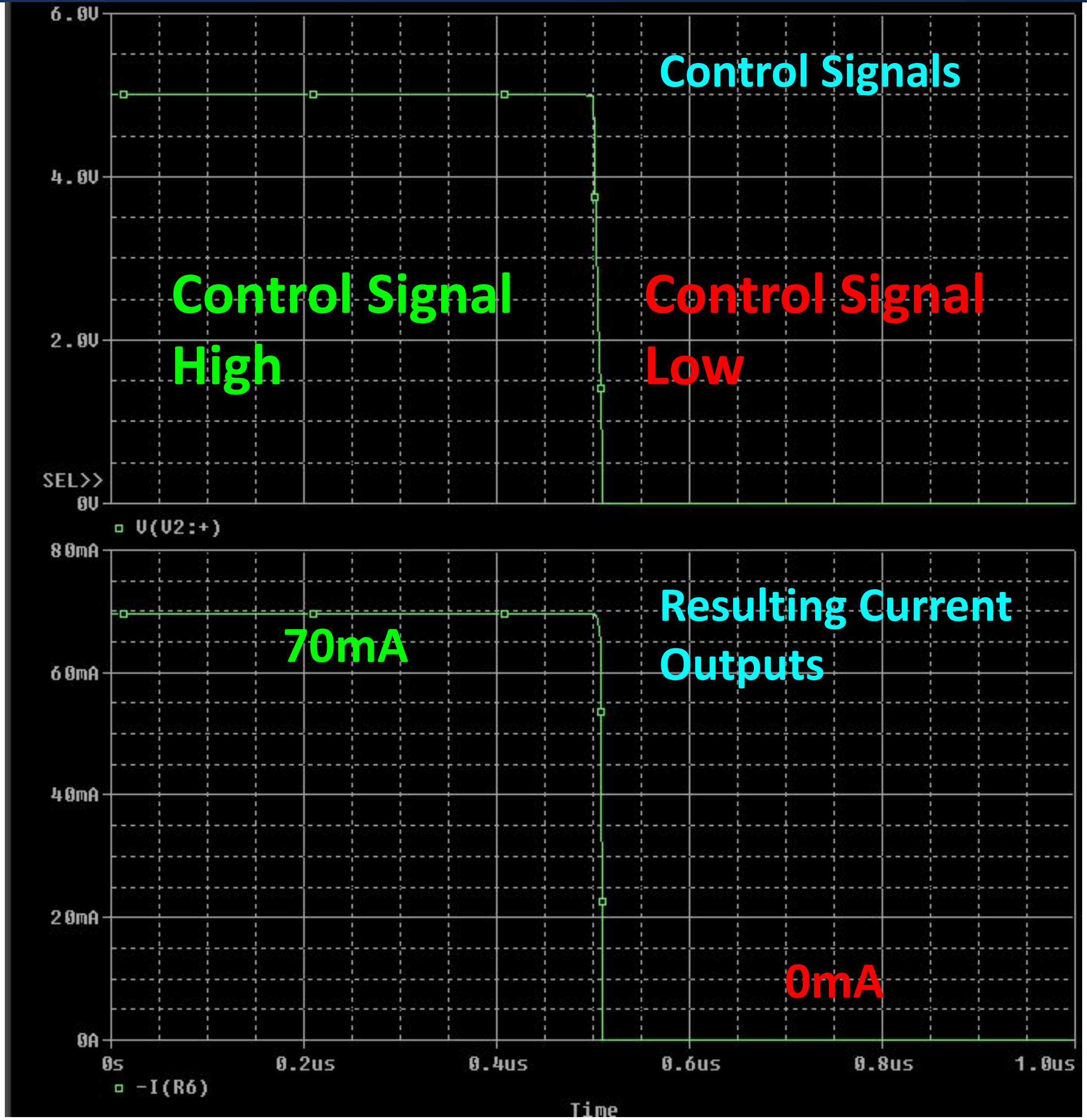
Block Diagram



Block diagram with our different subsystems: input power system, intermediate voltage/current regulation, UI, and load

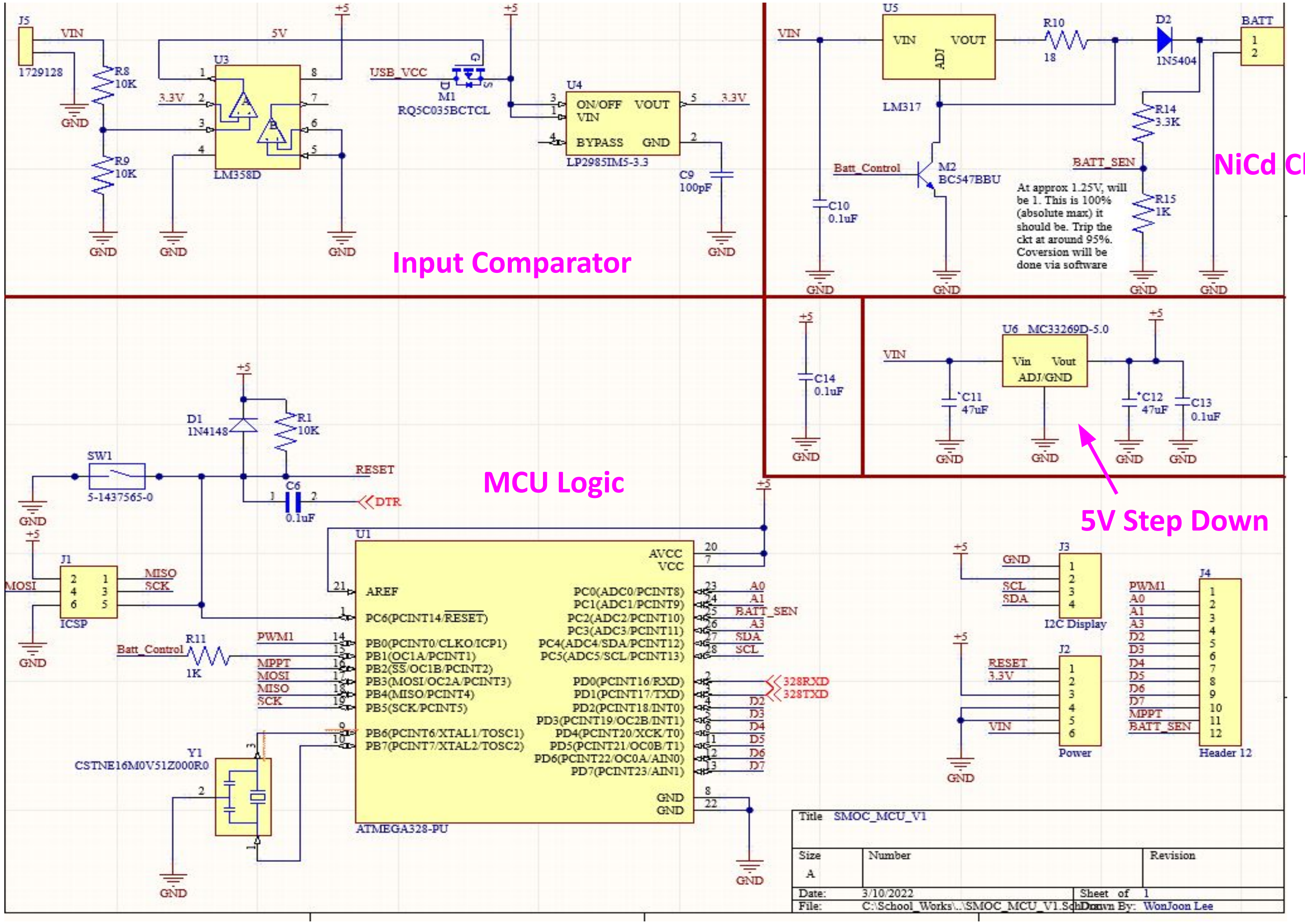
NiCd Battery Charger Design Considerations



