DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

CMOS Solar-Powered Battery Charger

Joseph Jacob, Thomas Lipetzky, Price Nguyen, Vincent Tan

A. JAMES CLARK SCHOOL OF ENGINEERING

Mission Statement

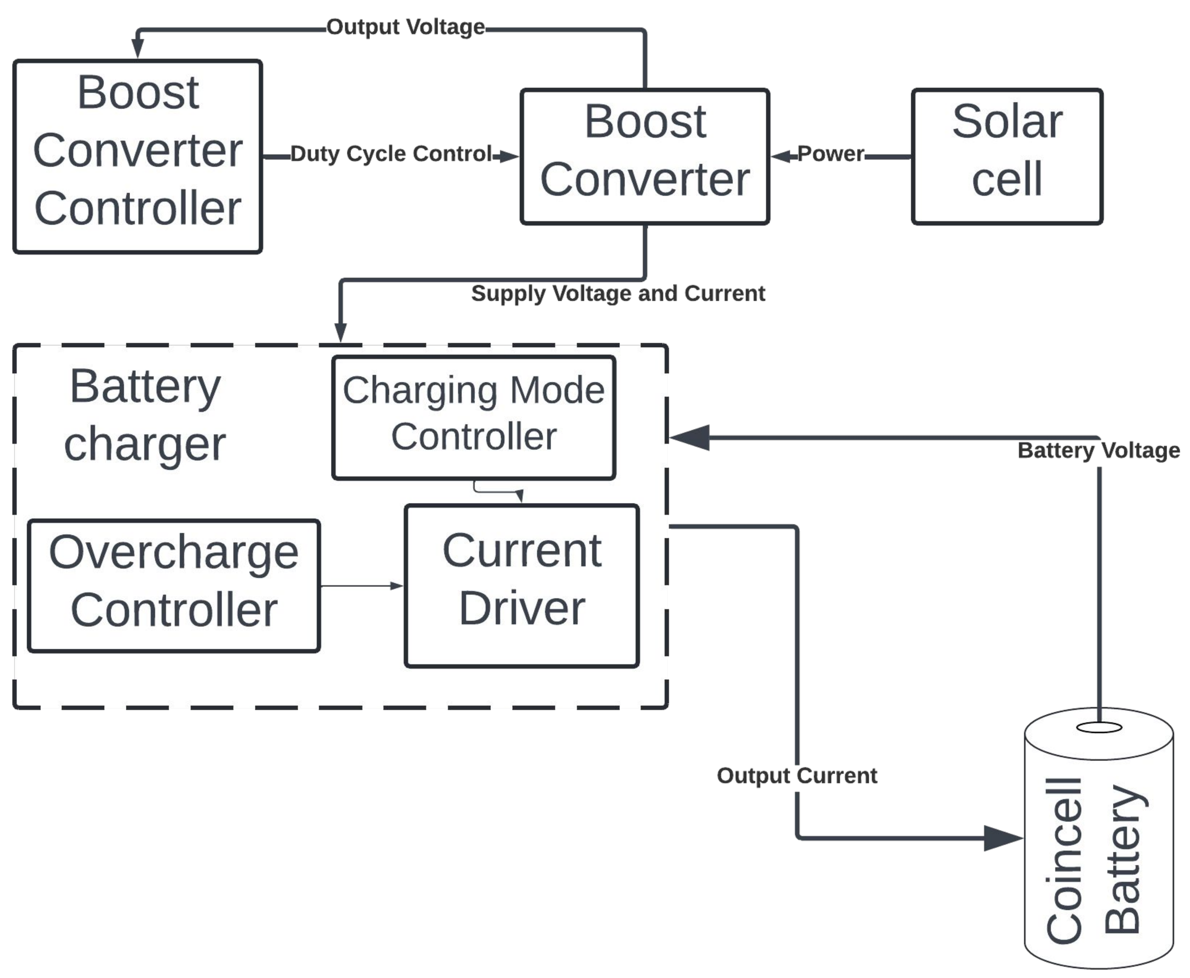
The CMOS Solar-Powered Battery Charger is a unique approach to solve the rapidly growing need for more renewable energy sources and sustainable practices in our ever-evolving world. This design would enable both the usage of clean solar energy for charging and increase the usage of rechargeable batteries, eliminating the single-use batteries that currently plague many of our landfills and devices.

