Educational Wind Powered Charger

ECE 445 / Group 23

Zixi Li

Lingxiao Mou

María Carrallo

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Purpose & Problems to Solve

1. **Green Energy Education**. Educate people about the importance of green energy and realize that the use green energy can be started from small steps.
2. **Scarce electricity in remote area**. Provide an alternative portable power source for cyclists interested in remote areas where electricity is scarce or absent. Provide charges to portable electronic devices such as GPS or phones.

Introduction

Design Objective

- Make a portable, inexpensive, easy-to-use bike-mounted wind turbine
- Efficient wind power harvest system from riding
- Provide charging capabilities to portable devices through a USB port.

Uniqueness

- No commercial alternatives.
- Ideas exists, but none of them focuses on efficiency or power storage.
- Most designs are composed a simple turbine, a diode and a USB power module.

High-Level Requirements

Portable Blade and Rotor System: The system is easily removable by the user with the use of common bike maintenance tools.

The system is able to charge a phone: The system should provide sufficient output power to a phone.

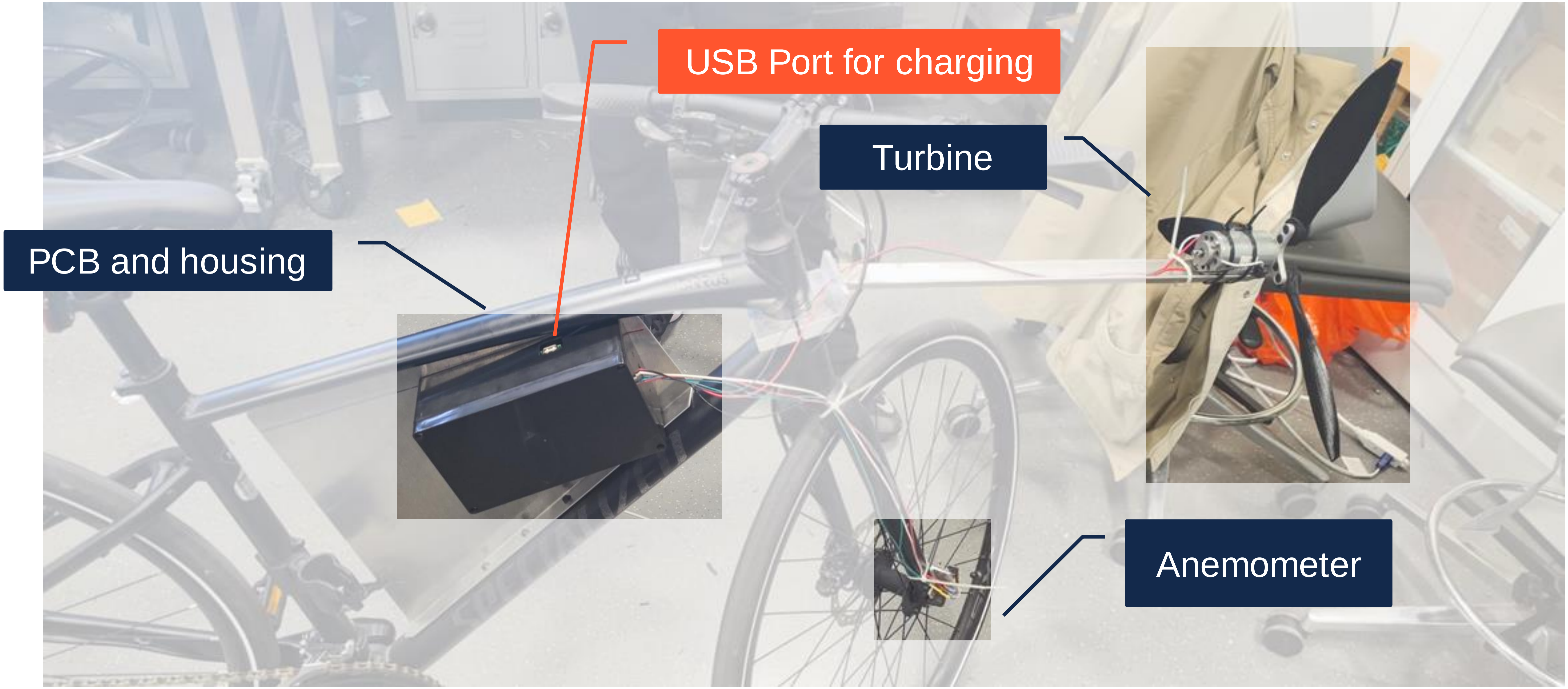
The entire system's width must not exceed 40 cm: We do not want our wind turbine to be too large in diameter, which might disturb view of riders.

Main Components

The design will consist of three main components:

1. **A wind turbine mounted at the front of the bike.** This is the main power input to the system. Power is harvested from the turbine and delivered to the PCB.
2. **An anemometer mounted on the frame of the bike.** The anemometer provides information to a microcontroller, that dictates the best operating voltage of the fan and adjust the input accordingly.
3. **PCB.** This PCB houses all the circuitry, including DC-DC converters, microcontroller and battery (shown on following slides)

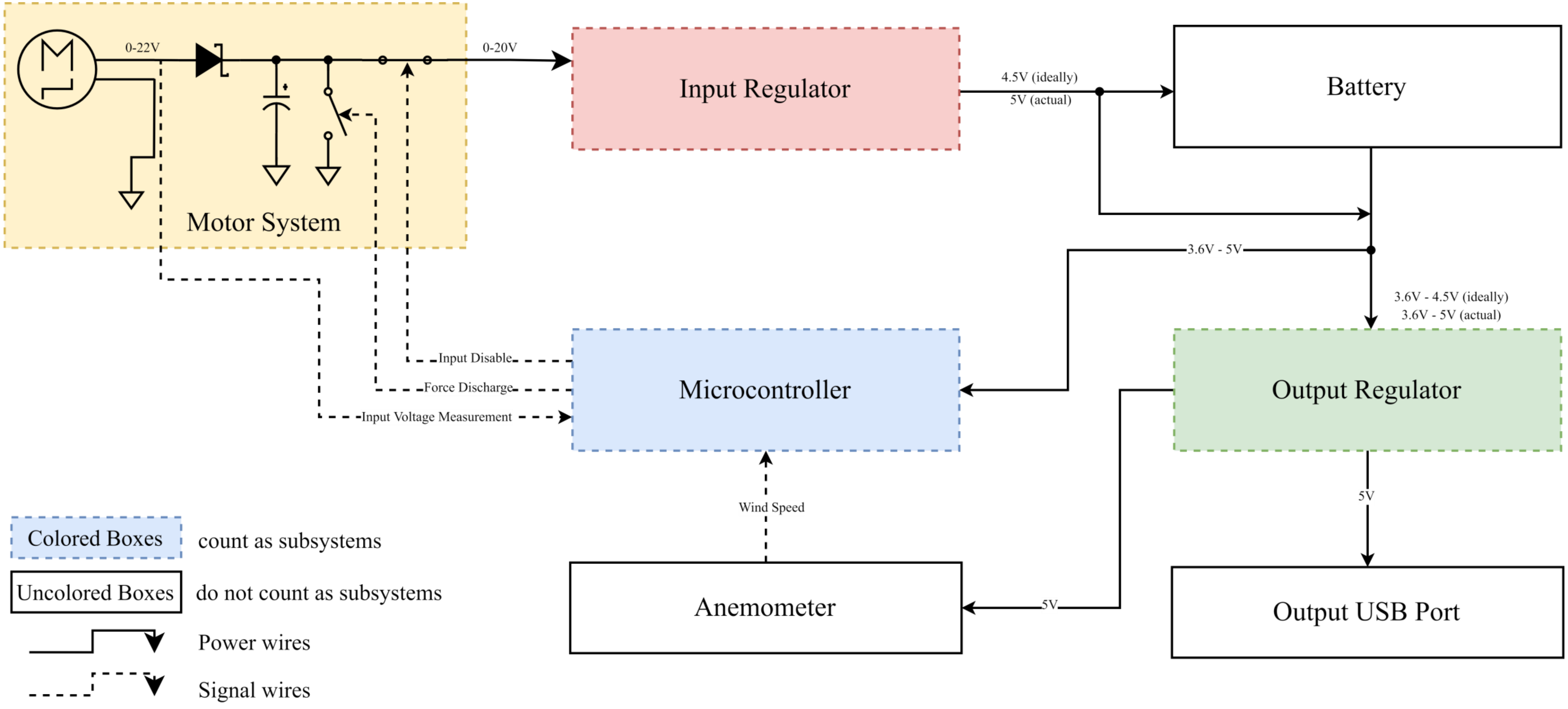
Design: Final system



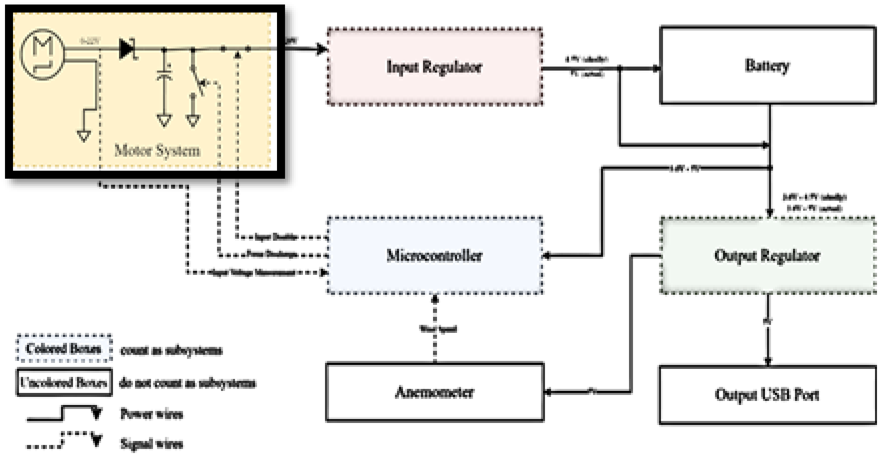
Video Demonstration

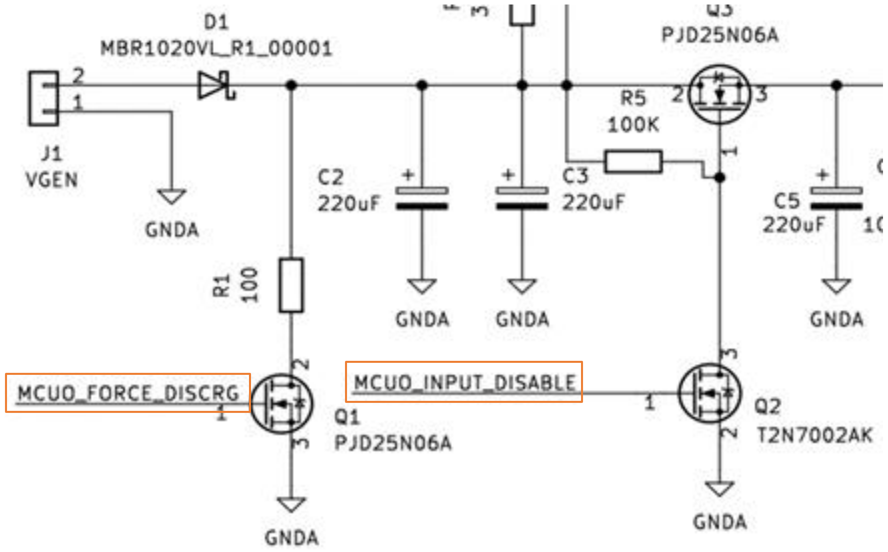
https://youtu.be/V-zmpaJNkLA

Design: Block Diagram



Design: Motor System





Motor Subsystem

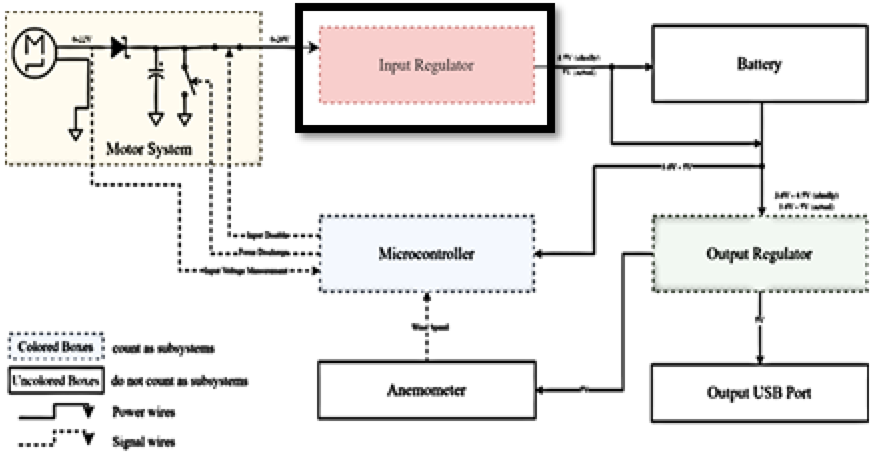
The motor subsystem takes the power input from the motor and buffers it, reducing voltage fluctuation and preventing damage to the circuit when motor is spinning in reverse.

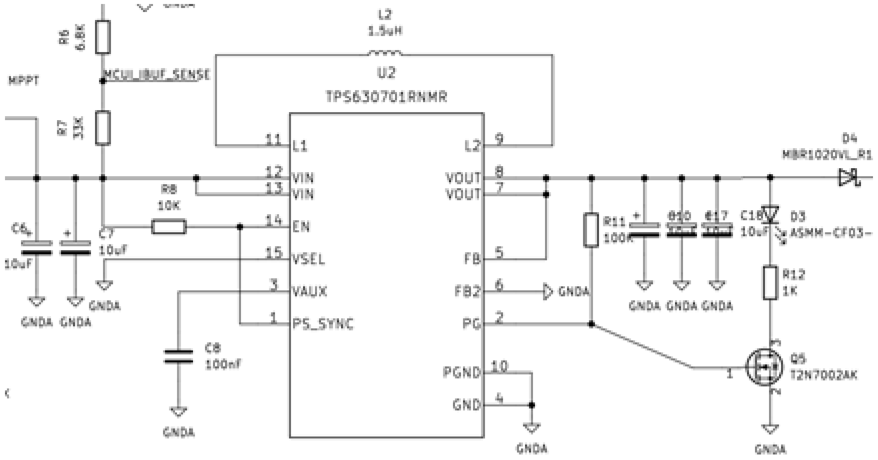
It also accepts two control signals from the MCU that could:

1. Disconnect the motor from the system so no current is drawn.
2. Forcefully draw a large current from the motor and slow it down.

I/O Description

It takes a fluctuating voltage around 0-20V from the motor, and outputs a less fluctuating 0-20V to the following stages.