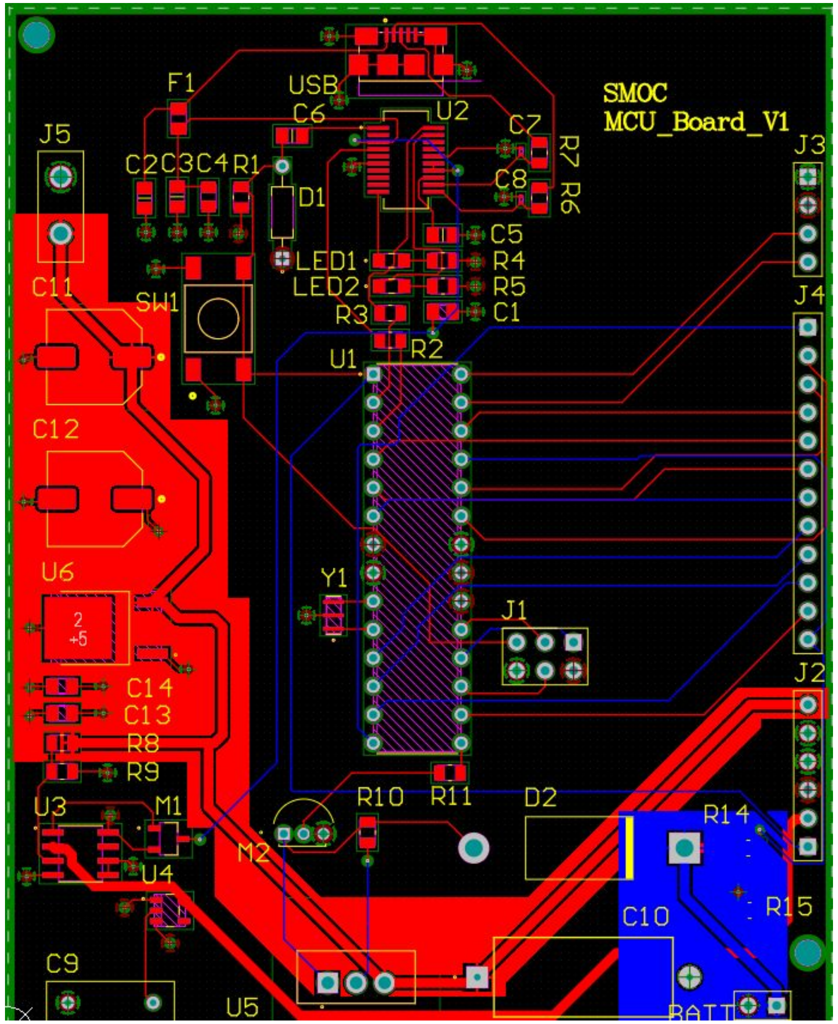


- NiCd Battery is recommended to charge with constant current rating that is 10% of the total capacity.
  - 700mAh with 70mA
- Solution: Constant current output configuration using LM317