This Battery Charger can be implemented to charge small batteries which can power devices such as: Small Sensor Devices, Glucose Monitors, and RFID Tags

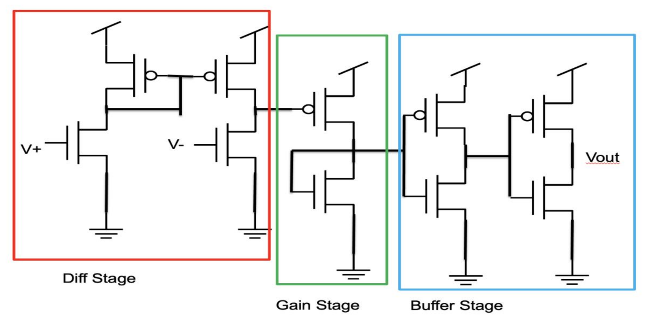
Design Goals and Constraints

- Create a Battery Charger Circuit that can perform trickle charging, constant current charging, and constant voltage charging
- Design the Circuits for maximum efficiency
- No external power supplies, all power must come from the solar cell
- Limited to chip area of $1mm^2$
- Maintain IEEE standards std. 2405-2022 and std. 1725-2021, to ensure optimal performance, and to maintain best practices
- Ensure that the battery charging circuitry complies with the battery manufacturer's specifications (maximum current and voltage)

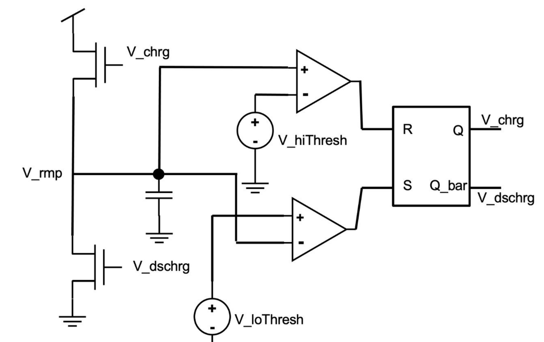
Block Diagram



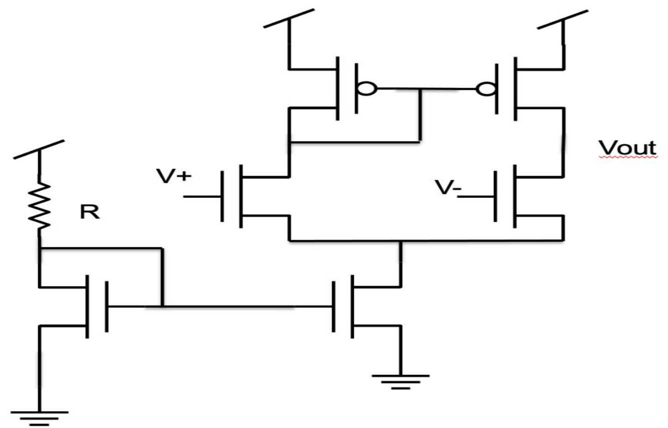
CMOS Circuits

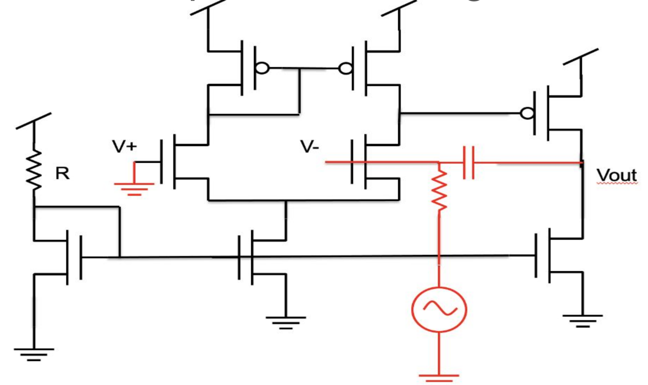


Comparator circuit outputs 1.8V whenever voltage on + exceeds voltage on -. Used for ramp generation and the final PWM output