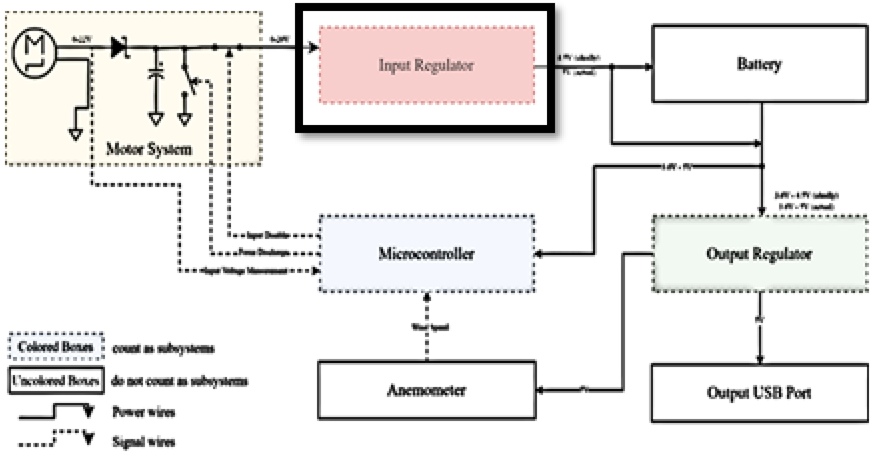
Input Regulator

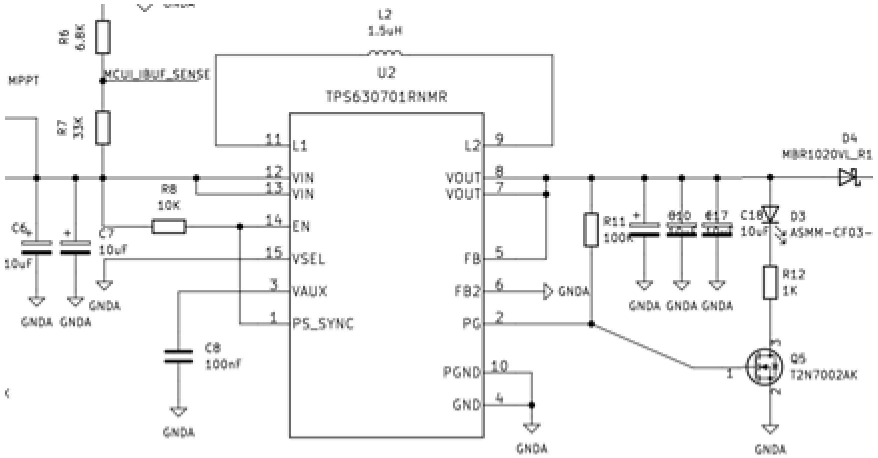
The input regulator operates when the input voltage is greater than 2V, and outputs 5V, suitable for charging the battery.

When the output is clamped to battery voltage (3.7 – 4.2V), the regulator operates like a current source.

I/O Description

The block takes an input of 0-20V and converts it into a constant 5V output.





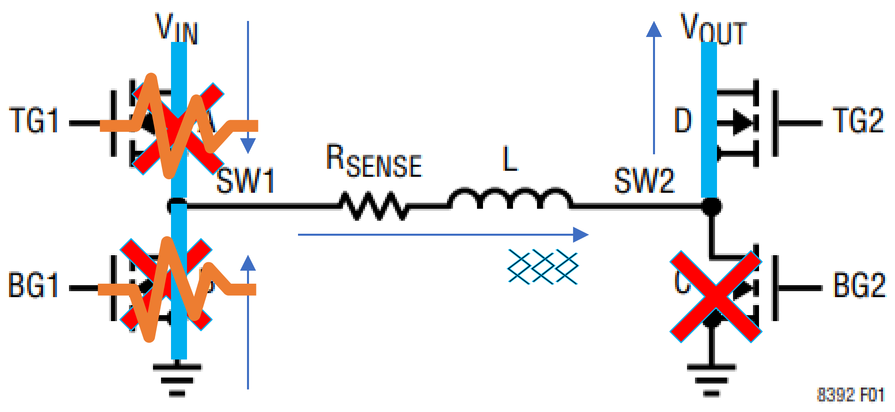
Difficulties of design

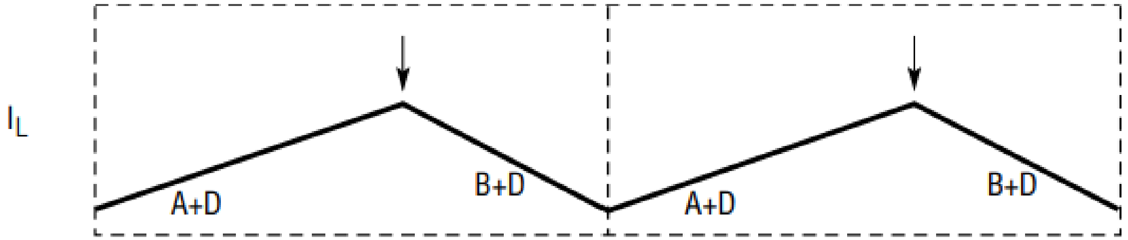
The input voltage range is wide, so the regulator hardware must be designed to perform both step-up and step-down conversions.

Efficiency is also important since the input power is not very high from the beginning.

Design Choice: Buck-Boost architecture

Technical: Buck-Boost architecture





Diagrams from LT8392 datasheet

Stepping down ($V_{IN} > V_{OUT}$)

Phase 1: A & D turned on, I_L increases

Phase 2: B & D turned on, I_L decreases

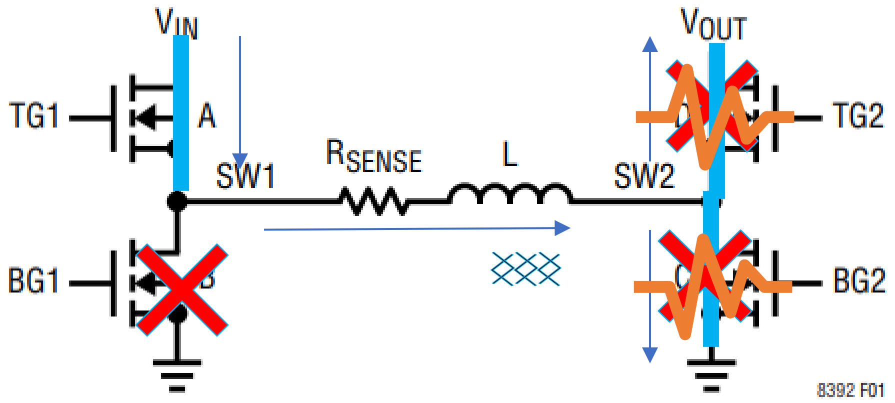
… and the cycle repeats.

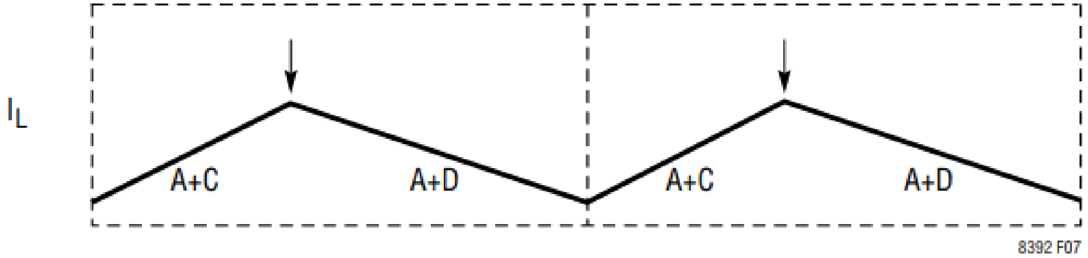
The duty cycle is controlled by comparators in the IC.

When output gets lower than $V_{OUT} - V_{ripple}$, goes into Phase 1.

When output gets higher than $V_{OUT} + V_{ripple}$, goes into Phase 2.

Technical: Buck-Boost architecture





Diagrams from LT8392 datasheet

Stepping up ($V_{IN} < V_{OUT}$)

Phase 1: A & C turned on, I_L increases

Phase 2: A & D turned on, I_L decreases

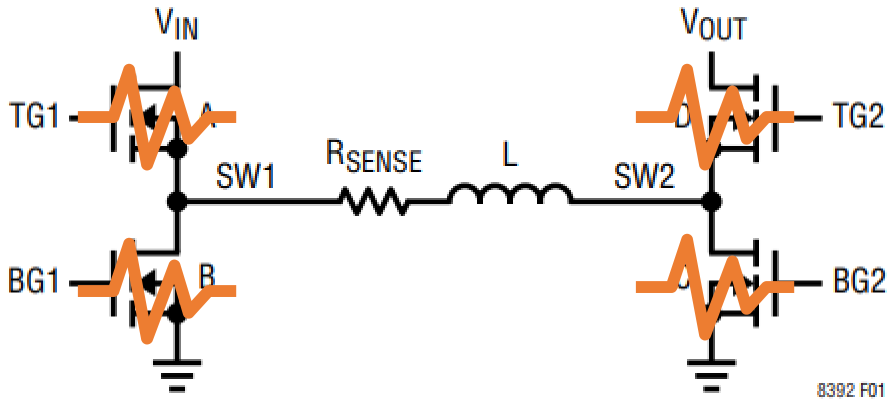
… and the cycle repeats.

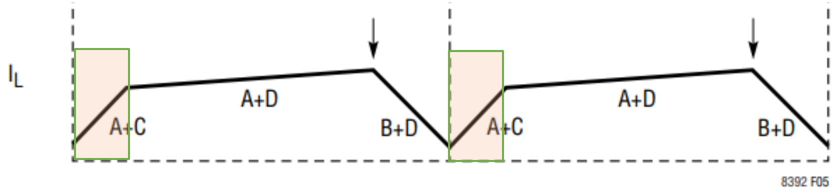
The duty cycle is controlled by comparators in the IC.

When output gets lower than $V_{OUT} - V_{ripple}$, goes into Phase 1.

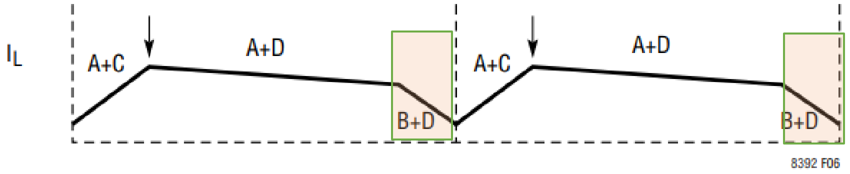
When output gets higher than $V_{OUT} + V_{ripple}$, goes into Phase 2.

Technical: Buck-Boost architecture





$V_{in} \approx> V_{OUT}$



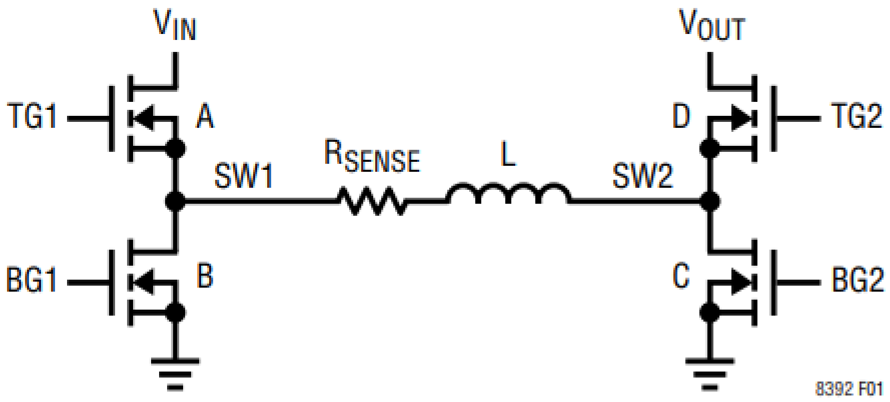
$V_{in} <\approx V_{OUT}$

Diagrams from LT8392 datasheet

Hybrid buck-boost ($V_{IN} \approx V_{OUT}$)

Depends on individual optimization, not talked about here.

Technical: Buck-Boost architecture



Advantages:

1. **Wide Input Voltage Range**. Input voltage depends on the specifications of chosen MOSFETs, and since it can either step-up or down, input voltage is less limited by output voltage.

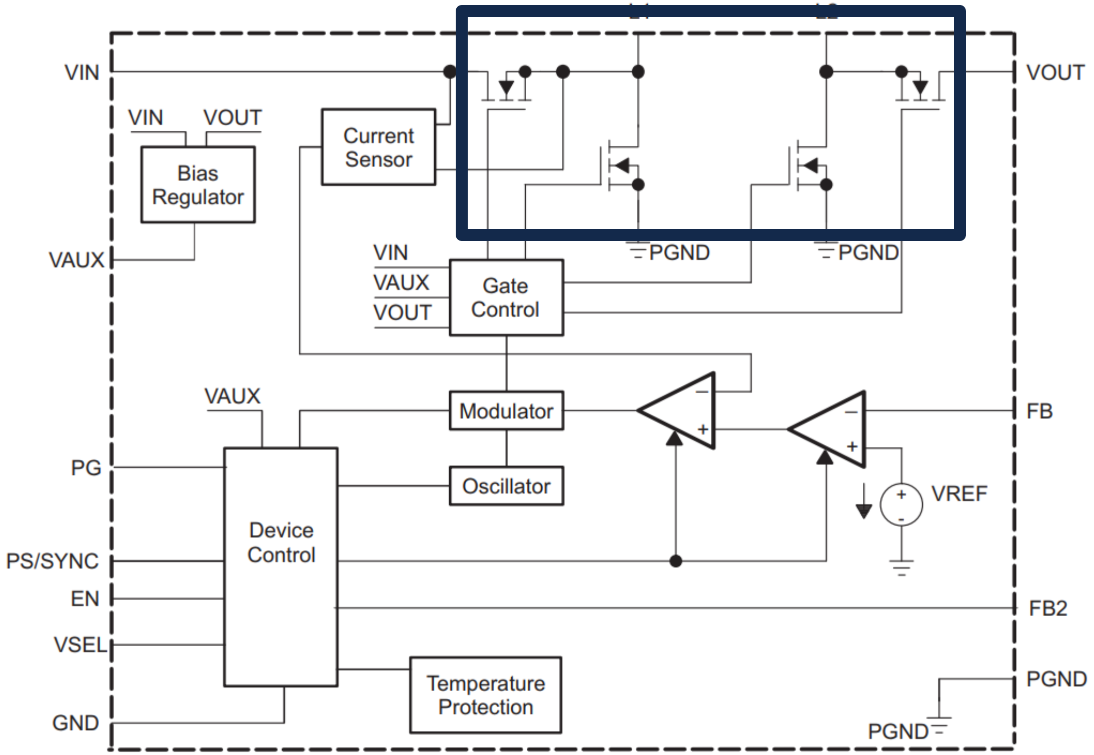
2. **Configurable quiescent current and high/low-power preference.** Quiescent current depends on switching frequency and MOSFET gate charge, linear to $f_{switch} \times (\Sigma Q_c)$. Output current depends on MOSFET I_{DS} and R_{DS}.