PCB Design: MCU Board

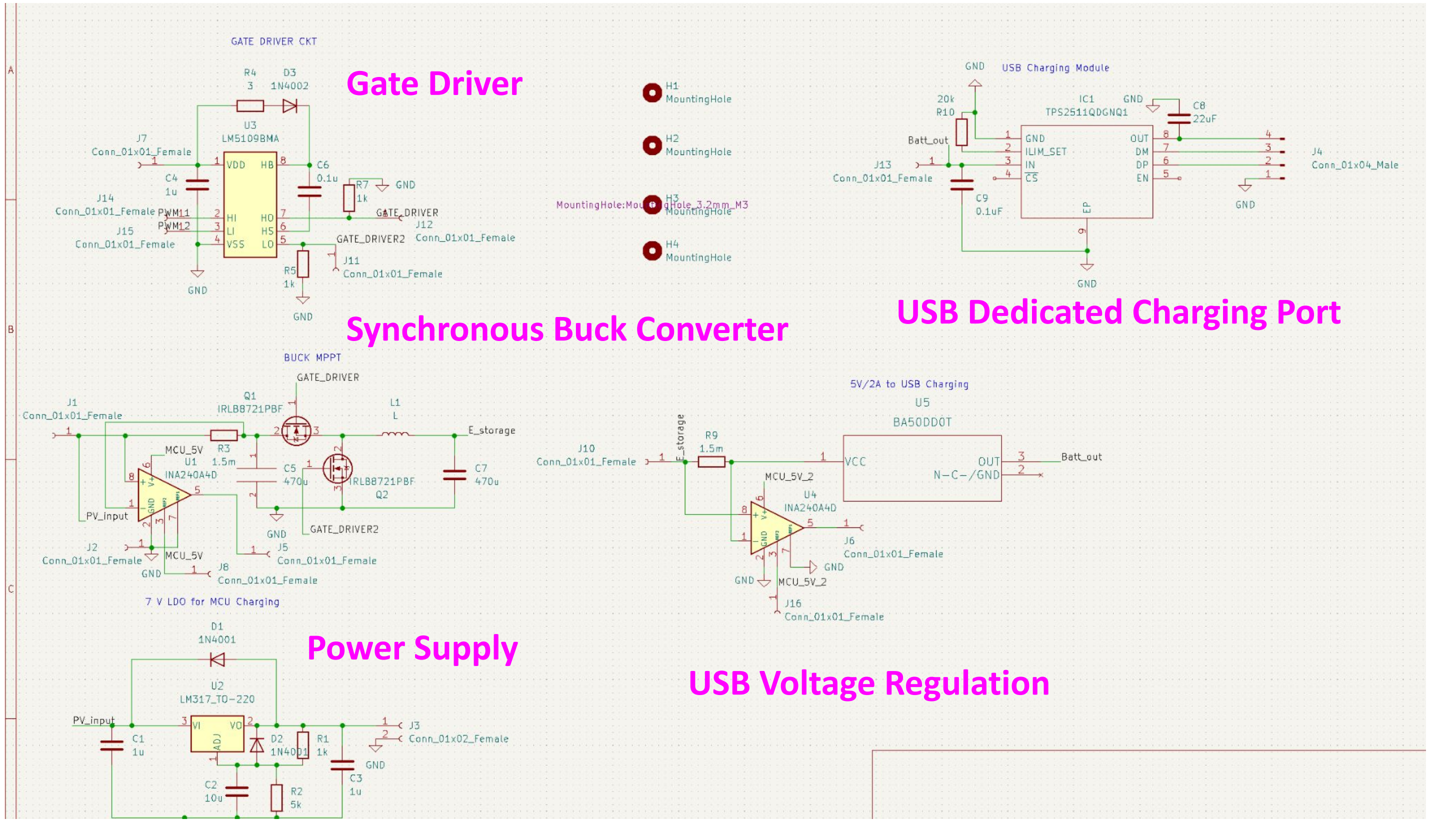


MCU Board Schematic

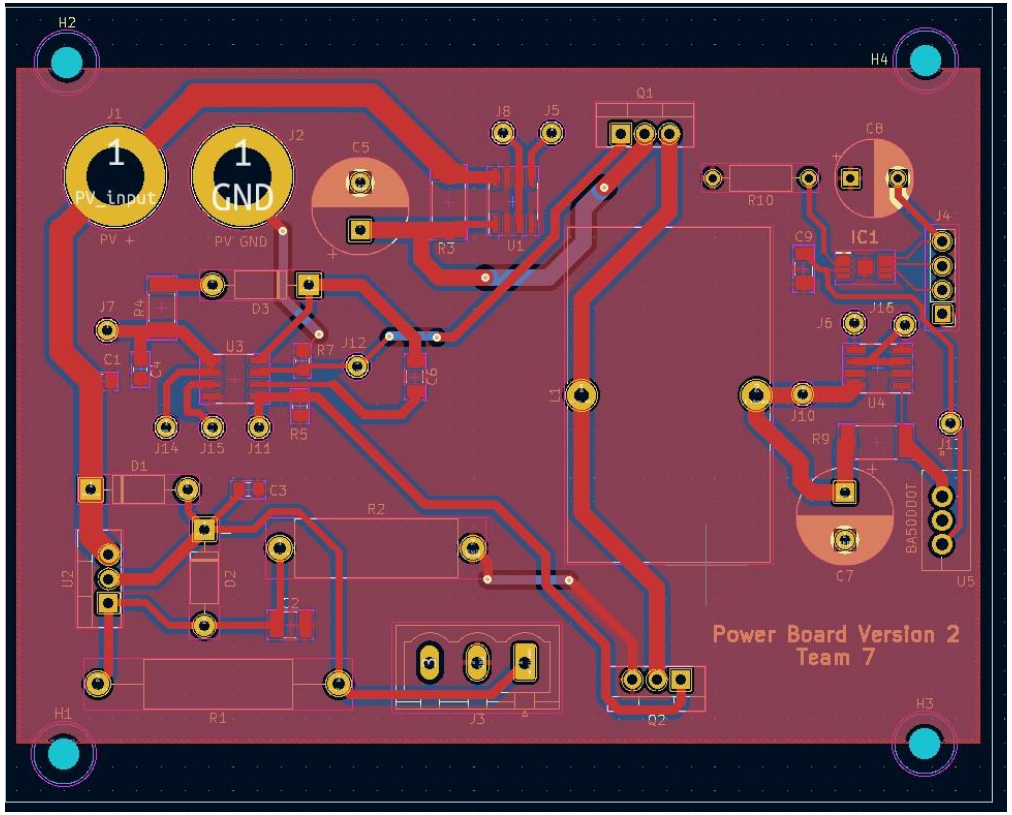


MCU Board Board Layout

PCB Design: Power Board

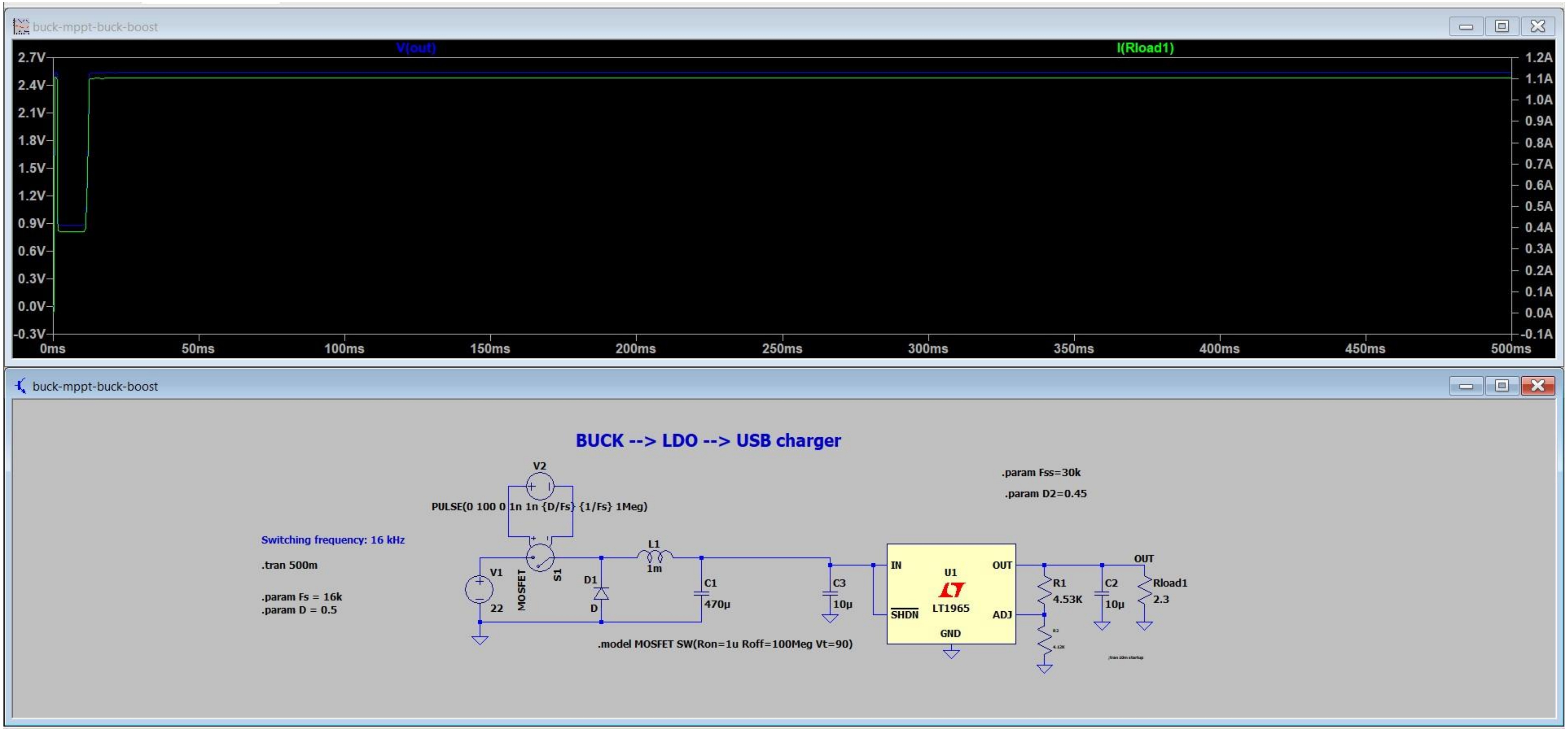


Power Board Schematic



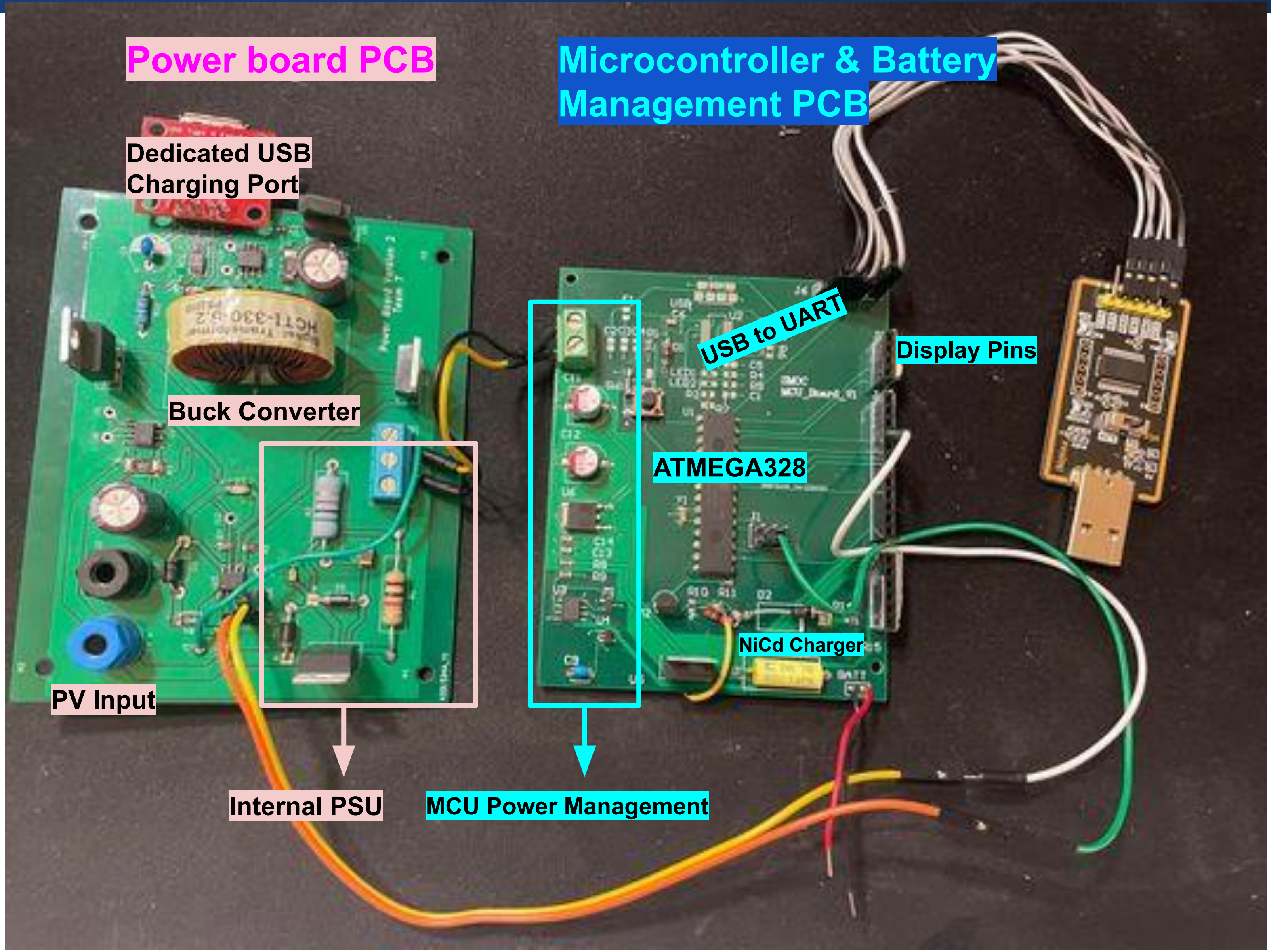
Power Board Layout

Changes since Design Doc - Buck Converter Sizing



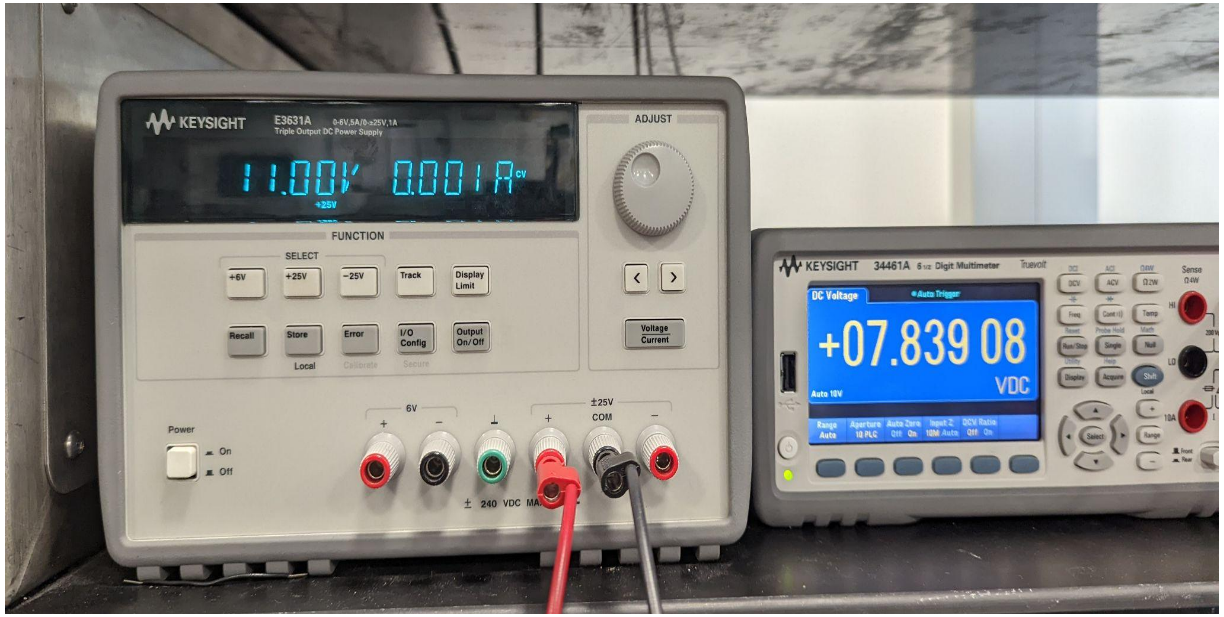