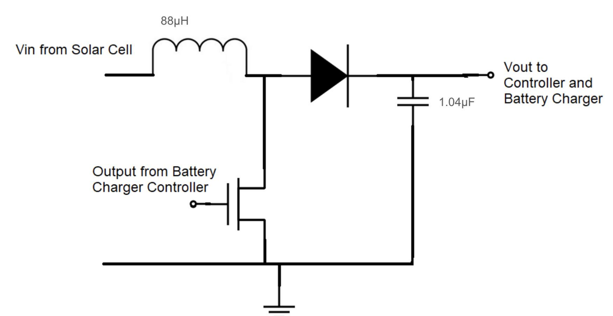


Ramp generator circuit. Uses comparators and an SR latch to charge and discharge a capacitor linearly, which produces a sawtooth patterned voltage



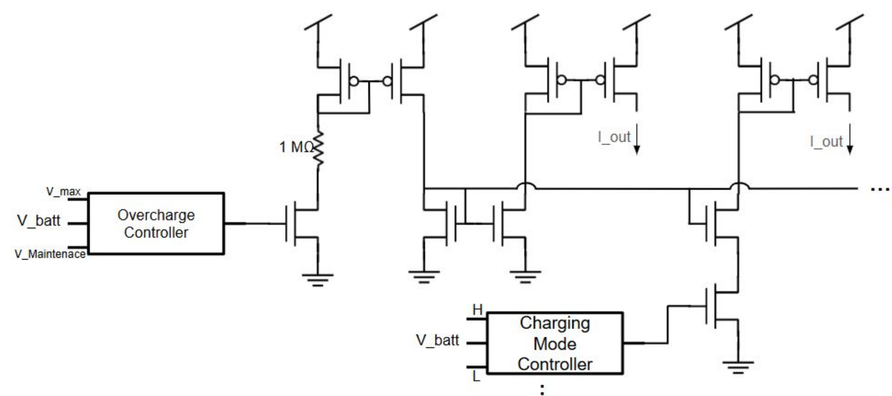


Differential amplifier (left) is used to read in the output voltage of boost converter and a reference voltage, amplify it, and use that value to control the duty cycle of the boost converter. Operational amplifier (right) works similar with the differential amplifier, except it integrates and amplifies the difference. Both of these circuits are combined together to create our PI controller