Disadvantages:

1. **Complicated Control Logic.** Four MOSFETs has to be driven, and the top gates (TG1 and TG2) has to be biased with the voltages at SW1 and SW2, requiring a charge pump to provide gate signals.
2. **Too much hardware.** Large amount of hardware increases cost.

Design: Input Regulator

Functional Block Diagram TPS63070



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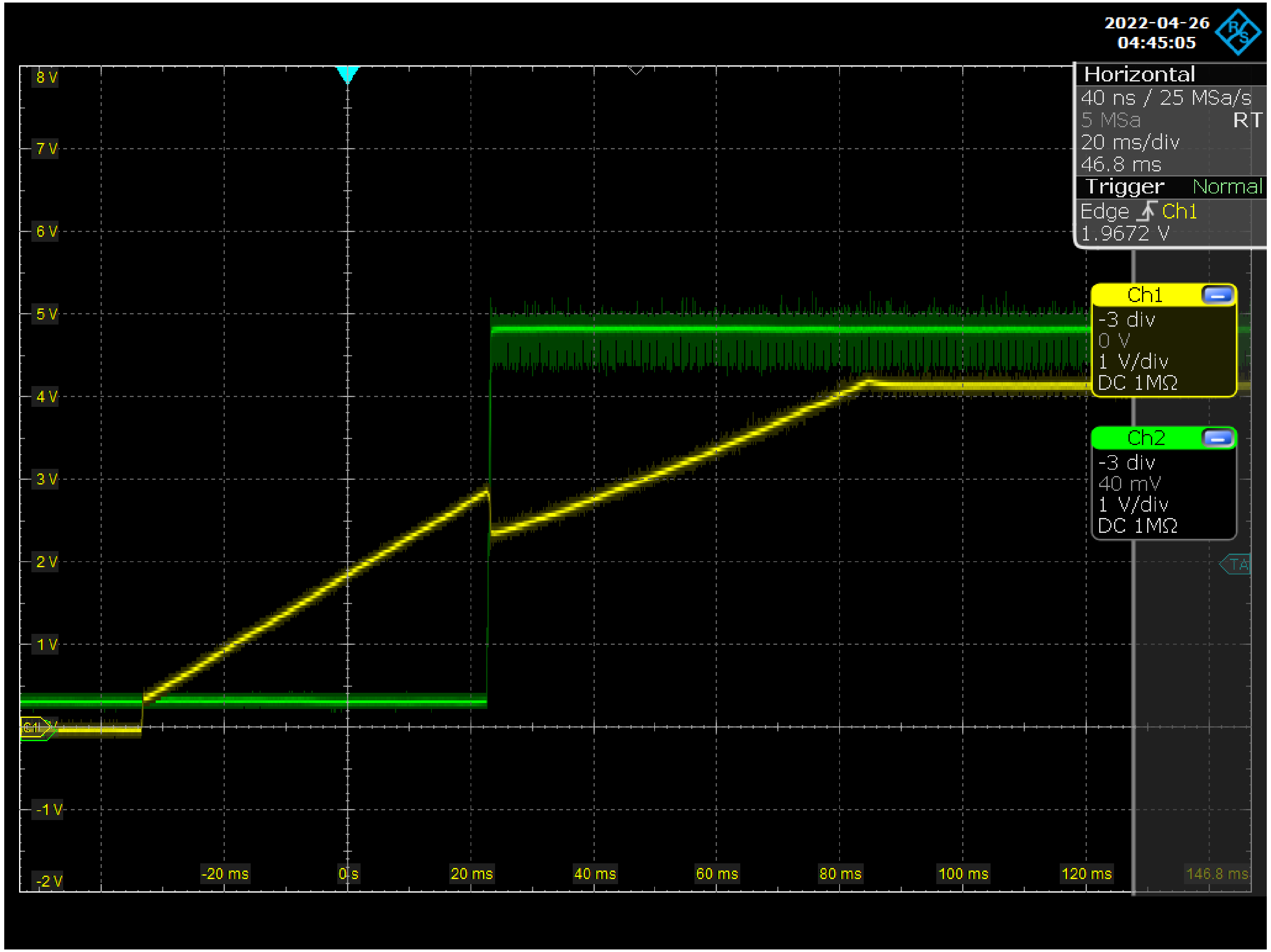
IC with integrated MOFSETs

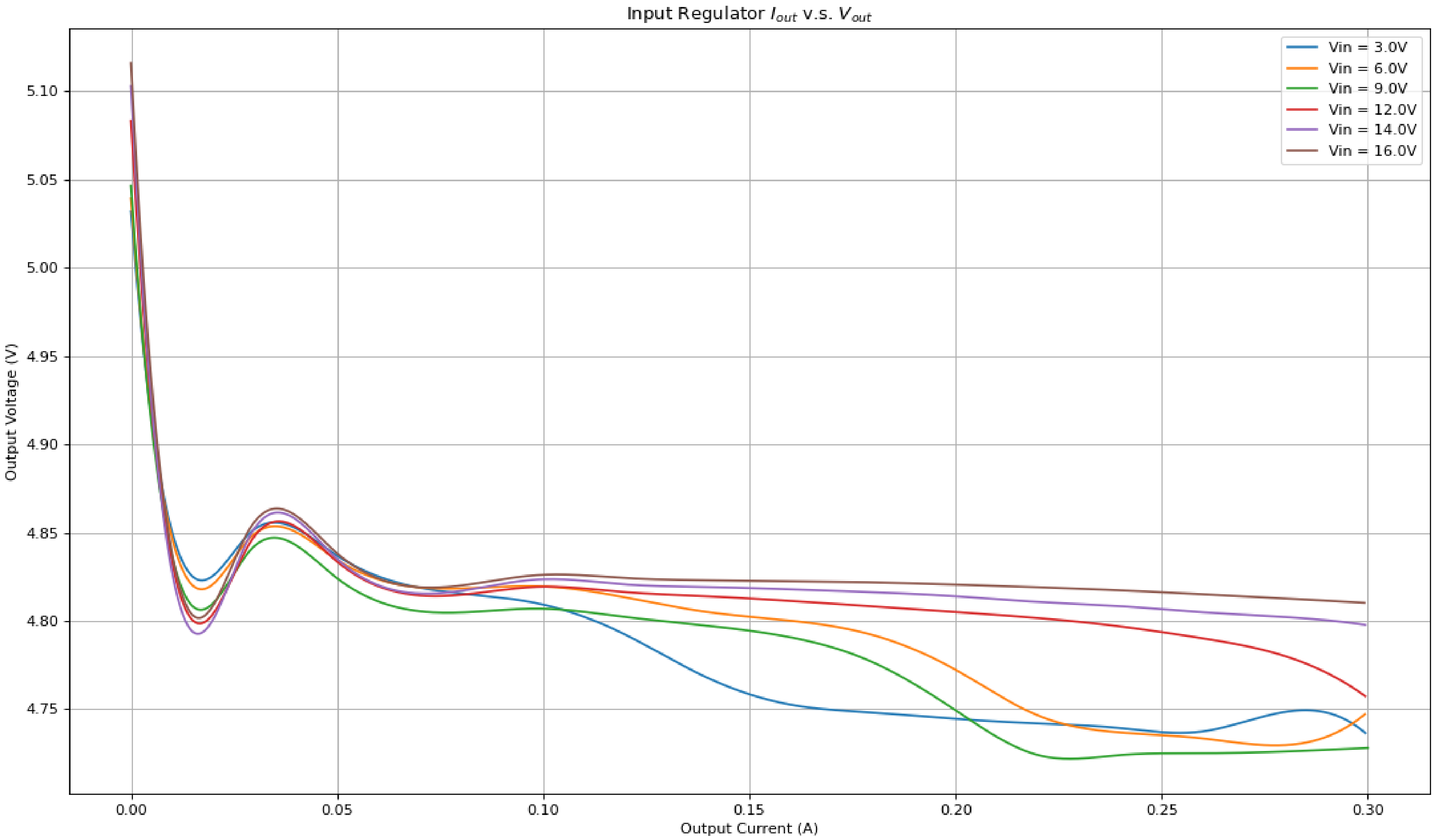
We chose an IC with integrated MOSFETs. It is designed for lower powered electronics, has a low quiescent current and requires fewer external components.

This IC is also cheap.

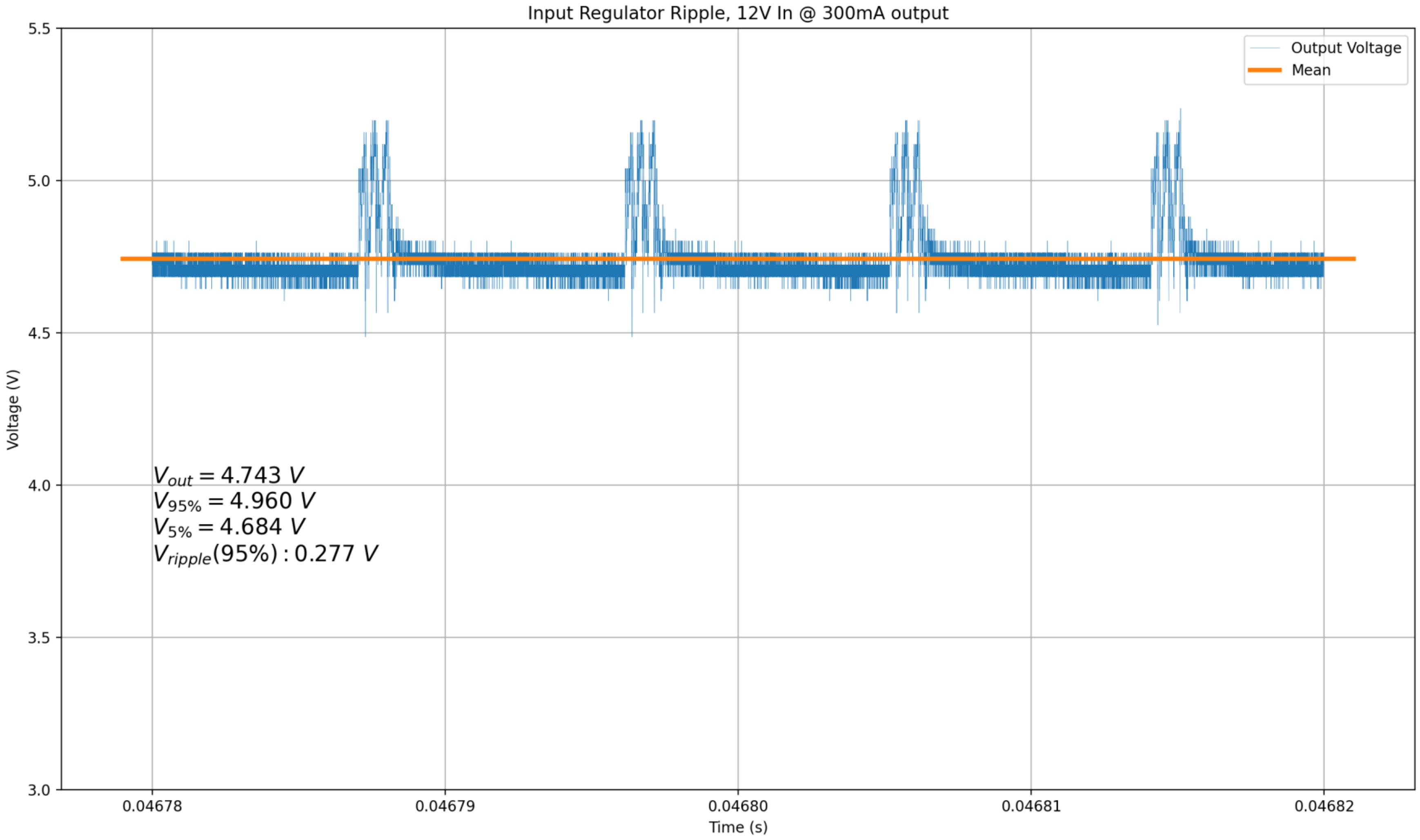
Testing: Input Regulator – Start-up performance