Project Build and Testing

PCBs & Hardware Utilized

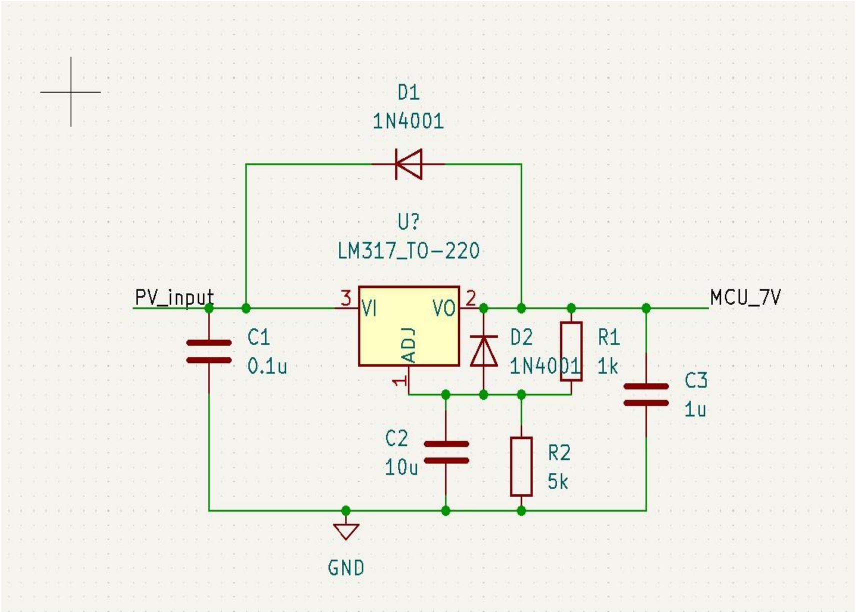


Powering the MCU Board

Testing for internal power management and MCU board operation



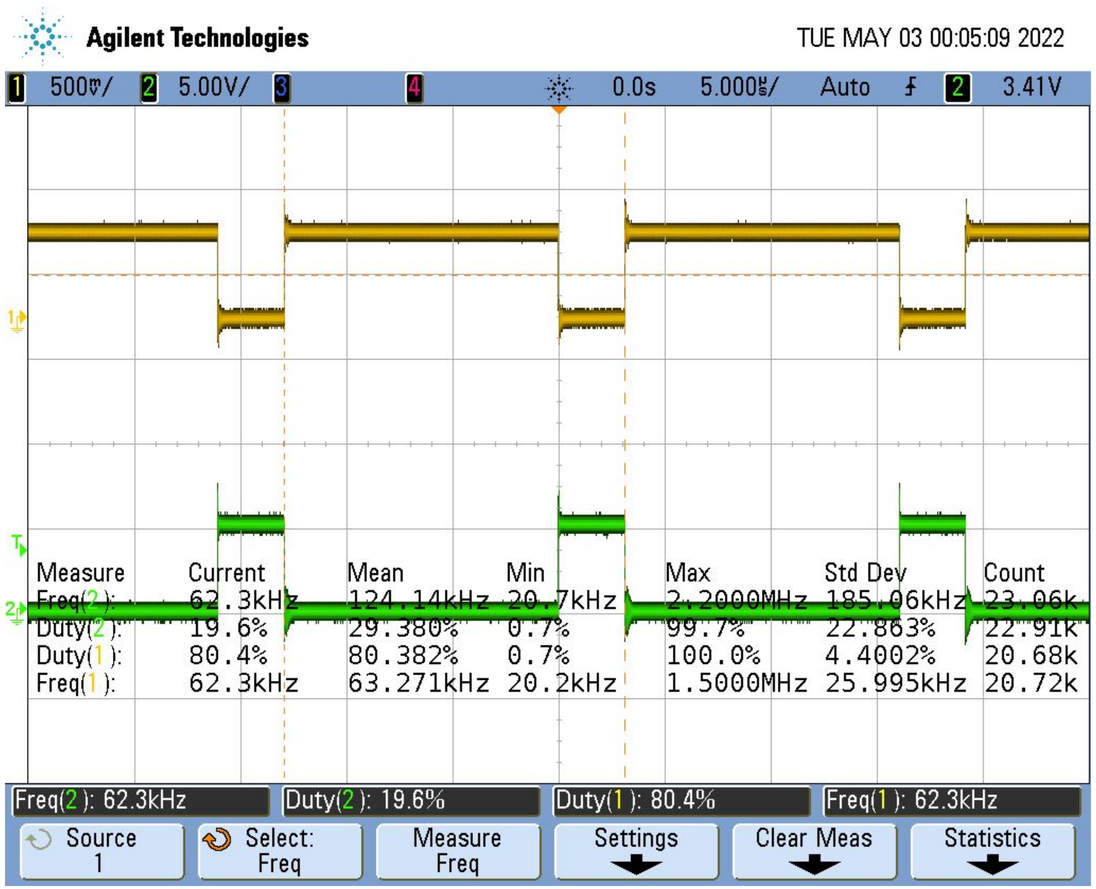
Probed output for the MCU Board



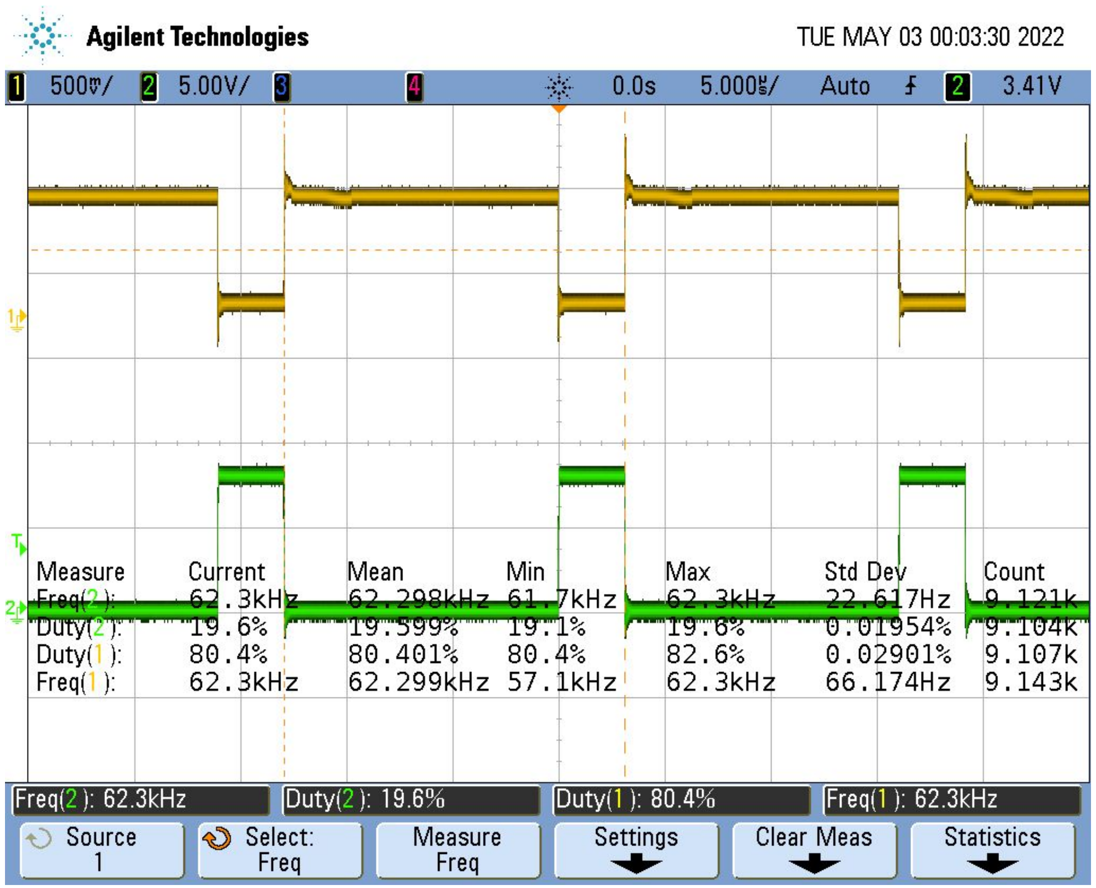
Schematic for Powering MCU

Control Signals and Feedback