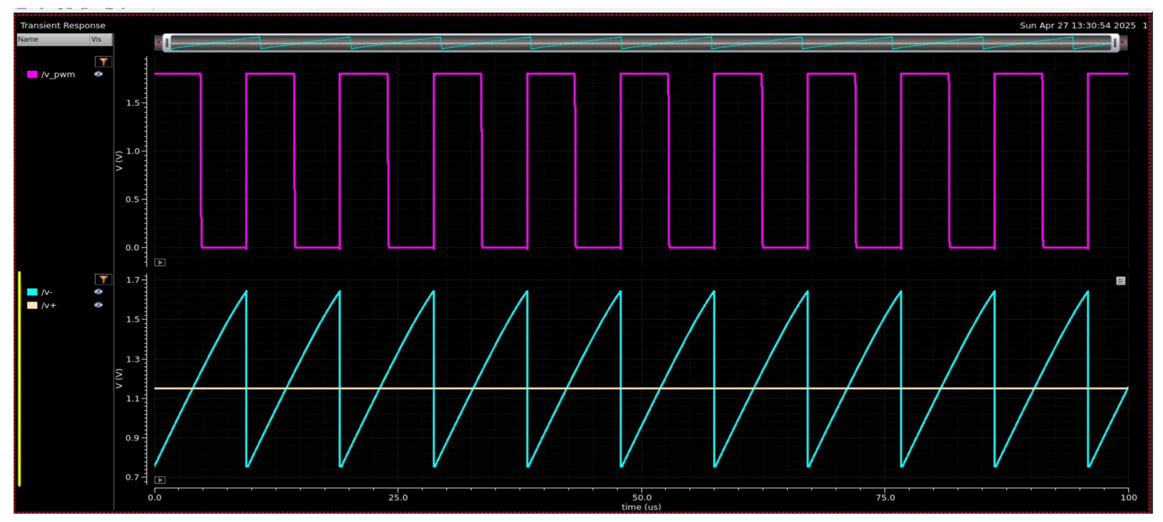


Boost converter itself. By switching the MOSFET on and off periodically, we can produce a higher output voltage. As we increase the time in which we have the switch on, the output voltage also increases.

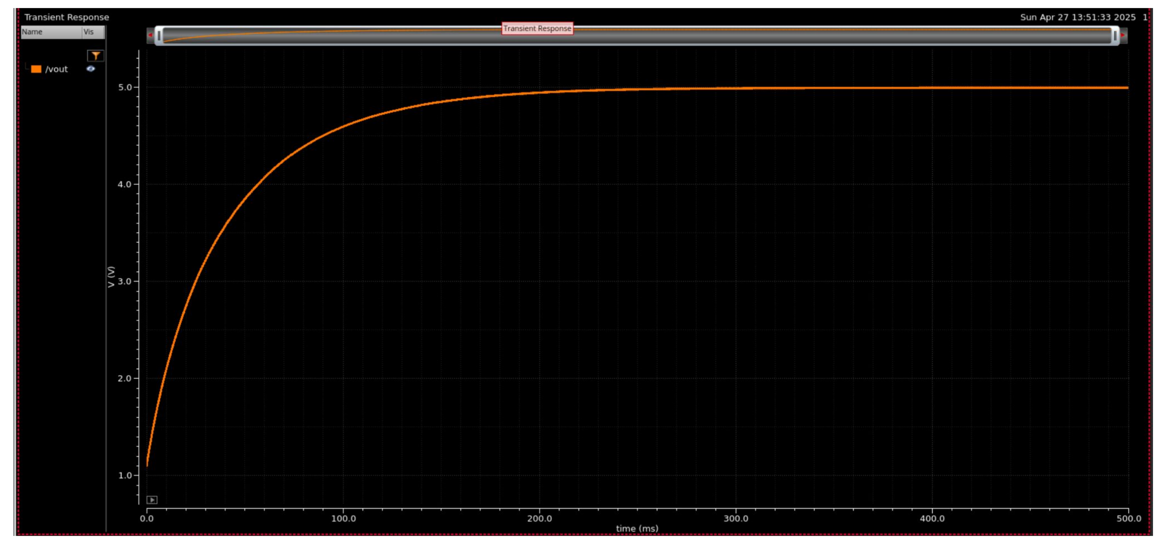
Battery Charger Circuit (Right), this circuit is used to supply the charging modes to the battery. This is done using the Charging Mode Controllers, which send an on/off signal to a series of current mirrors to add or remove current from the output. Additionally, the Battery Charger Contains an Overcharge Controller, which prevent the overcharging of the battery if it is already full.