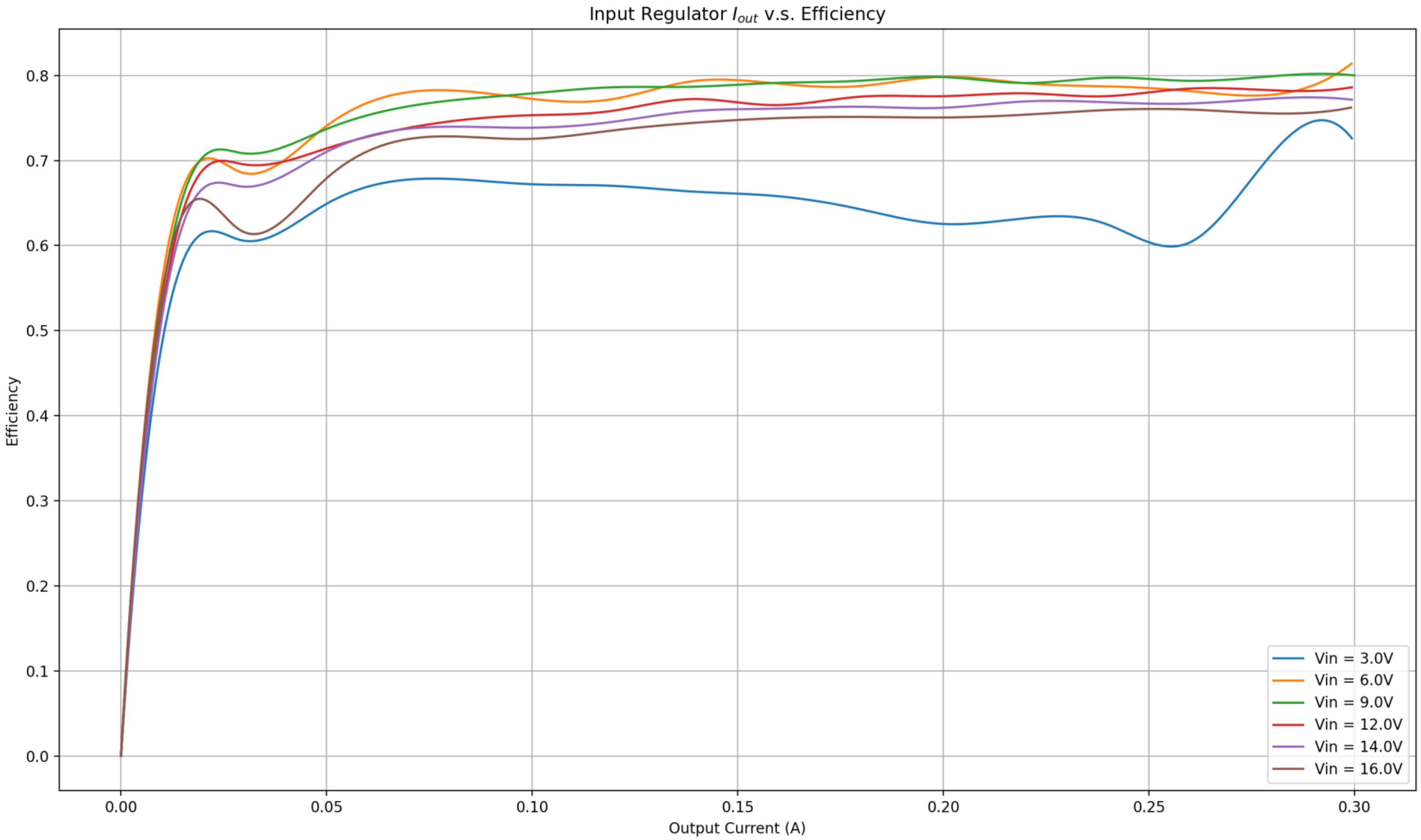
Testing: Input Regulator – Voltage Drop



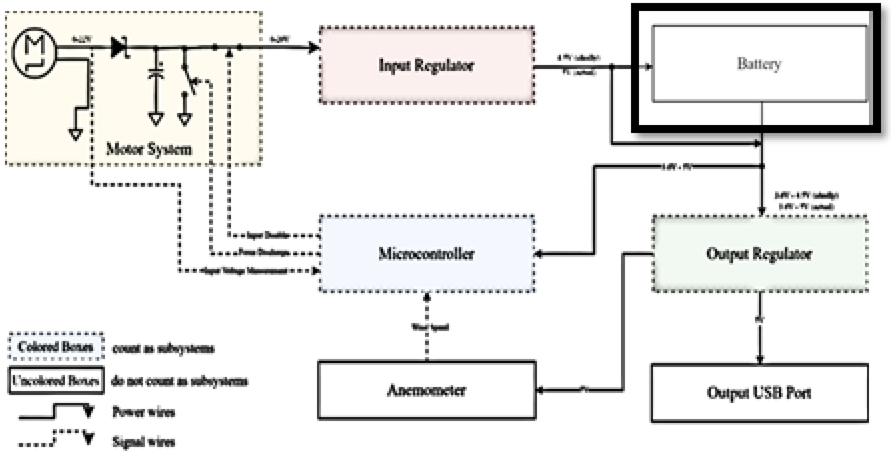
Testing: Input Regulator – Voltage Drop

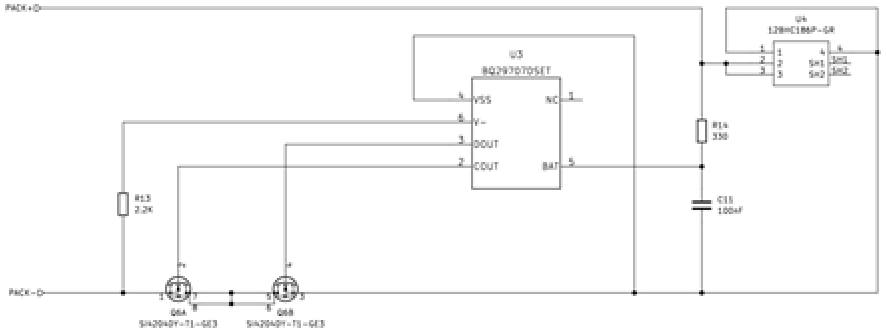


Testing: Input Regulator – Voltage Drop



Design: Battery





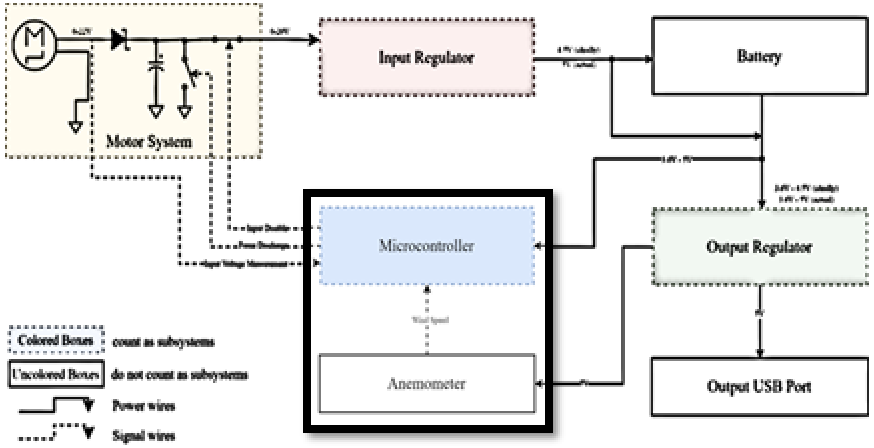
Battery

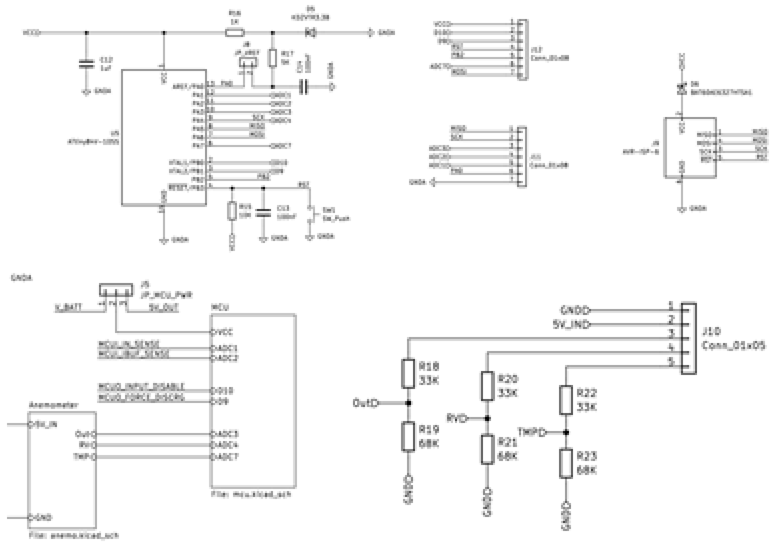
The battery acts as a pool for the MPPT algorithm.

The MPPT algorithm will produce the maximum amount of current possible at any moment, but usual appliances is not willing to take any amount of input current, therefore not suitable for being connected directly.

A raw battery can accept charging at a wide range of current, therefore essential for MPPT operation. A protection circuit is used to prevent overcharging, undercharging or overcurrent.

Design: Microcontroller Subsystem





MCU & Anemometer

The microcontroller monitors the motor output voltage and regulator input voltage, as well as taking measurements from the anemometer. It runs the MPPT algorithm.

I/O Description

Input: Anemometer signals. Input voltage sense signals.
Output: Motor System control signals.

MPPT Algorithm

Controls the motor, make it operate at the optimal spinning speed and achieve high efficiency.

Anemometer

It is a thermal anemometer based on a traditional method for measuring wind speed called “hot-wire”.

Hot-wire method

- Heat element to a constant temperature
- Measure the electrical power needed to maintain the temperature
- The wind speed is proportional to the heat used

Outputs

- Out
- RV
- TMP

Relevant data

- Zero Wind Voltage

Maximum Power Point Tracking

It is technique used with variable power sources to maximize energy extraction as conditions vary

Low speed

Disable the power usage to let the blades speed up

Adequate speed

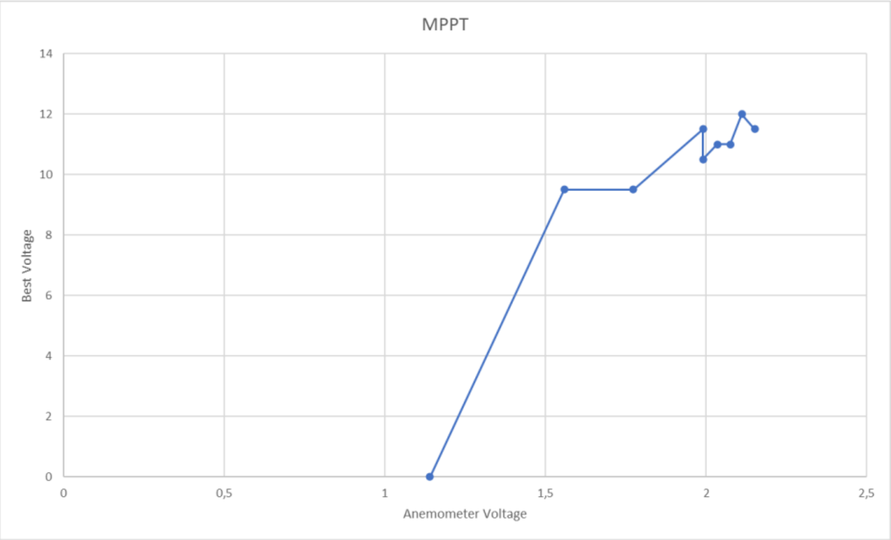
Use the MPPT to feed the system with the optimal power

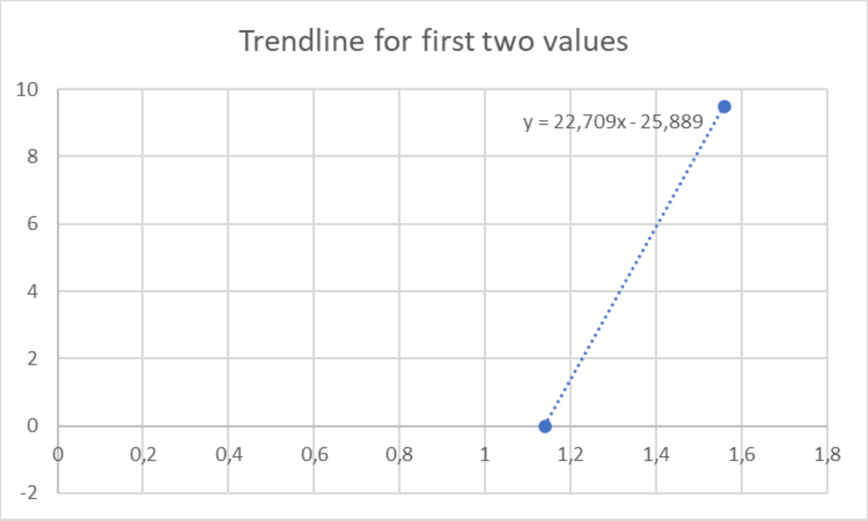
High speed

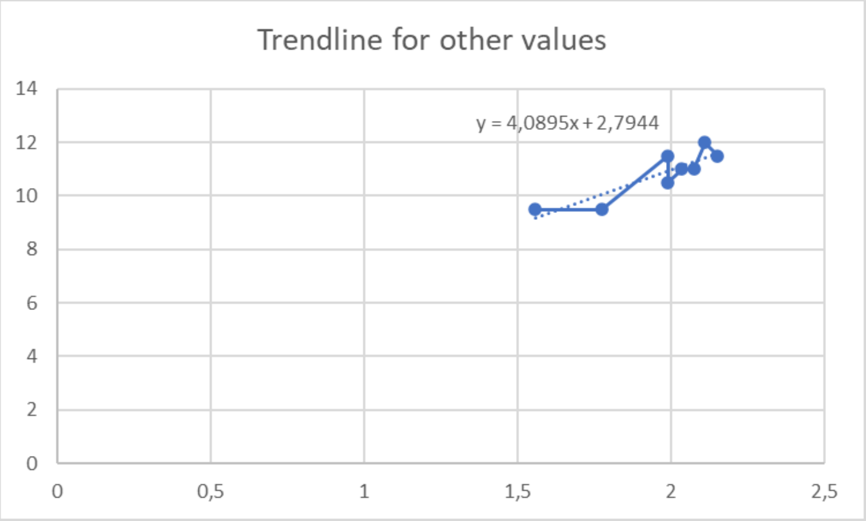
Able the discharge switch to let the system drag a lot of current to slow down the blades

MCU Logic Testing

	Anemometer		Generator			
	MPH	Voltage	Voltage (V)	Current (A)	Power (W)	Calculated power
Speed 2 5 cm			9	0,017	0,157	0,153
	10,2134	2,07534	9,5	0,018	0,175	0,171
			10	0,0182	0,189	0,182
			10,5	0,0185	0,2	0,19425
			11	0,0215	0,235	0,2365
			11,5	0,0195	0,225	0,22425
			12	0,0187	0,223	0,2244
			12,5	0,0167	0,21	0,20875
			13	0,0153	0,193	0,1989
			13,5	0,0125	0,175	0,16875
Speed 2 10 cm	7,7439	1,99023	9	0,0113	0,106	0,1017
			9,5	0,0115	0,11	0,10925
			10	0,012	0,117	0,12
			10,5	0,0102	0,108	0,1071
			11	0,0179	0,175	0,1969
			11,5	0,0144	0,177	0,1656
			12	0,0128	0,164	0,1536
			12,5	0,0119	0,144	0,14875
			13	0,0101	0,128	0,1313
			13,5	0,0087	0,114	0,11745
Speed 2 15 cm	5,8437	1,7737	9	0,0101	0,087	0,0909
			9,5	0,0095	0,087	0,09025
			10	0,0086	0,085	0,086
			10,5	0,079	0,081	0,8295
			11	0,0067	0,079	0,0737
			11,5	0,0057	0,064	0,06555
			12	0,0039	0,045	0,0468
			12,5	0,0028	0,03	0,035
			13	0,001	0,013	0,013
			13,5	0	0	0
Speed 2 20 cm	3,92417	1,55833	9	0,0124	0,105	0,1116
			9,5	0,0113	0,108	0,10735
			10	0,011	0,105	0,11
			10,5	0,0098	0,102	0,1029
			11	0,085	0,096	0,935
			11,5	0,0063	0,078	0,07245
			12	0,0049	0,068	0,0588
			12,5	0,0044	0,053	0,055
			13	0,0031	0,039	0,0403
			13,5	0,0012	0,014	0,0162
Speed 3 5 cm	10,835	2,11083	9	0,0374	0,332	0,3366
			9,5	0,0371	0,364	0,35245
			10	0,0361	0,363	0,361
			10,5	0,0376	0,399	0,3948
			11	0,0343	0,373	0,3773
			11,5	0,0331	0,378	0,38065
			12	0,0317	0,389	0,3804
			12,5	0,0302	0,378	0,3775
			13	0,0284	0,368	0,3692
			13,5	0,0277	0,372	0,37395
Speed 3 10 cm	11,429	2,151	9	0,0371	0,33	0,3339
			9,5	0,0355	0,338	0,33725
			10	0,0379	0,371	0,379
			10,5	0,0374	0,397	0,3927
			11	0,0336	0,37	0,3696
			11,5	0,0339	0,387	0,38985
			12	0,0307	0,377	0,3684
			12,5	0,0303	0,371	0,37875
			13	0,0266	0,357	0,3458
			13,5	0,025	0,339	0,3375
Speed 3 15 cm	7,485	1,99083	9	0,0385	0,353	0,3465
			9,5	0,0387	0,375	0,36765
			10	0,0374	0,375	0,374
			10,5	0,0373	0,392	0,39165
			11	0,0329	0,363	0,3619
			11,5	0,0299	0,34	0,34385
			12	0,0276	0,337	0,3312
			12,5	0,027	0,342	0,3375
			13	0,0248	0,338	0,3224
			13,5	0,0225	0,315	0,30375
Speed 3 20 cm	10,8808	2,035	9	0,0354	0,303	0,3186
			9,5	0,0339	0,326	0,32205
			10	0,0335	0,33	0,335
			10,5	0,0329	0,345	0,34545
			11	0,0332	0,372	0,3652
			11,5	0,0309	0,355	0,35535
			12	0,029	0,347	0,348
			12,5	0,0283	0,351	0,35375
			13	0,0259	0,336	0,3367
			13,5	0,0242	0,32	0,3267