PWM waveforms generated by MCU



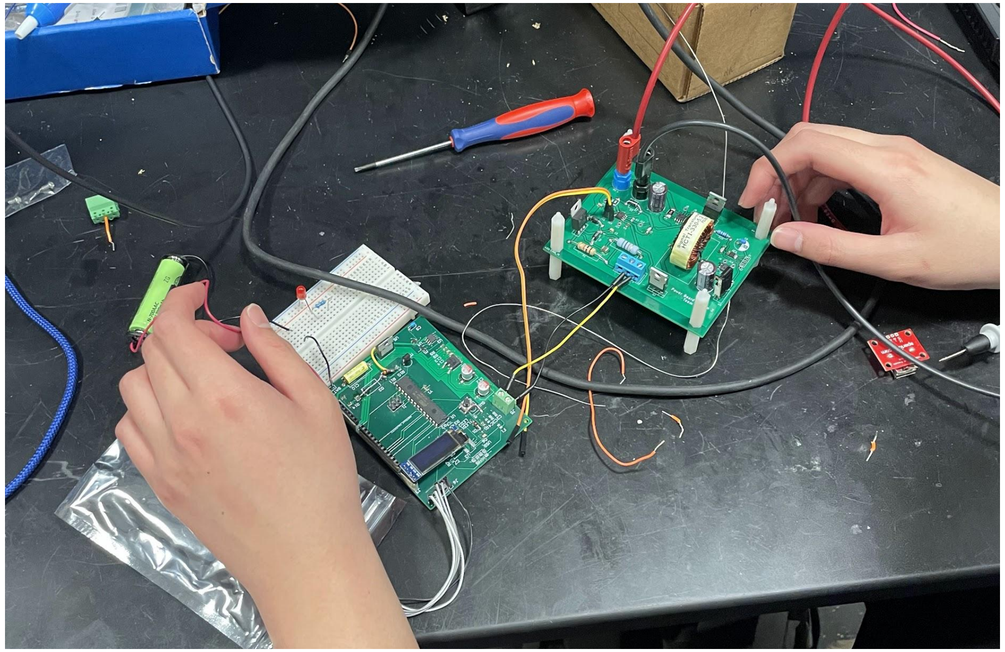
Complimentary switching duty cycles from MCU



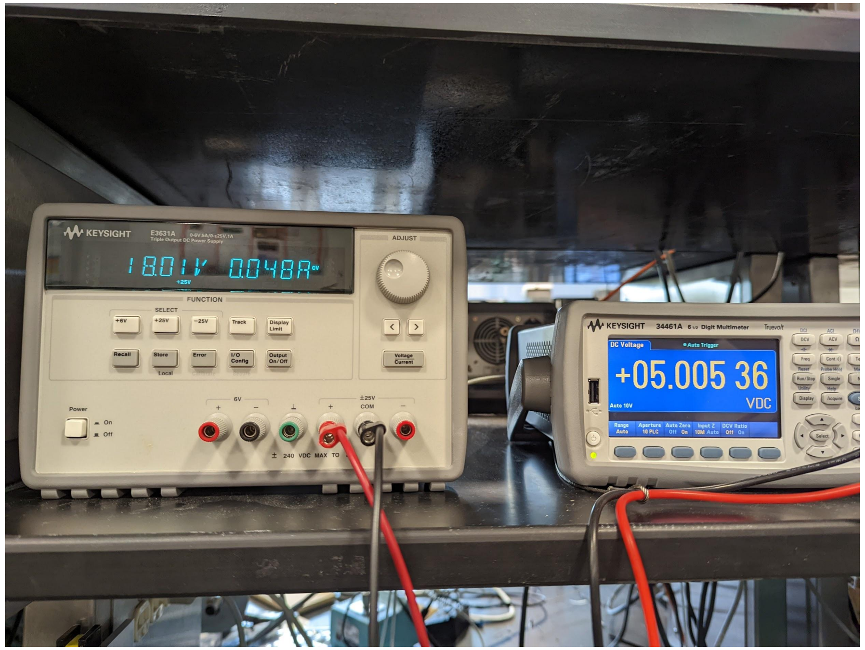
Output of the gate-drivers

Testing with Power Supply at Different Voltages

This test was done without the waveform generator to emulate a PV input. The MCU is providing the PWM signals to control the Buck-Converter.