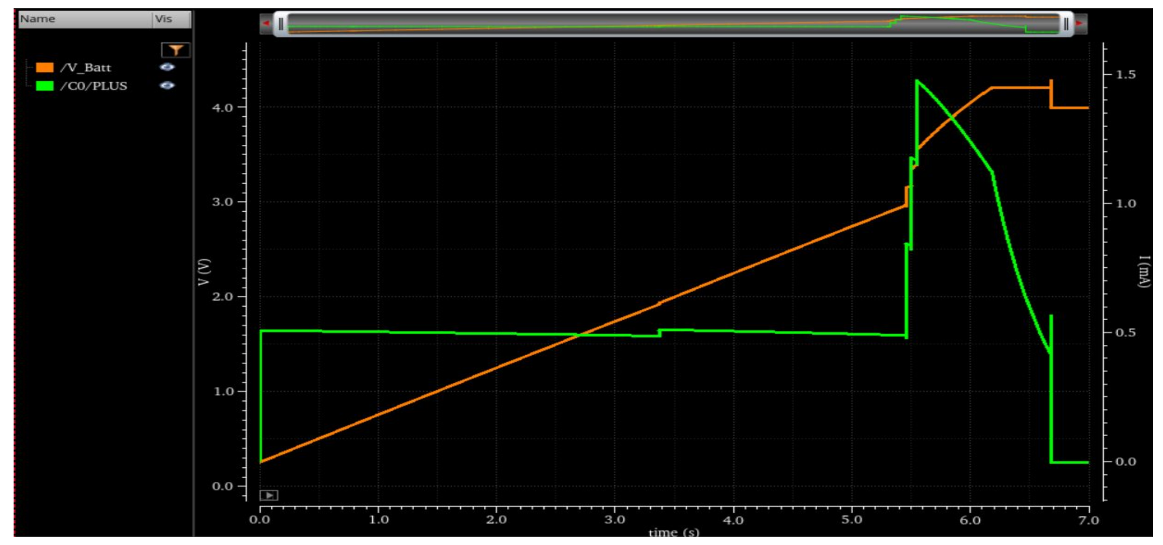
Simulation Results



Output of the PWM generator, We compare the ramp signal (blue) with the constant duty control voltage (tan). Every time the constant signal exceeds the ramp, the PWM signal (purple) goes high



Output voltage of the boost converter



Battery Charger Output (Current and Voltage)

Boost Converter Equations

$$H(S) = \frac{\left(-\frac{sI_L}{C} + \frac{V_{out}D'}{LC}\right)}{s^2 + \frac{s}{RC} + \frac{D'^2}{LC}}$$

From this transfer function detailing the dynamics across frequencies, we see marginal stability but with very light damping and large oscillations Our controller has to further dampen the oscillations

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$

Equation for calculating the size of the inductor for the boost converter. Vin is the input voltage, Vout is the output voltage IL is the current ripple, and fs is the switching frequency.

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

Equation for calculating the size of the capacitor for the boost converter. Iout is the output current, D is the Duty cycle, fs is switching frequency, and Vout is output voltage

References

1. "IEEE Standard for the Design of Chargers Used in Stationary Battery Applications," in IEEE Std 2405-2022, vol., no., pp.1-48, 7 Nov. 2022, doi: 10.1109/IEEESTD.2022.9938449. Published: 07 November 2022. https://ieeexplore.ieee.org/document/9938449 Accessed: 14 March 2025.
2. Gopika Gopinath E and A. Gubbi, "Four transistor comparator based PWM for DC-DC Converters," 2015 1st International Conference on Next Generation Computing Technologies (NGCT), Dehradun, India, 2015, pp. 536-539, doi: 10.1109/NGCT.2015.7375177
3. Sudharshan, K. M., Pallavi, R., Anilkumar, C. S., & Yatheesh, H. G. (2018). Modeling and simulation of on-chip ramp generator for power management IC's using cadence. 20183rd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), 2115–2119. https://doi.org/10.1109/rteict42901.2018.9012344
4. "IEEE Standard for Rechargeable Batteries for Mobile Phones," in IEEE Std 1725-2021, vol., no., pp.1-80, 23 Aug. 2021, doi: 10.1109/IEEESTD.2021.9514813. Published: 13 August 2021. https://ieeexplore.ieee.org/document/9514813 Accessed: 14 March 2025.
5. International Electrotechnical Commission. (2017). Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications – Part 3: Prismatic and cylindrical lithium secondary cells, and batteries made from them (IEC 61960-3:2017). IEC. https://www.iec.ch
6. JEITA RC-1001A Japan Electronics and Information Technology Industries Association. (2010). Safety standards for lithium-ion secondary cells and batteries for use in portable electronic applications (JEITA RC-1001A). JEITA. https://www.jeita.or.jp/english/
7. Hauke, Brigitte. "Basic Calculation of a Boost Converter's Power Stage." TI, TI, Nov. 2009, www.ti.com/lit/an/slva372d/slva372d.pdf?ts=1692923766521.