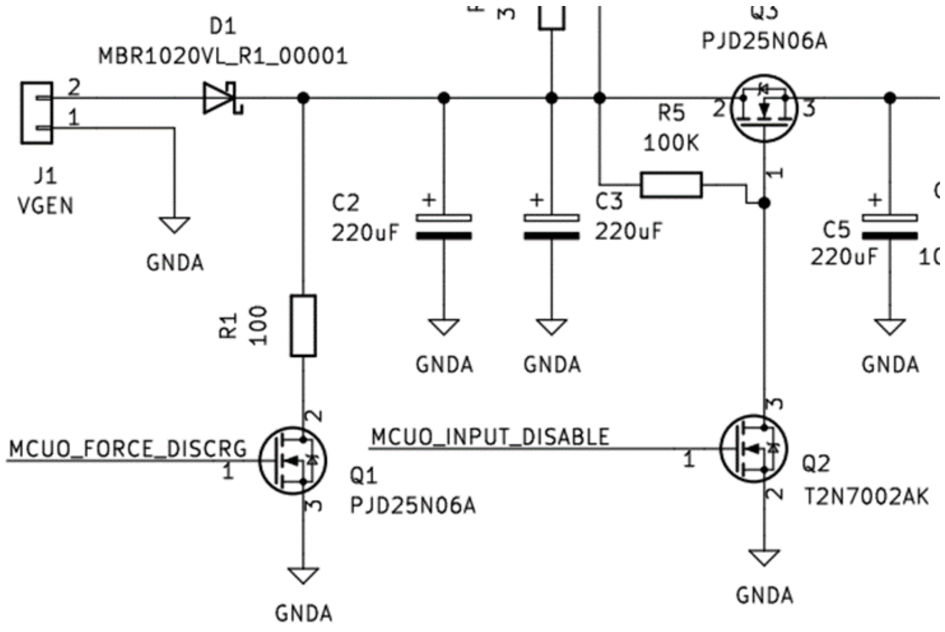




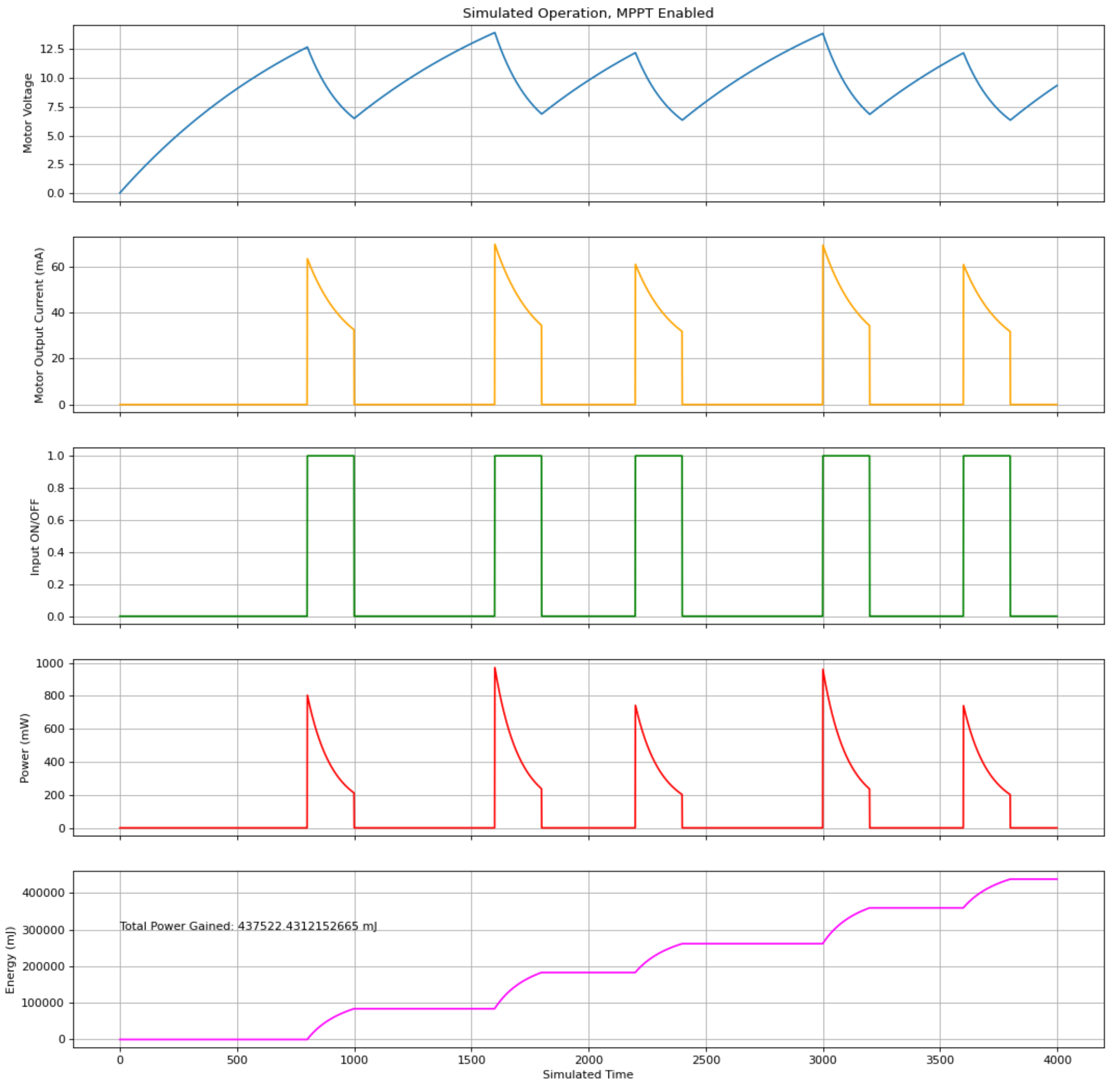


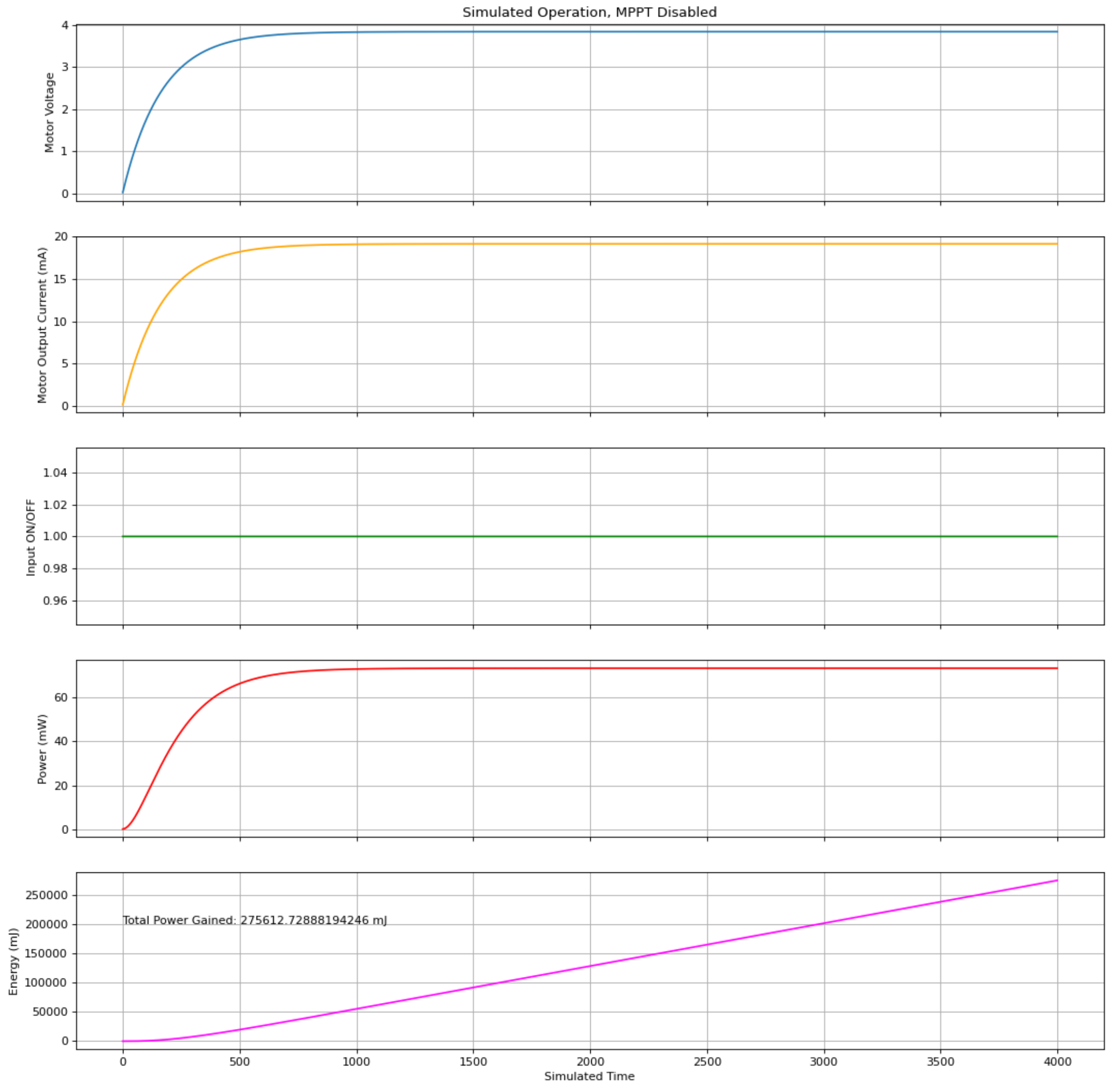
Technical Details: MPPT

```
    // MCU Logic
    if (orig_volt >= 18)
    {
        digitalWrite(MCUO_FORCE_DISCRG, HIGH);
        digitalWrite(MCU_IN_DISABLE_PIN, LOW);
#ifdef DEBUG
        mySerial.println("C-1");
#endif
    }
    else
    {
        if (orig_IBUF_volt > orig_volt)
        {
#ifdef DEBUG
            mySerial.println("C-2");
#endif
            digitalWrite(MCUO_FORCE_DISCRG, LOW);
            digitalWrite(MCU_IN_DISABLE_PIN, LOW);
        }
        else
        {
            if (orig_volt > best_voltage)
            {
#ifdef DEBUG
                mySerial.println("C-3");
#endif
                digitalWrite(MCUO_FORCE_DISCRG, LOW);
                digitalWrite(MCU_IN_DISABLE_PIN, LOW);
            }
            else
            {
#ifdef DEBUG
                mySerial.println("C-4");
#endif
                digitalWrite(MCUO_FORCE_DISCRG, LOW);
                digitalWrite(MCU_IN_DISABLE_PIN, HIGH);
            }
        }
    }
```



Technical Details: MPPT – Simulations





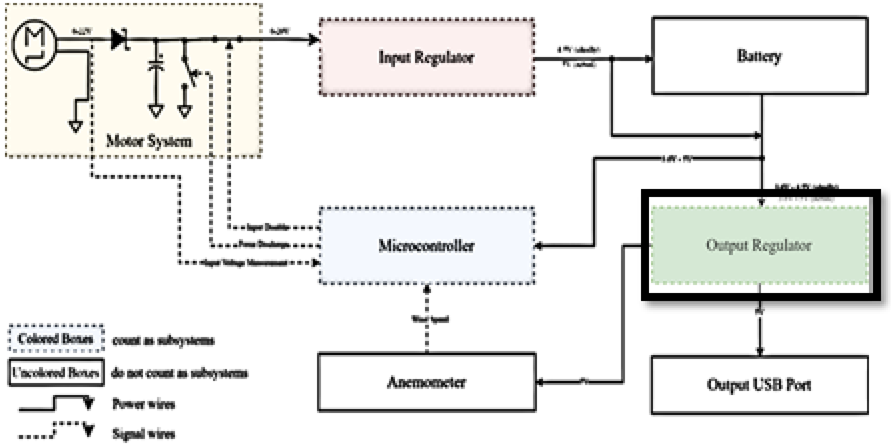
Power consumption

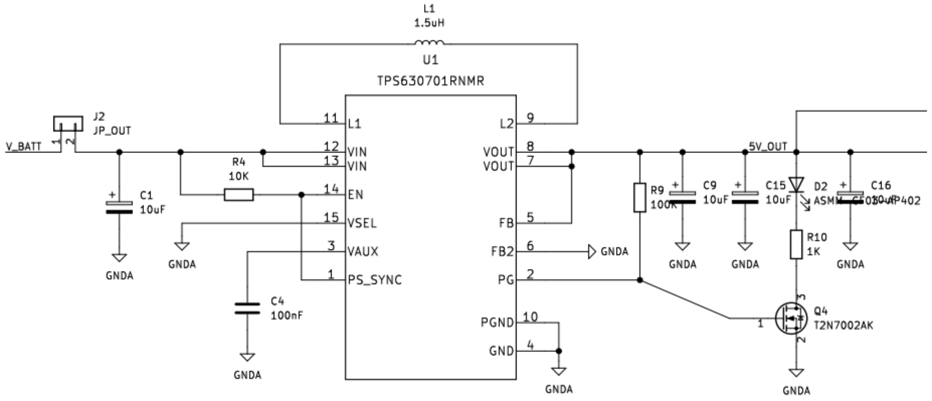
Expected input power: 10 Watts

Real input power: 1 Watt

- Solution 1: Eliminate the anemometer and use a constant value of best_voltage of 12 V
- Find an anemometer that consumes less power, such as spinning-speed based anemometer or pitot tubes.
- Find a generator that provides a higher input power