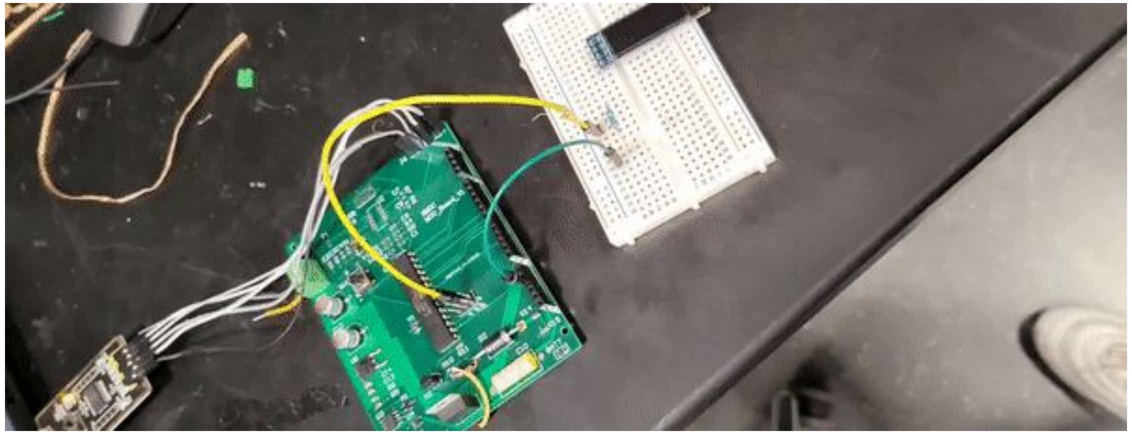


Integration of both PCBs

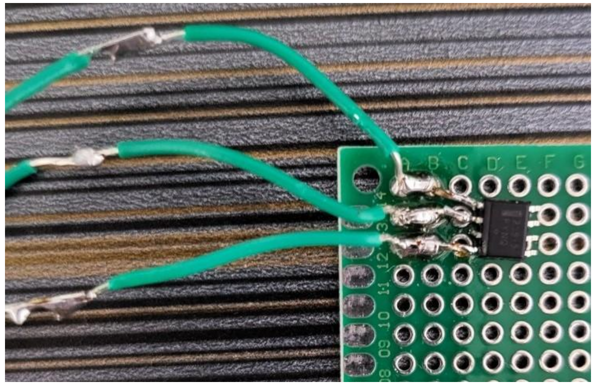


Testing USB V_{OUT} using PWM from MCU

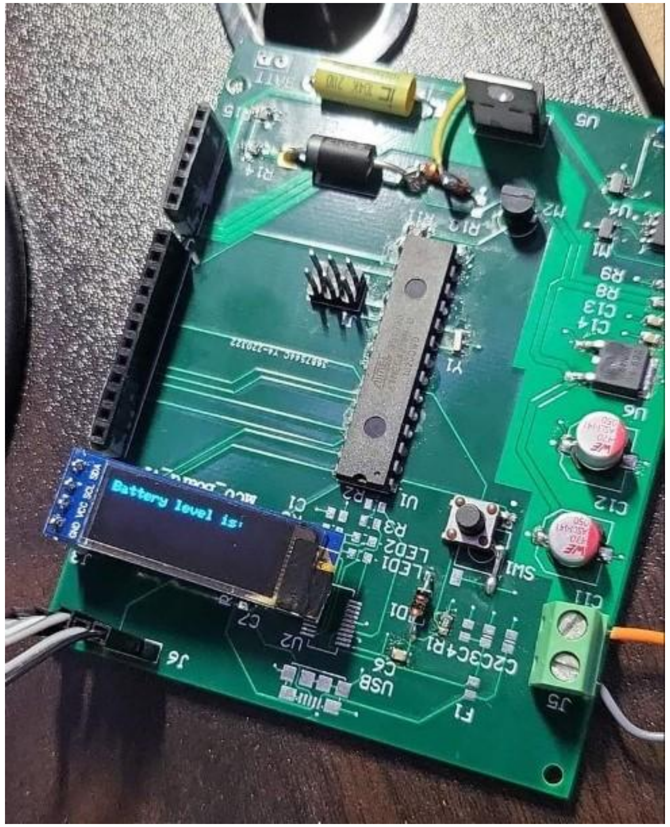
MCU Board Testing



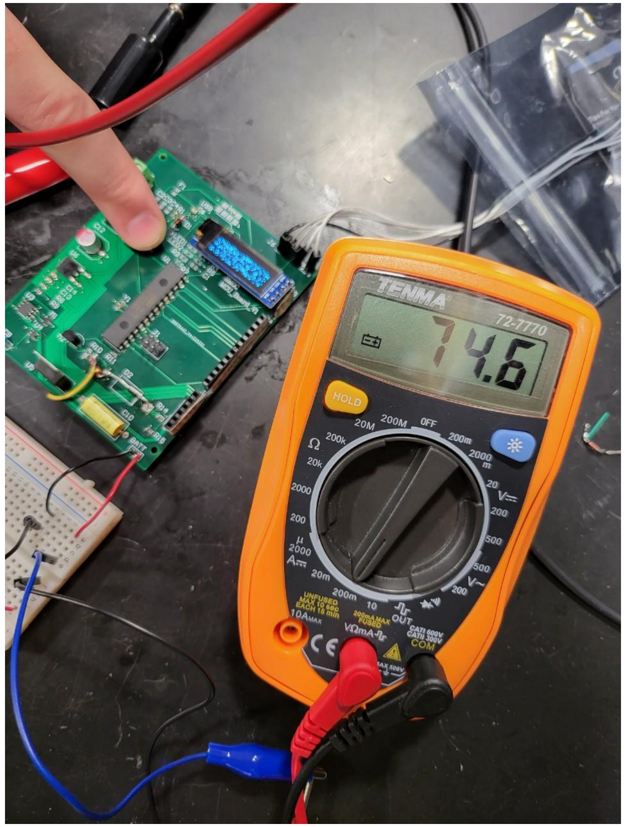
Bootloading and Programming Success of the MCU Board



MCU Board Power Logic Debugging and Testing



I2C Display Initialization



NiCd Charging Debugging

Implemented Design

Areas of Success

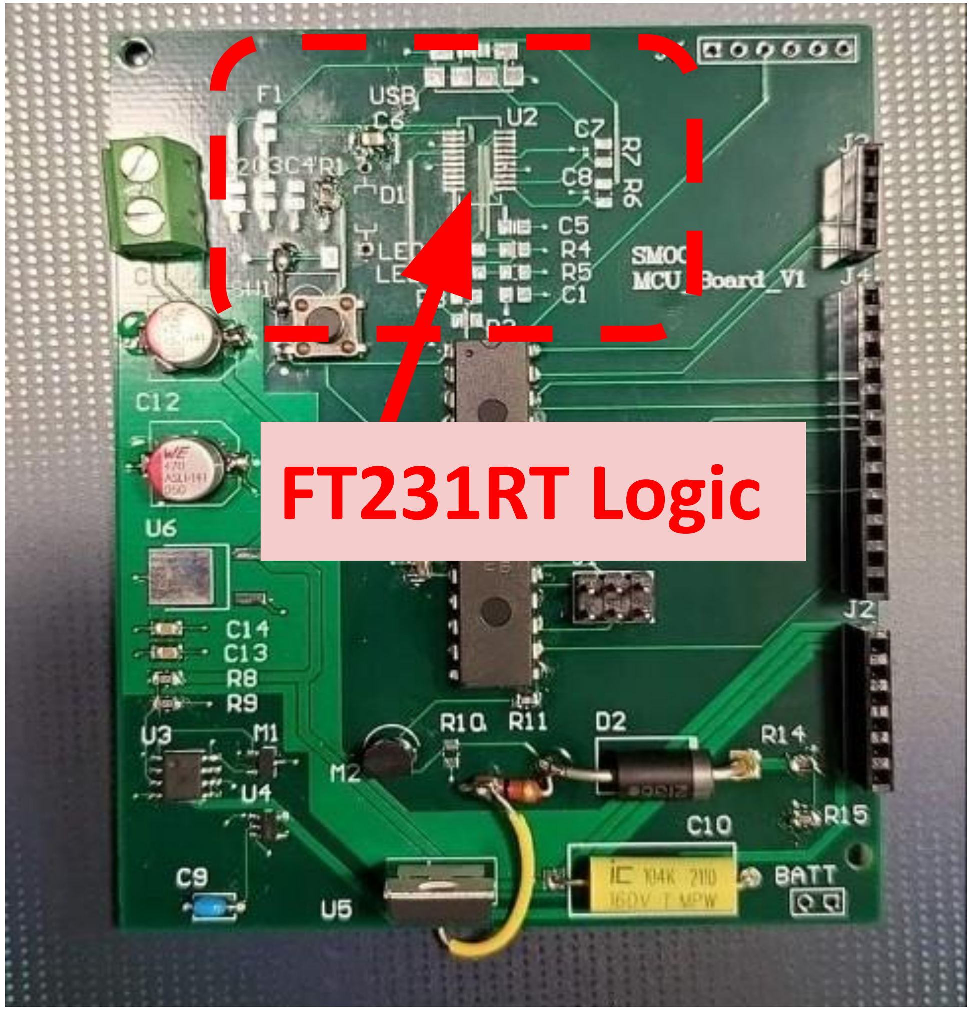
- Buck-Converter delivers 5V to a USB device
- INA240 Current Sensors to measure power
- Able to operate entirely off-grid
- USB dedicated charging port
- MCU detects voltage of NiCD batteries and provides 70mA when necessary
- LCD displays battery status and measurements for return of investment
- Functioning prototype that aggregates each subsystem into a single device

Challenges

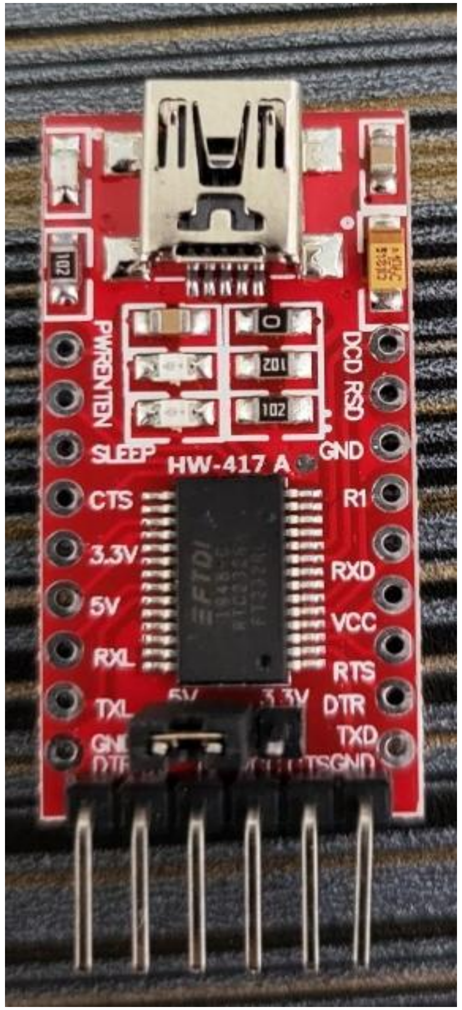
USB to UART Chip Shortage

USB Programmer Errata:

- USB to UART chips backordered
- Faulty over-the-shelf FT232 Product
- Missing convenient onboard capabilities