Output Regulator Subsystem





Output Regulator

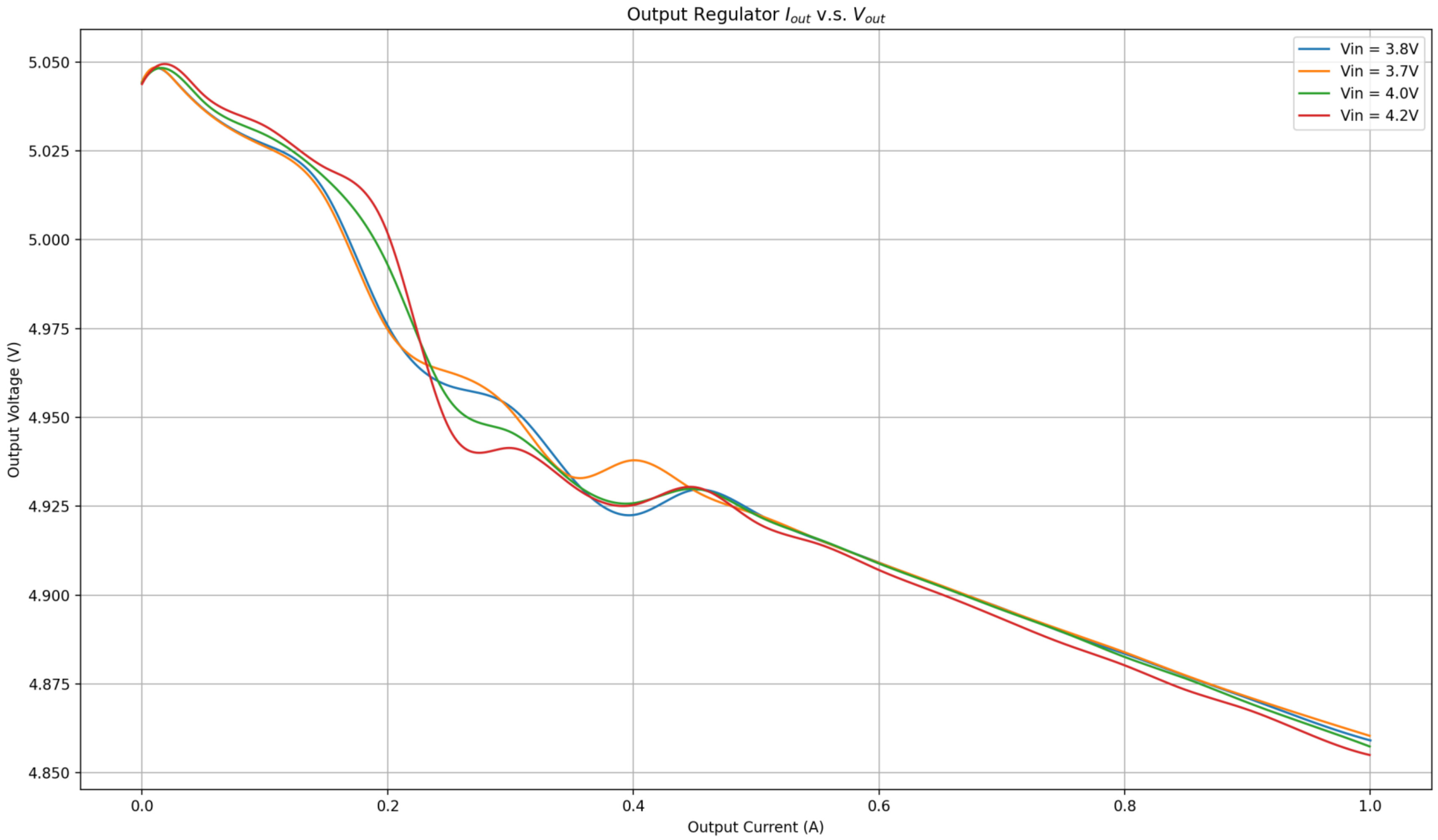
The output regulator takes an input voltage from either the battery or the input regulator and converts it to 5V for the USB port. The output voltage must meet USB specification, between 4.75 – 5.25V

Used the same IC as the input regulator to save design effort.

I/O Description

Input: 3.7-5.0V (In most cases 3.7 – 4.2V)
Output: 5V (tolerance: 5%)

Testing: Output Regulator – Voltage Drop



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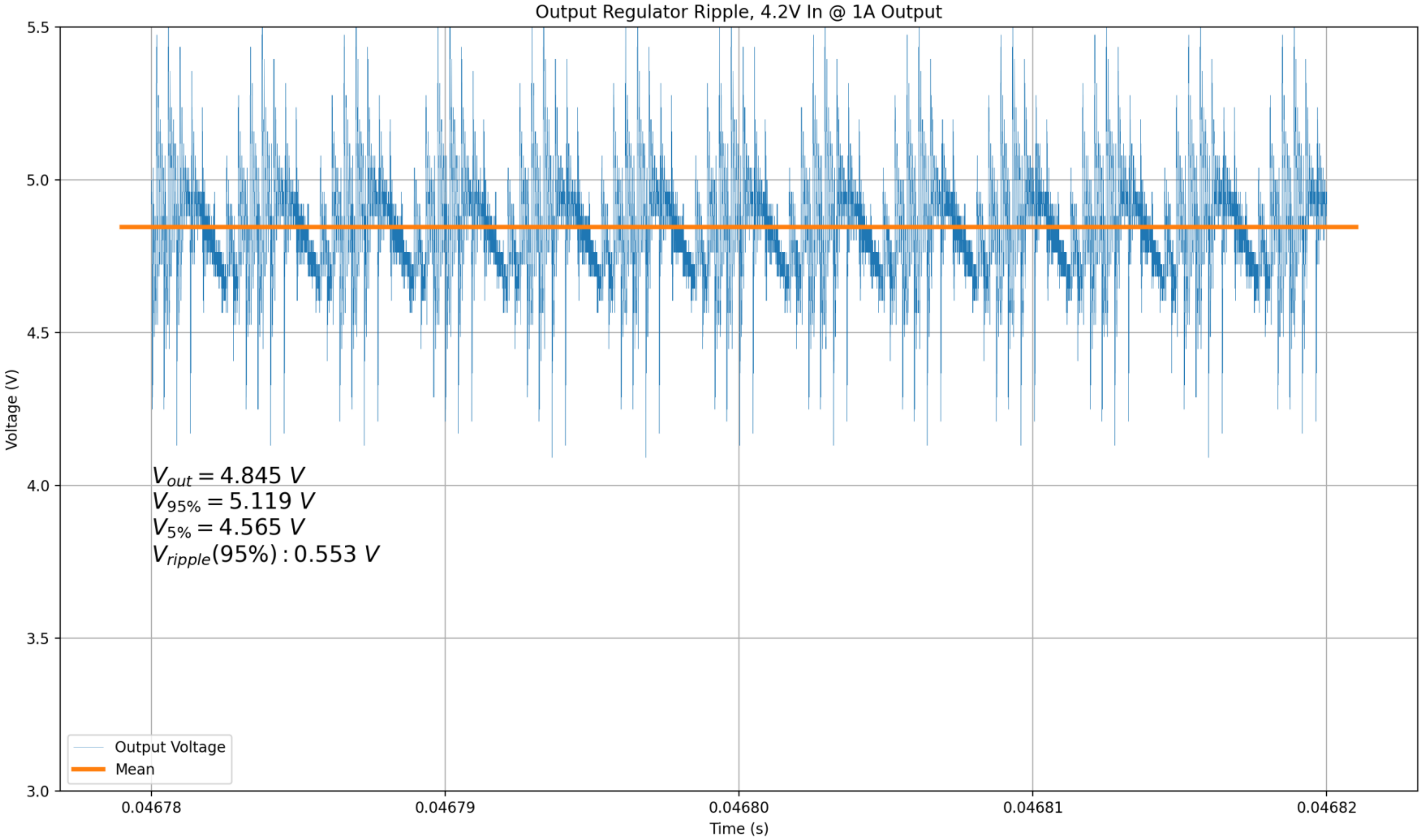

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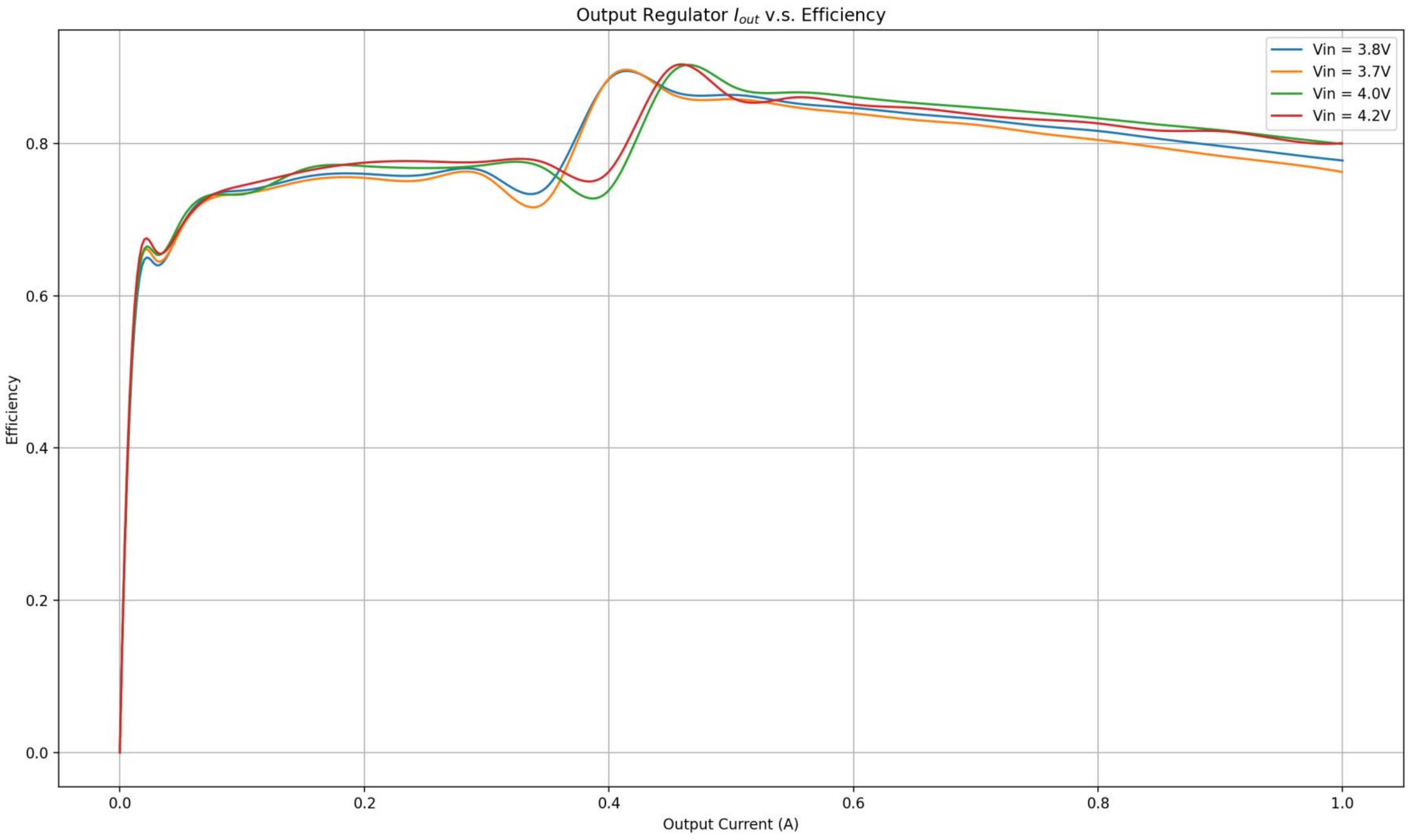
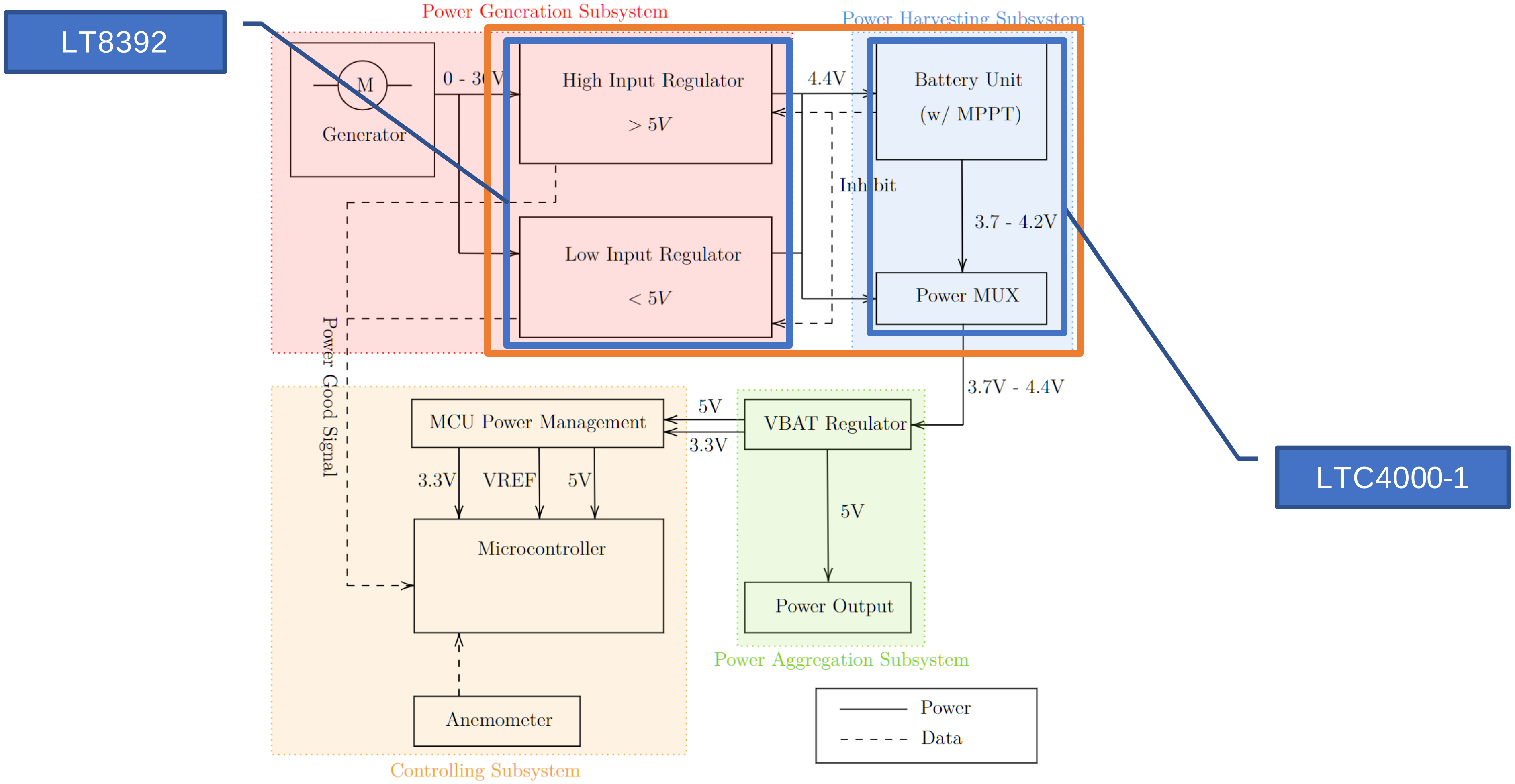


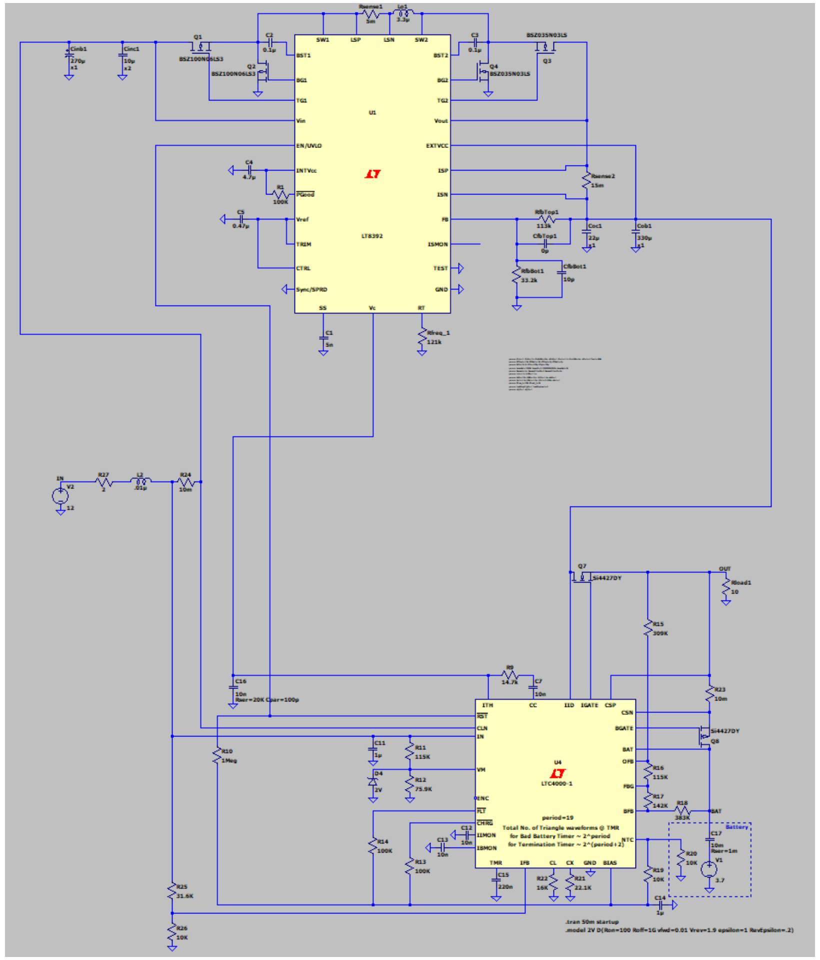
Setbacks and challenges: Design: Version 1 & 2

1. The first and second version PCBs was ambitious and complicated, they did not work, and it is hard to diagnose what happened.



Setbacks and challenges: Design: Version 1 & 2

1. The first and second version PCBs was ambitious and complicated, they did not work, and it is hard to diagnose what happened.



Version 1 & 2 PCB

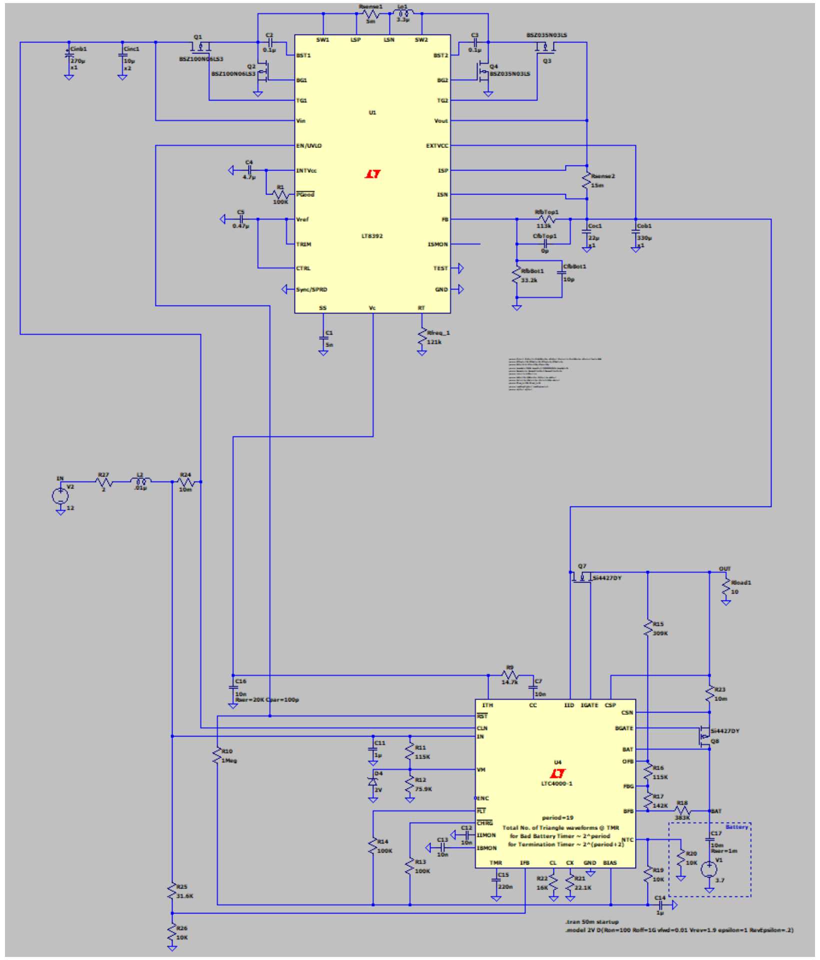
Top: DC/DC Converter

This is also a Buck-Boost architecture converter, MOSFETs are external. It has a Inhibit pin for controlling output current.

Bottom: MPPT & Battery Management IC

This IC measures input voltage, compares it with a set optimal voltage(provided by the MCU & Anemometer or transistor), and pulls the inhibit pin to control output current.

Setbacks and challenges: Design: Version 1 & 2



Version 1 & 2 PCB

Advantage:

Fine-grained control over input voltage and current, responds to fluctuations in input instantly, instead of a simple digital ON/OFF.

Disadvantage:

1. The two subsystems cannot work without each other.

The management IC provided lots of signals to the controller IC. The ITH pin lacks specification to simulate with instruments.

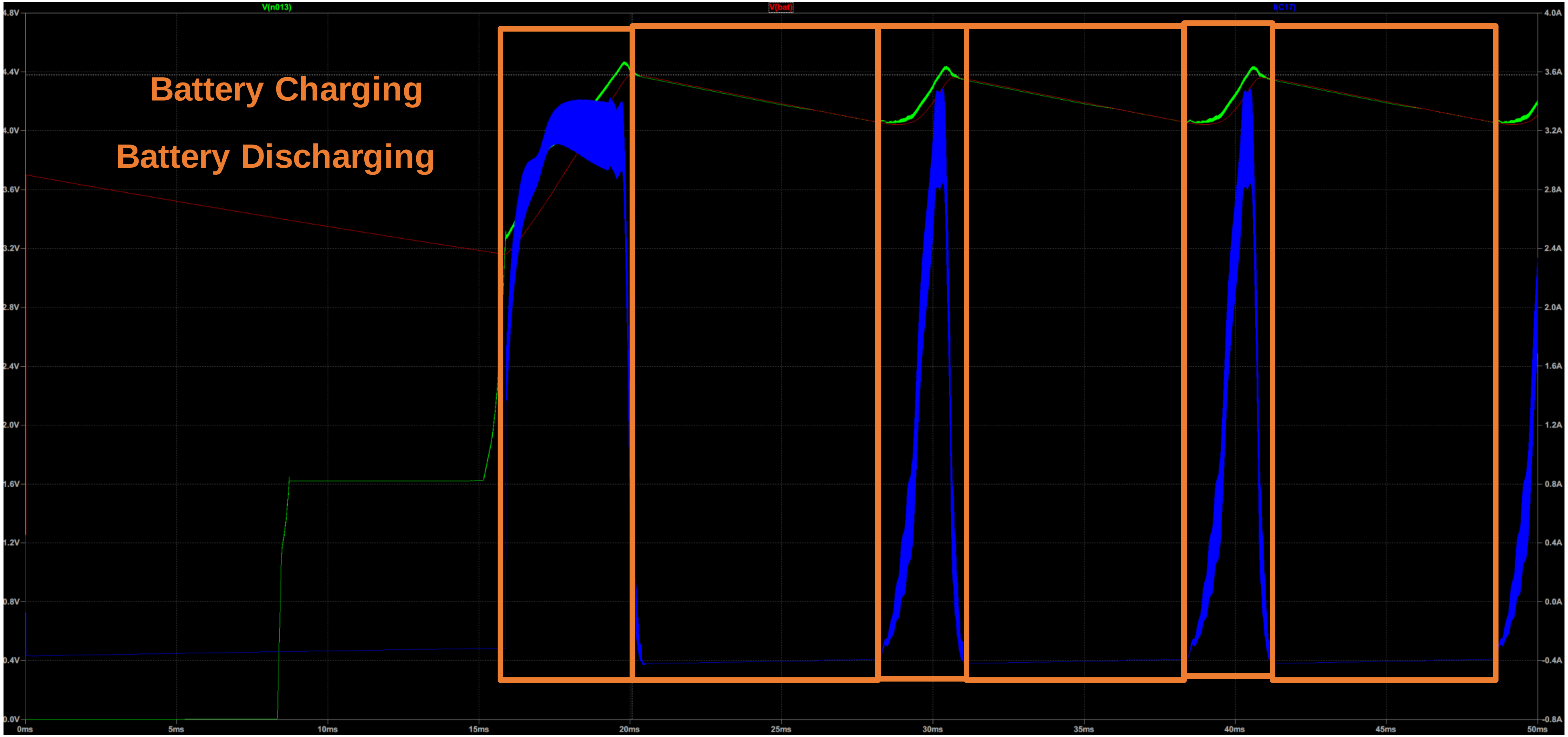
2. Not designed for low-power operation.

The DC/DC converter is designed for systems up to 300W. Expected our system to work at 10W. We chose smaller MOSFETs to suit our use case, but the IC itself contains too much internal logic.

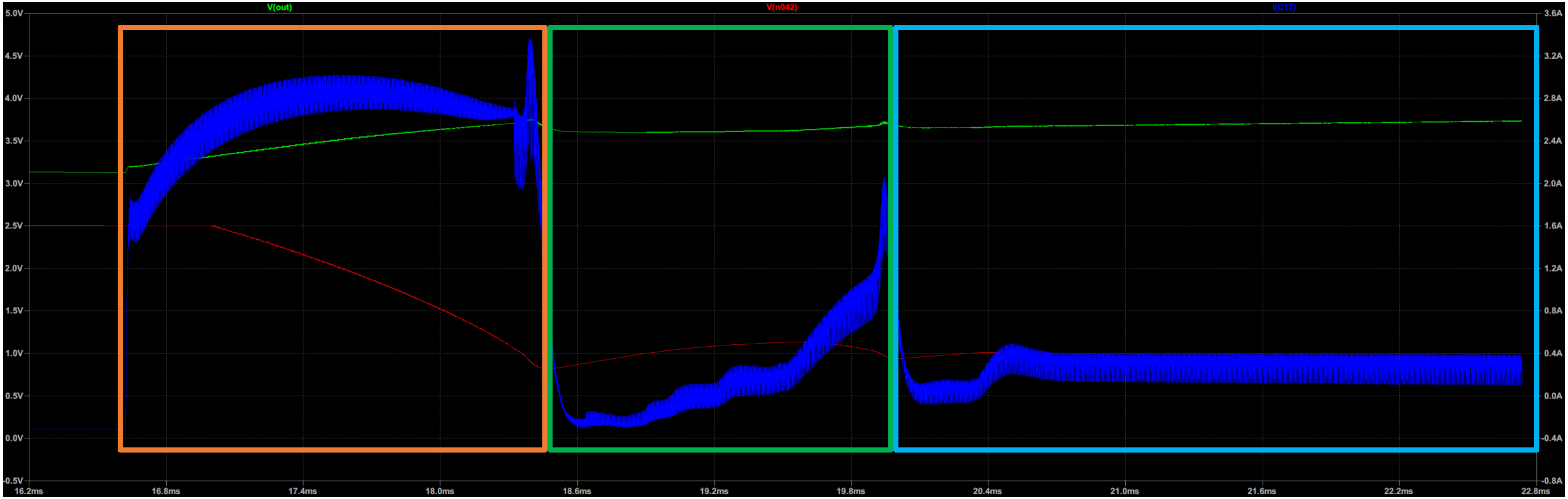
3. Requires complicated PCB design

The DC/DC IC provided guidelines for PCB design but no example layouts. A similar IC from Texas Instruments gave out a 6-layer PCB layout recommendation.