Onboard FT231RT USB to UART Programmer Logic

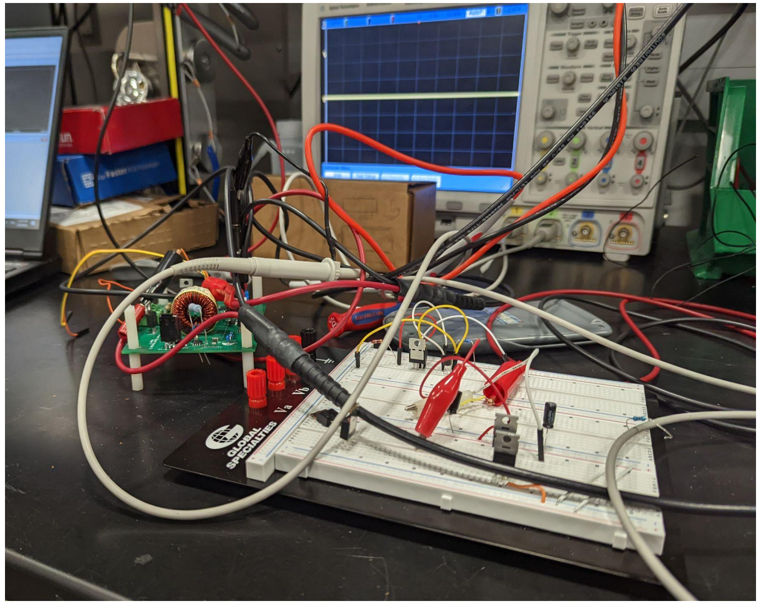


Faulty FT232 Chip

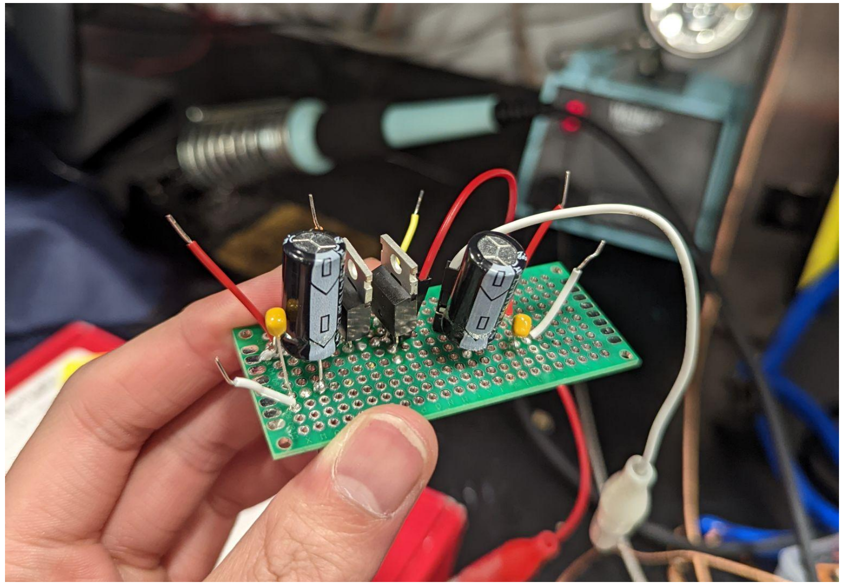
Debugging and Verification

Possible Sources of Error:

1. Discontinuous Conduction Mode vs Continuous Conduction Mode
2. EMI Loop of PCB
3. ESR and ESL of Electrolytic Capacitors and Inductor
4. Errors within the bootstrap circuit



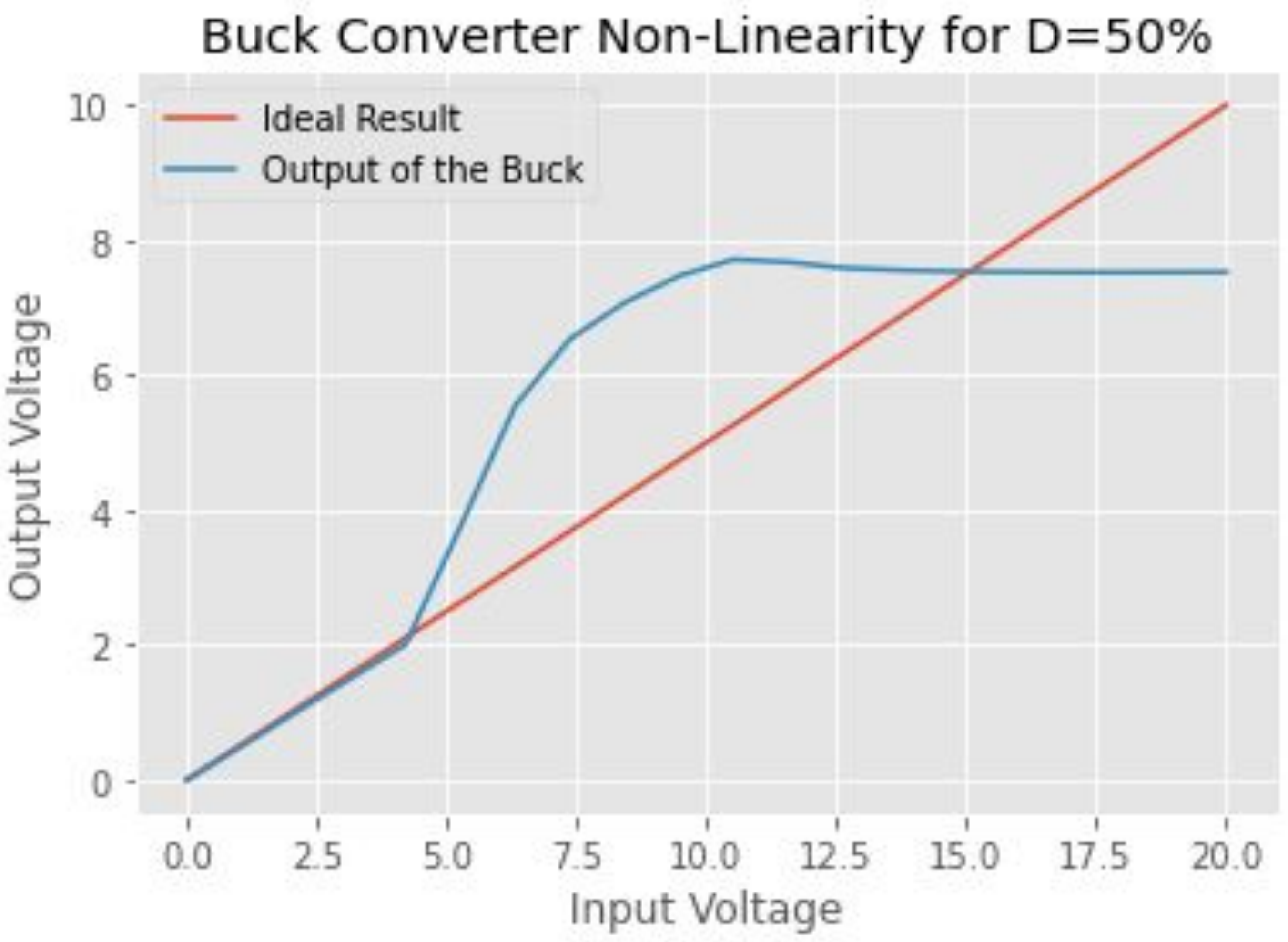
Buck converter on a breadboard



Buck converter on a perfboard

The exact cause of the buck converter not working can be attributed to these four factors

Debugging and Verification



Buck Converter Gain:

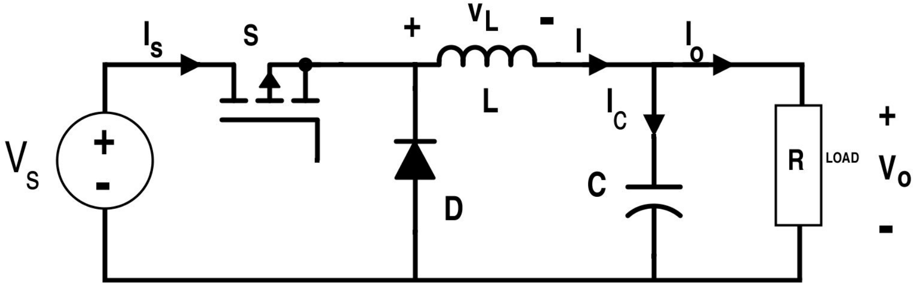
$$V_{out} = DV_{in}$$

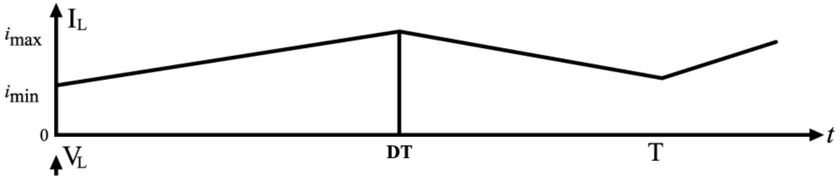
DCM vs CCM

Buck converters can operate in two main modes:

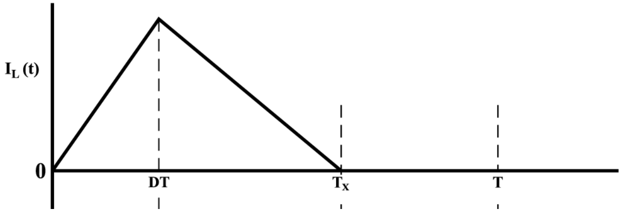
- Continuous conduction mode (CCM)
- Discontinuous conduction mode (DCM)

If our inductors are selected at a too low of a value, the energy is not completely transferred from the inductor and thus DCM is observed.





Inductor current in CCM



Inductor current in DCM

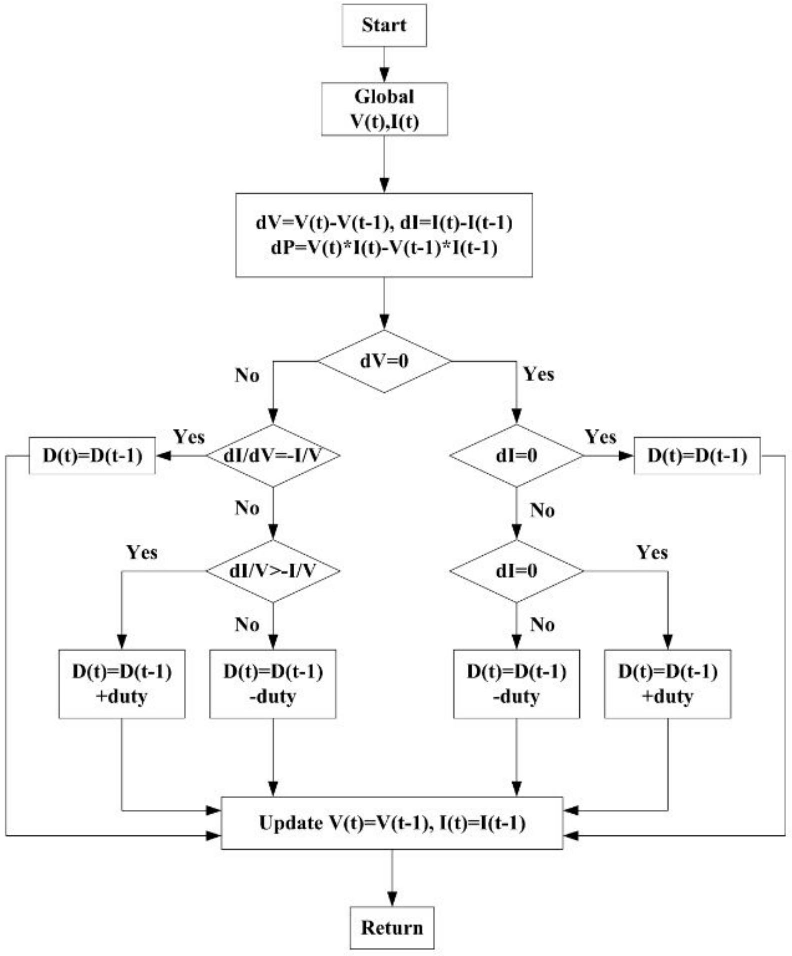
$$L_{CCM} = \frac{D(V_S - V_O)R}{2fV_O}$$

This affects the overall ripple voltage and DCM limits our current to low values.

Referenced from:
https://www.allaboutcircuits.com/technical-articles/discontinuous-conduction-mode-of-simple-converters/

Further Work and Additional Ideas

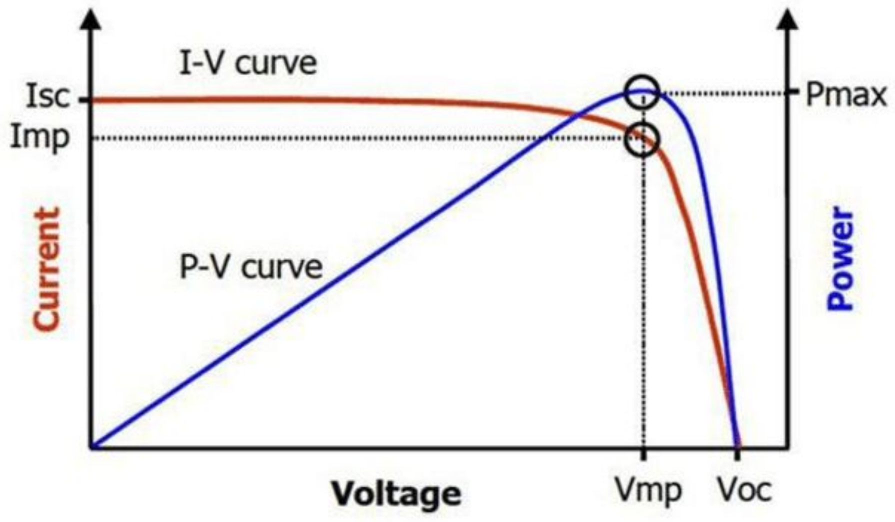
Incorporating MPPT Into Our System



Algorithm flowchart [2]

Finish Implementation of Variable Step-size Incremental Conductance Algorithm

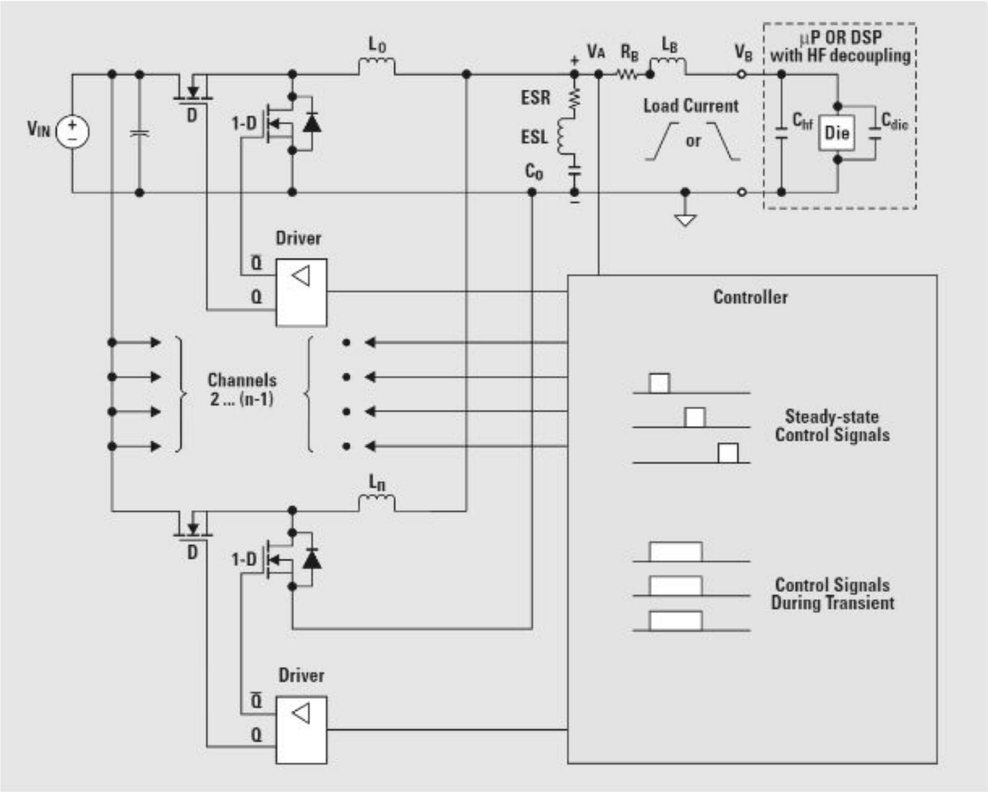
- This algorithm has high accuracy predicting the MPP.
- Calculates the derivative of power and adjusts duty cycle at each iteration.
- Variable step sizes leads to faster convergence.



Improving the DC-DC Converter Topology

- Synchronous Buck-Converter requires specific sizing to meet the voltage and current ripple tolerance.
- An interleaved Buck-Converter uses several stages to further limit the voltage and current ripple.
  - Requires more complex switching/control signals
  - Each stage is conducting in different intervals
- Tradeoff between efficiency and accuracy

*** We could not utilize this topology with our choice of the ATMEGA328. This microcontroller cannot output more than two duty cycles that share the same clock/frequency.*



Example Schematic [3]

Curtailment and Auxiliary Power

Storing the Excess MPPT Power

- Implementation of additional storage units for low demand.
- Allowing for all day stable power supply.

Control logic for supply of auxiliary power

- The additional power should be routed from auxiliary battery unit.

Current examples from industry:

- ESS - Energy Storage Systems → supplied by Huawei, Eaton, Samsung, Sungrow etc.
- Lithium Ion Batteries.

Conclusions and Learning Points

Takeaways from our Project

- The most significant aspect of our project was learning PCB design
- Unit testing of each circuit
- Integrating two PCBs into one device/system
- Identifying tolerances and design constraints
- Battery safety and ethics

Final Thoughts

- Our largest challenge was finding compatible parts and navigating manufacturing delays
- Needed more time to test with the solar panel
- Successfully met most of our R&Vs


OUTSIDE VIEW
INSIDE VIEW
CLOSE-UP
LCD
USB PORTS
BATTERY OUTPUT

Thank you for your time, if you have any questions you can reach out to us!

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The Grainger College of Engineering

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References

- [1] “World Campus alerts aim to provide assurance to students during natural disaster | Penn State University,” *www.psu.edu*. https://www.psu.edu/news/world-campus/story/world-campus-alerts-aim-provide-assurance-students-during-natural-disaster/ (accessed Apr. 29, 2022).
- [2] T. Instruments, “Mppt charge controller reference design for 12-v, 24-v and 48-v solar panels,” accessed: 2022-3-14.
- [3] H.-T. Yau, Q.-C. Liang, and C.-T. Hsieh, “Maximum power point tracking and optimal li-ion battery charging control for photovoltaic charging system,” Comput. Math. Appl., vol. 64, no. 5, pp. 822–832, 2012.