Setbacks and challenges: Simulation: Version 1&2



Setbacks and challenges: Simulation: Version 1&2

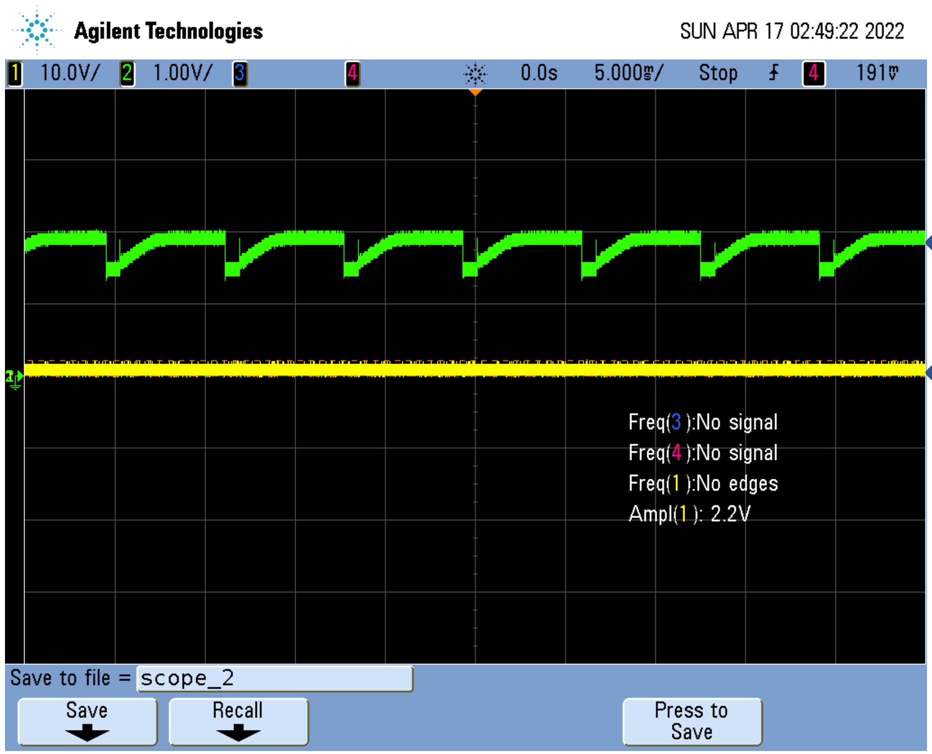


Drawing too much current
Input Voltage Drops

Current reduced
Input voltage rises back

Current stabilized
Optimal point reached

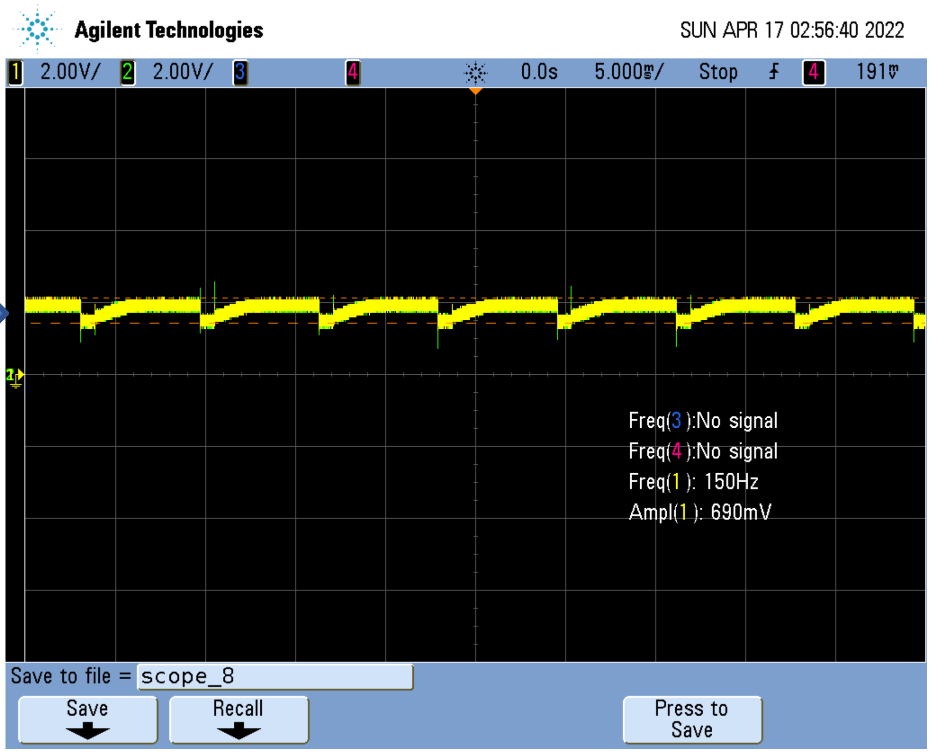
Setbacks and challenges: Measurements: Version 1&2

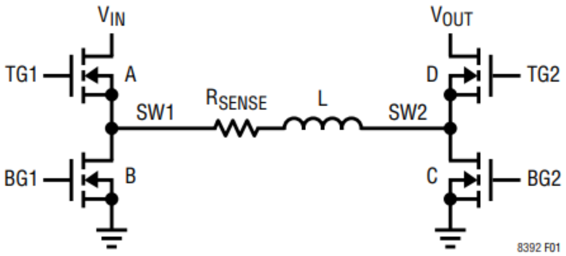


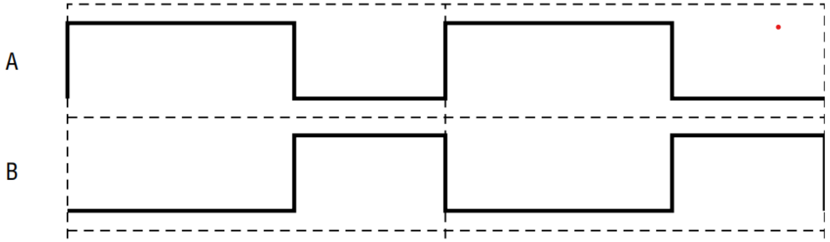
Measured TG1 (A + SW1)

Measured SW1

Measured BG1 (B)



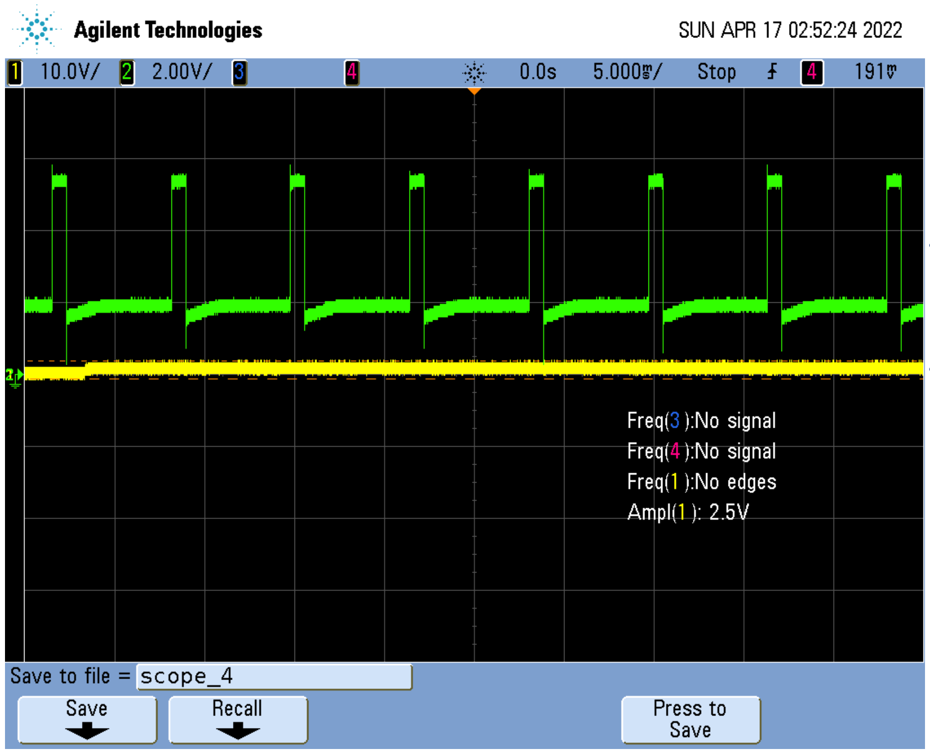




Expected A&B

Conclusion:
MOSFETs A & B are both turned off.
No such status exists in buck-boost architecture or LT8392’s datasheet.

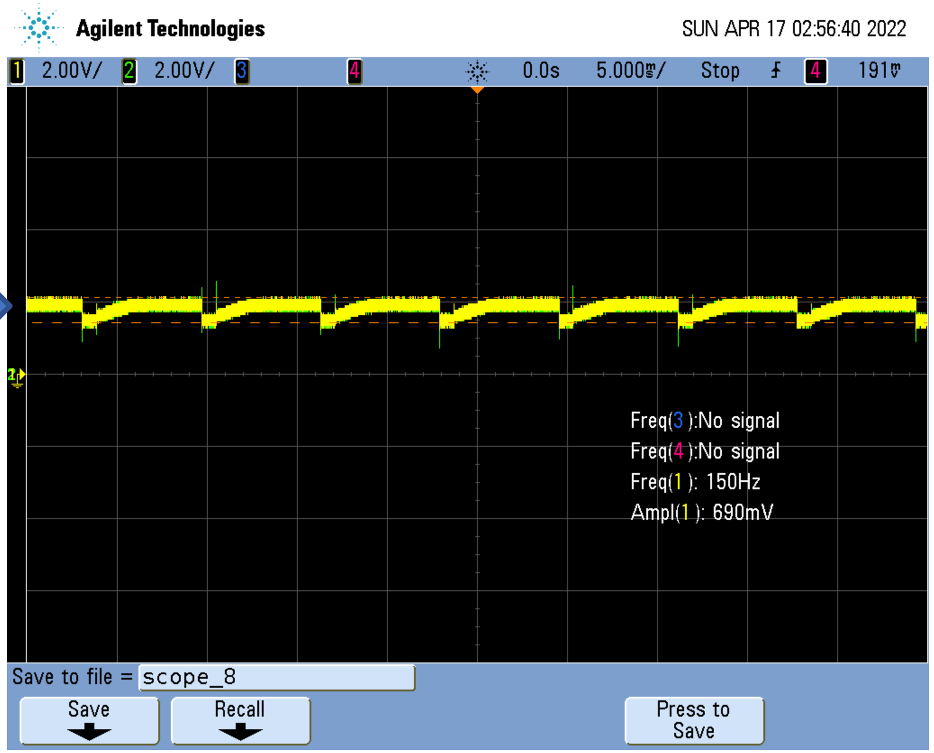
Setbacks and challenges: Measurements: Version 1&2

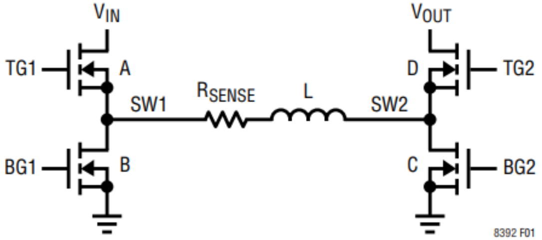


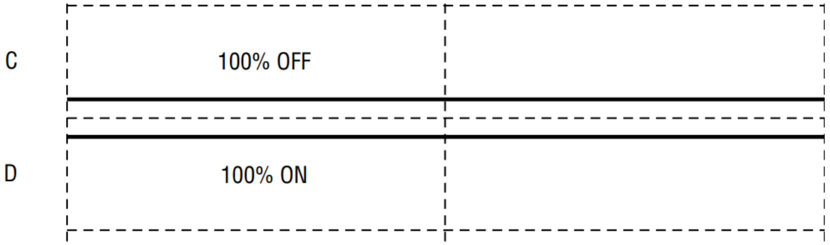
Measured TG2 (D + SW2)

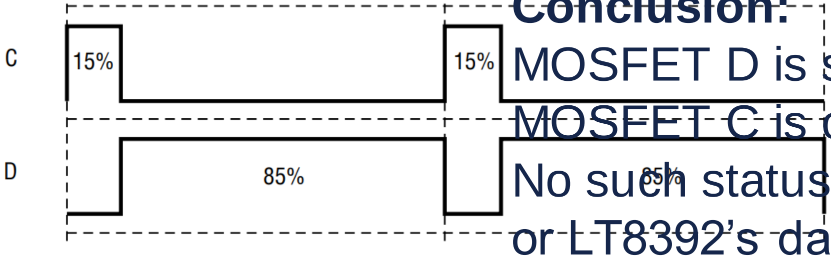
Measured SW2

Measured BG2 (C)









Conclusion:

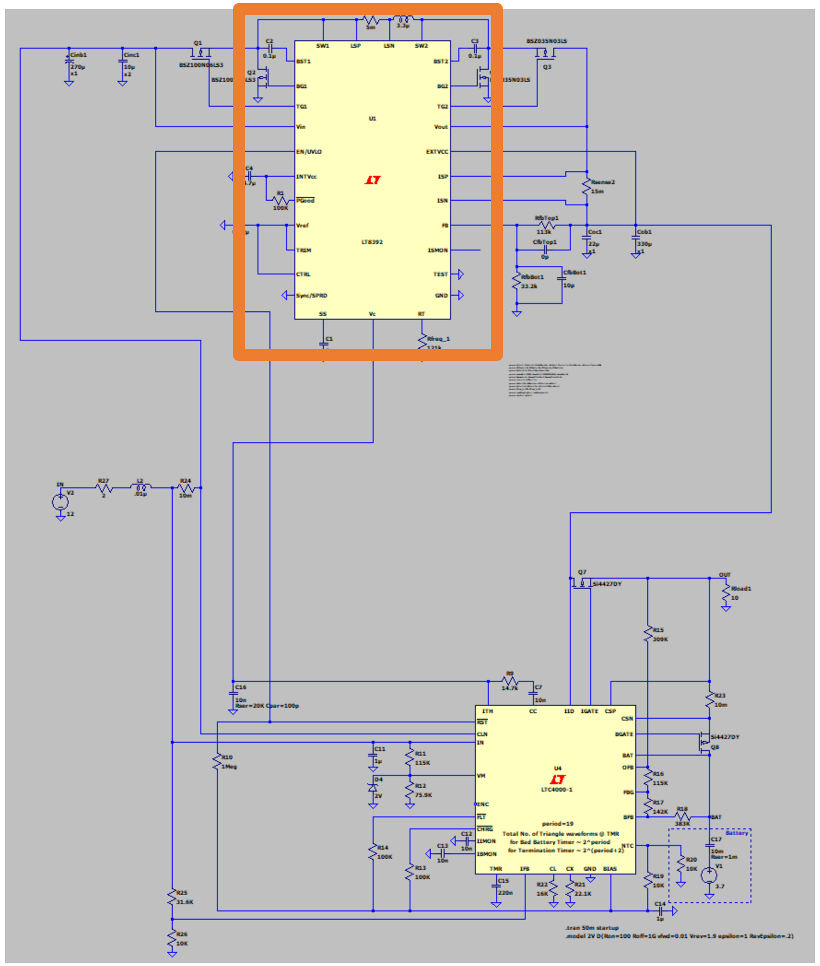
MOSFET D is switched at around 15%

MOSFET C is off.

Expected C&D (Either)

No such status exists in buck-boost architecture or LT8392's datasheet

Setbacks and challenges: Measurements: Version 1&2



Conclusion

The IC is not providing correct signals for buck-boost operation.

1. **Soldering temperature?** We used lead-free Sn99/Cu0.7/Ag0.3 solder, which has a higher melting temperature than normal Sn63/Pb37 solder.

- The IC we use, *Analog Devices LT8392* is RoHS (lead-free), but did not say explicitly in the datasheet that it is compatible with higher temperatures for lead-free soldering
- A similar IC from Texas Instruments, *LM34936-Q1* has almost same functionality and same packaging. In the datasheet it explicitly said it is compatible with lead-free processes.

2. **PCB Design?** We followed all PCB design guidelines in *LT8392's* datasheet, but an example design from *LM34936-Q1's* application note showed a 6-layer PCB design.

Ethics

Following the guidelines from the IEEE Code of Ethics, we are willing to develop this project to hold paramount the safety, health and welfare of the public (IEEE Code of Ethics, 2015).

We have made sure that:

- The mechanism is safe to attach to a bicycle.
- Avoid any possible accidents due to a piece of our project falling off.
- The system will not distract the cyclists' view.
- The system does not expose the user to harmful chemicals

Future Work

1. Use more efficient anemometers to assist with MPPT.

2. Investigate on more efficient blades or motors in achieving the optimal theoretical power.

3. Tweak the MPPT algorithm, take DC/DC converter efficiency into account.

The Grainger College of Engineering

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN