

SMART BATTERY CHARGER WITH BARGRAPH

Alexandru Gabriel Brabete, Botizan Thomas
[TECHNICAL UNIVERSITY OF CLUJ-NAPOCA]

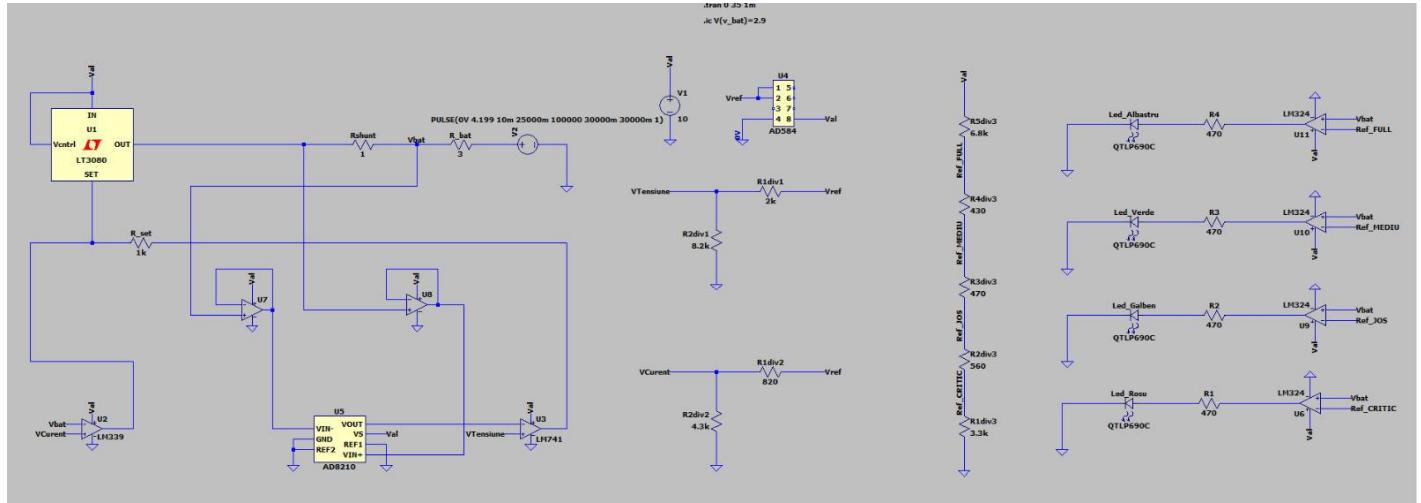
PROJECT THEME

- 3.8Vnom LI-FE-PO or LI-IO battery charger with LT3080 stabilizer and current monitor with AD8210.
- Adjustable output current
- Bargraph batteries with blink on LED charge level.

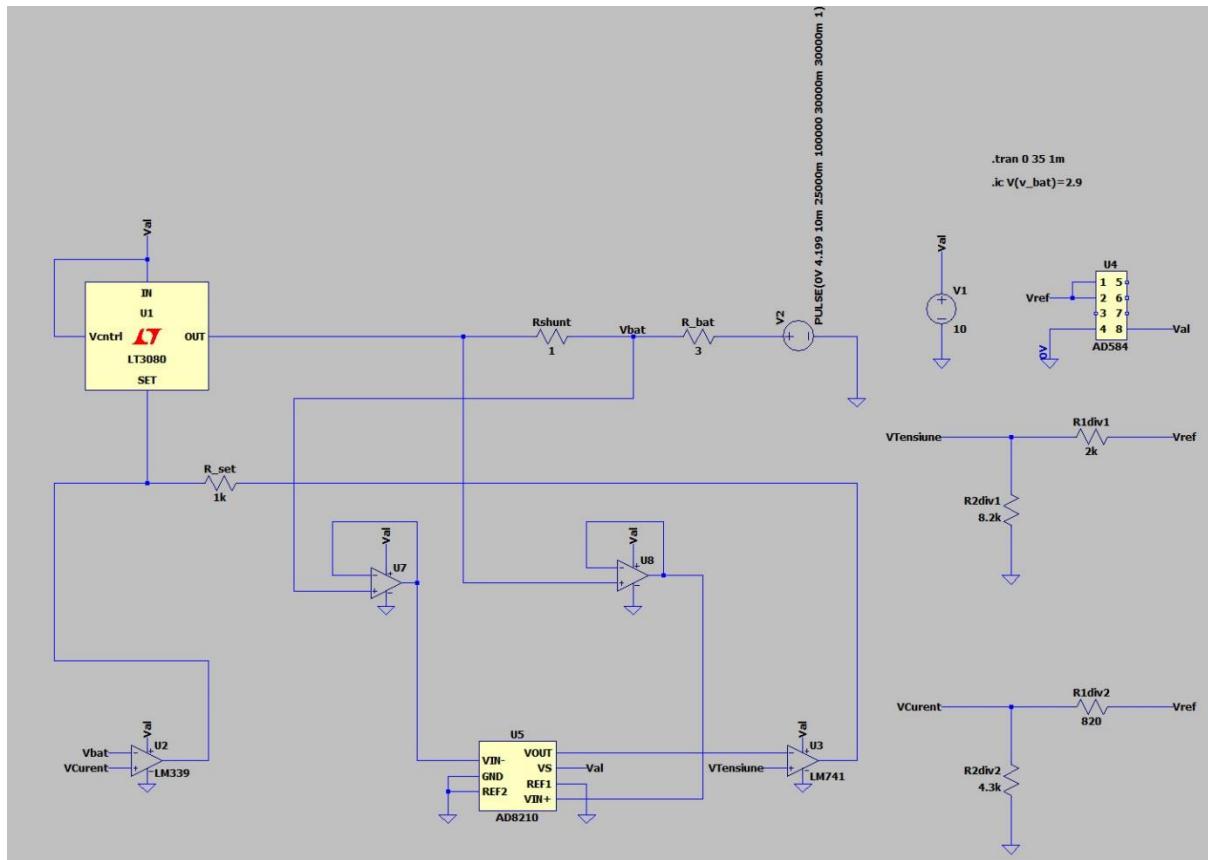
SOLVING THE THEME IN THE LTSPICE SIMULATOR

WIRING DIAGRAMS OF THE CIRCUIT

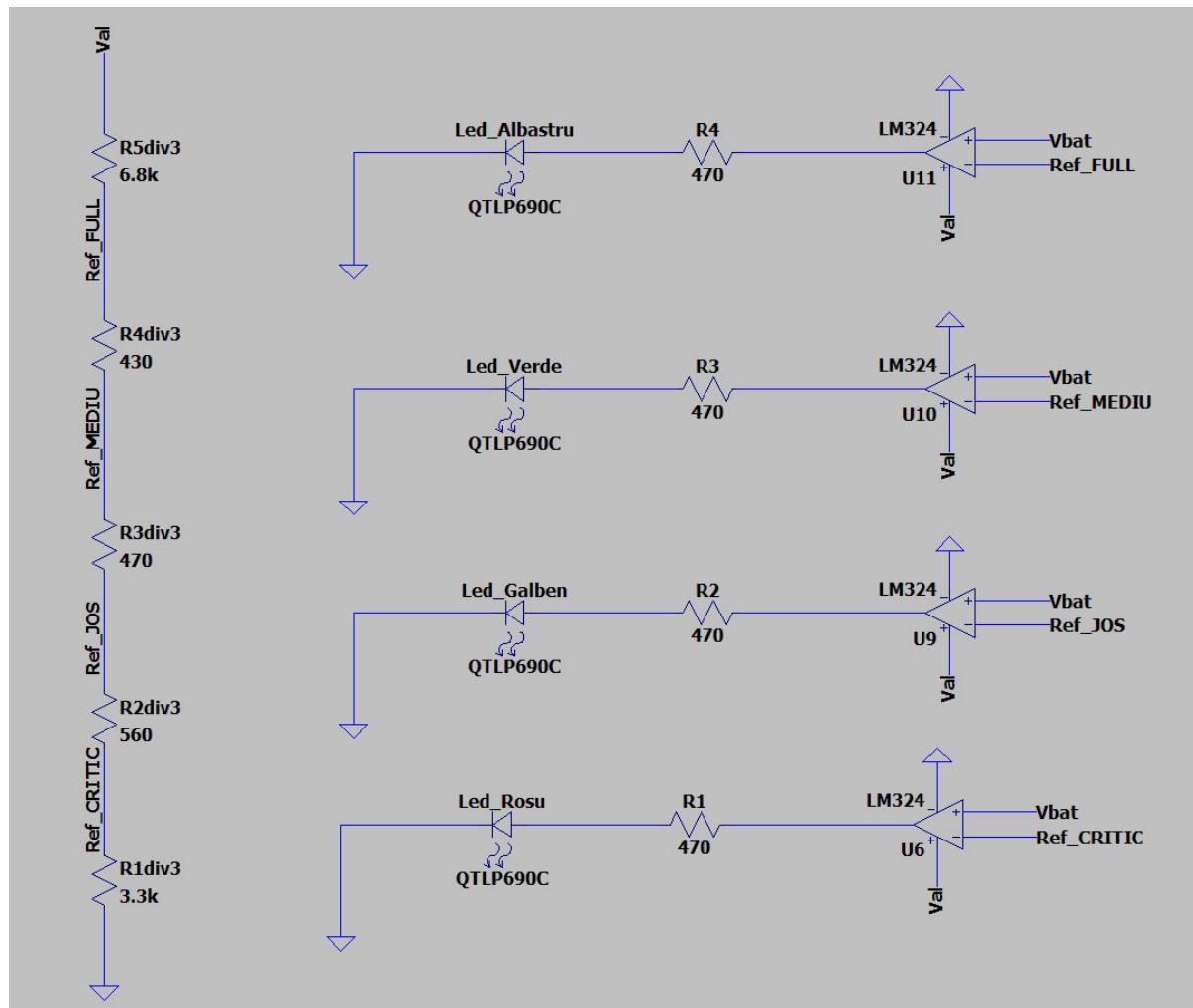
GENERAL SCHEME:



THE CHARGER ITSELF:



BARGRAPH:



OVERVIEW

This circuit represents a complete **charging and monitoring system for Li-Ion batteries**.

We can divide the electrical circuit into **three major functional blocks**:

1. Power and Control Block (Left Side)

This is the part responsible for delivering power to the battery.

- **Execution element (LT3080):** It is the main component that regulates the voltage and current that reach the battery.
- **Current Sensor (AD8210):** Measures how much current "flows" through the shunt resistor (Rshunt) and sends the information to the controller.
- **Control (LM339 and LM741):**
 - **LM339 (U2):** Provides **DC (Constant Current) mode** – limits the current at the start of charging.
 - **LM741 (U3):** Provides **CV (Constant Voltage) mode** – limits the voltage at the end (to 4.2V), so as not to overcharge the battery.

2. Precision Reference Block (Center-Top)

- **AD584 (U4):** This is the circuit reference. It generates a fixed and stable voltage (V_{ref}).
- All circuit decisions (when to turn off charging, when to turn on an LED) are made by comparison with this reference.

3. Visual Monitoring Block / Bargraph (Right Side)

It shows the user how charged the battery is in real time.

- **Scaled Resistive Divider (R1div3 ... R5div3):** This column of resistors divides the reference voltage into several fixed thresholds (voltage steps), for example:
 - Ref_CRITIC (low battery)
 - Ref_JOS (low battery)
 - Ref_MEDIU (half battery)
 - Ref_FULL (full battery)
- **Comparators (U6, U9, U10, U11 - LM324):** These compare the actual battery voltage (V_{bat}) with the above thresholds.
 - If the D1 LED lights $V_{bat} > V_{Ref_CRITIC}$ up.
 - If the D3 LED also lights $V_{bat} > V_{Ref_MEDIU}$ up, and so on.

- **LEDs:** Works as a progress bar. As the battery charges, they will successively light up from the bottom up, showing the state of charge.

SIZING AND CALCULATIONS

1. Current Control Divider (DC - Constant Current)

- Source: $V_{ref} = 5V$
- Resistances:
 - $R_{1div1} = 2k\Omega$
 - $R_{2div1} = 8.2k\Omega$
- Formula:

$$V_{tensiune} = V_{ref} \times \frac{R_{2div1}}{R_{1div1} + R_{2div1}}$$

- Voltage calculation:

$$V_{tensiune} = 5V \times \frac{8200}{2000 + 8200} = 5 \times \frac{8200}{10200} = 5 \times 0.8039 = 4.02V$$

2. Voltage Control Divider (CV - Constant Voltage)

- Source: $V_{ref} = 5V$
- Resistances:
 - $R_{1div1} = 820\Omega$
 - $R_{2div1} = 4.3k\Omega$
- Formula:

$$V_{current} = V_{ref} \times \frac{R_{2div2}}{R_{1div2} + R_{2div2}}$$

- Voltage calculation:

$$V_{tensiune} = 5V \times \frac{4300}{820 + 4300} = 5 \times \frac{4300}{5120} = 5 \times 0.8398 = 4.2V$$

3. Divider for Bargraph

- R5 (Up): $6.8 k\Omega$
- R4: 430Ω
- R3: 470Ω
- R2: 560Ω
- R1 (Bottom): $3.3 k\Omega$

3.1. Calculation of total resistance (R_{tot})

$$R_{tot} = 6800 + 430 + 470 + 560 + 3300 = \mathbf{11560\Omega}$$

3.2. Calculation of Threshold Voltages The divider is powered at 10V.

Threshold 1: CRITICAL

$$10V \times \frac{3300}{11560} = \mathbf{2.85V}$$

Threshold 2: DOWN

$$10V \times \frac{3300 + 560}{11560} = \mathbf{3.34V}$$

Threshold 3: MEDIUM

$$10V \times \frac{3860 + 470}{11560} = \mathbf{3.74V}$$

Pragul 4: FULL

$$10V \times \frac{4330 + 430}{11560} = \mathbf{4.117V}$$

THE LOGIC OF COMPONENTS WIRING

U1 – LT3080 (Regulator Liniar LDO)

- **Role:** The main execution element (it regulates the current).
- **Connection:** The IN pin receives the voltage from the source. The OUT pin delivers power to the battery. The SET pin is linked to the control system.
- **Operation:** Works as a *Voltage Follower*. The output voltage (OUT) will copy the voltage applied to the SET pin. If the control system lowers the voltage on the SET, the LT3080 immediately reduces the output.

Rshunt (1Ω) – Shunt Resistance

- **Role:** Passive current sensor.
- **Connection:** It is serialized between the output of the regulator and the battery.
- **Operation:** According to Ohm's law, the current passing through it creates a small voltage drop at its terminals. This voltage drop is "read" by the AD8210 amplifier to know how many amps are going into the battery.

R_{bat} (3Ω) and V2 (Pulse)

- **Role:** Real battery simulation.
- **Description:** In reality, this is where the physical Li-Ion battery will be connected. In the simulation, they model the battery's internal resistance and its variable voltage during charging.

U5 – AD8210 (Current Sense Amplifier)

- **Role:** Amplification of the small current signal.
- **Connection:** The input pins (VIN+, VIN-) are tied to the ends of the Rshunt resistor. The output (VOUT) goes to the U2 comparator.
- **Operation:** Measures the very small potential difference on the shunt (which represents the charging current) and amplifies it to a higher value that can be processed by the U2 comparator.

U7 and U8 – Buffer (Voltage Repeater)

- **Role:** Impedance isolation and adaptation.

- **Connection:** The inputs are linked to the measurement points, and the outputs send the signal further into the circuit.

U2 – LM339 (Current Comparator - DC)

- **Role:** Limits the maximum current (Constant Current).
- **Connection:**
 - + input: Receives the actual current signal from the AD8210.
 - -Input: Receives the set current threshold (VCcurrent).
 - Output: Linked to the LT3080's SET pin.
- **Operation:** If the measured current exceeds the set threshold, the output of the comparator drops to ground (Low), "pulling" down the control voltage of the regulator and forcing it to reduce the current.

U3 – LM741 (Voltage Error Amplifier - CV)

- **Role:** Keeps the fixed voltage at 4.2V (Constant Voltage).
- **Connection:** Compares the actual battery voltage (via the U8 buffer) to the reference voltage (VTvoltage).
- **Operation:** When the battery reaches its maximum threshold, the U3 begins to reduce the command on the LT3080's SET pin, keeping the voltage constant while the current naturally drops.

R_set (1kΩ)

- **Role:** Limiting/summing resistance.
- **Connection:** Between the outputs of the control amplifiers and the SET pin of the LT3080.
- **Operation:** Allows comparators (U2, U3) to control the SET pin without directly short-circuiting. Protects the control floor.

Reference Block

- **U4 – AD584 (Programmable Voltage Reference)**
 - **Role:** Provides a stable voltage (Vref).
 - **Connection:** Powers the resistive dividers on the right.
 - **Operation:** Creates a reference against which everything in the circuit is compared.

Dividers R1div1/R2div1 and R1div2/R2div2

- **Role:** Set thresholds.
- **Operation:**
 - VThe voltage: Sets the maximum charging voltage (4.2V).
 - VCurent: Sets the maximum charging current (200mA).

Chain of Resistances (R1div3 ... R5div3)

- **Role:** Multiple Voltage Divider (Voltage Scale).
- **Connection:** Divides the Vref reference voltage into 4 distinct thresholds (2.8V; 3.3V; 3.7V; 4.1V).
- **Operation:** Creates the reference points: Ref_CRITIC, Ref_JOS, Ref_MEDIU, Ref_FULL.

U6, U9, U10, U11 – LM324 (Operational Amplifiers)

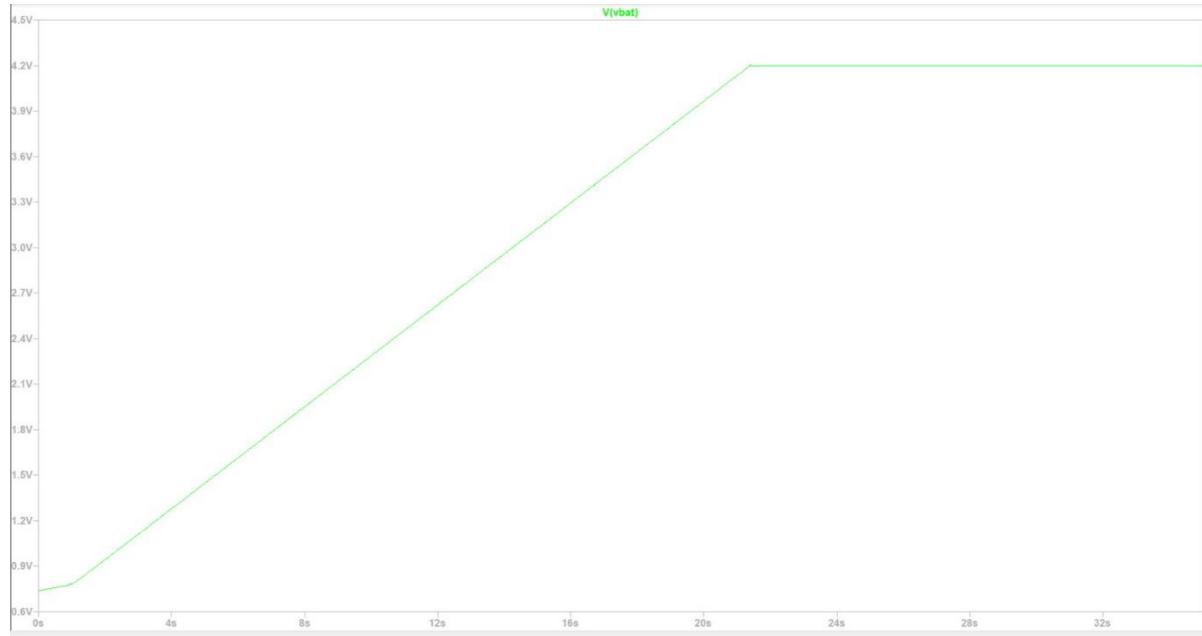
- **Role:** Level comparators.
- **Connection:**
 - + input: Linked to battery voltage (Vbat).
 - Input -: Tied to the corresponding threshold in the resistance chain.
- **Operation:** Each comparator checks if the battery voltage is higher than the set threshold. If YES, turn on the output (High).

LEDs and R1, R2, R3, R4 (470Ω resistors)

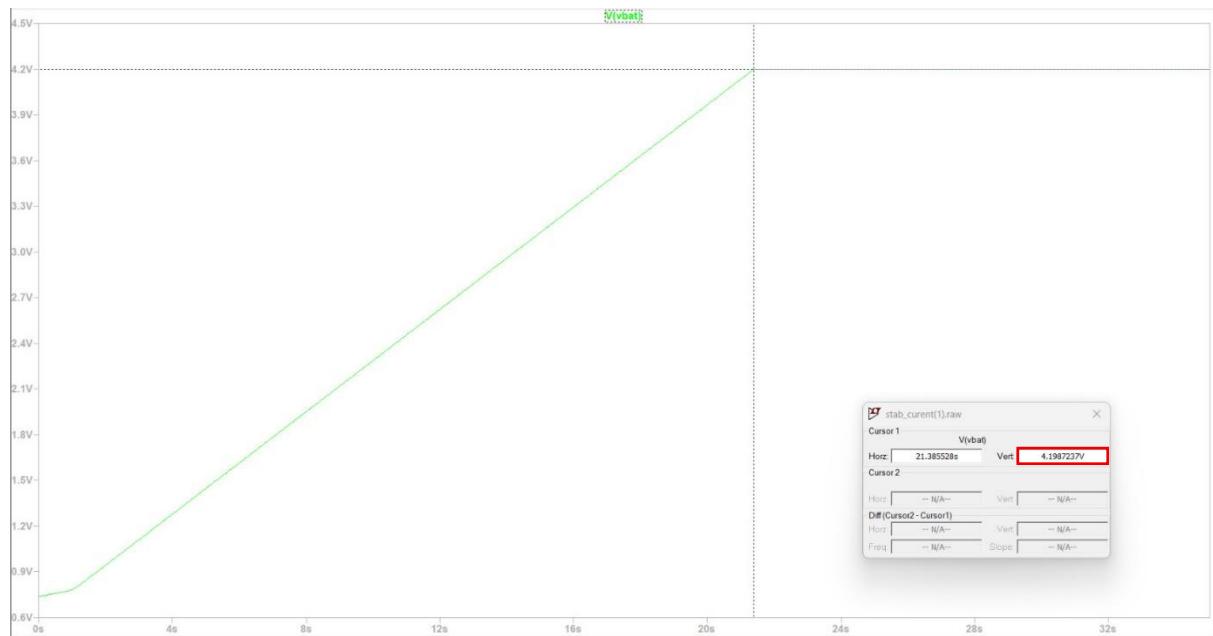
- **Role:** Visual interface.
- **Connection:** Between the output of the comparators and the table.
- **Operation:** They light up successively as the battery voltage increases, indicating the charge level. 470Ω resistors limit current so that LEDs don't burn out

SIMULATION RESULTS IN LTSPICE

VOLTAGE ON BATTERY:



MEASUREMENT:



INTERPRETATION RESULT:

The graph shows the evolution of the voltage at the battery terminals. The behavior of the curve confirms the two operating modes of the charger:

1. Constant Current (DC) Charging Regime – Upward Slope

- **Visual observation:** The green line has a linear upward trajectory (a constant slope).
- **Explanation:** In a capacitor or battery, a linear increase in voltage (V) over time (t) mathematically proves that charging is done with a constant current (I), according to the relationship:

$$I = C \times \frac{dV}{dt}$$

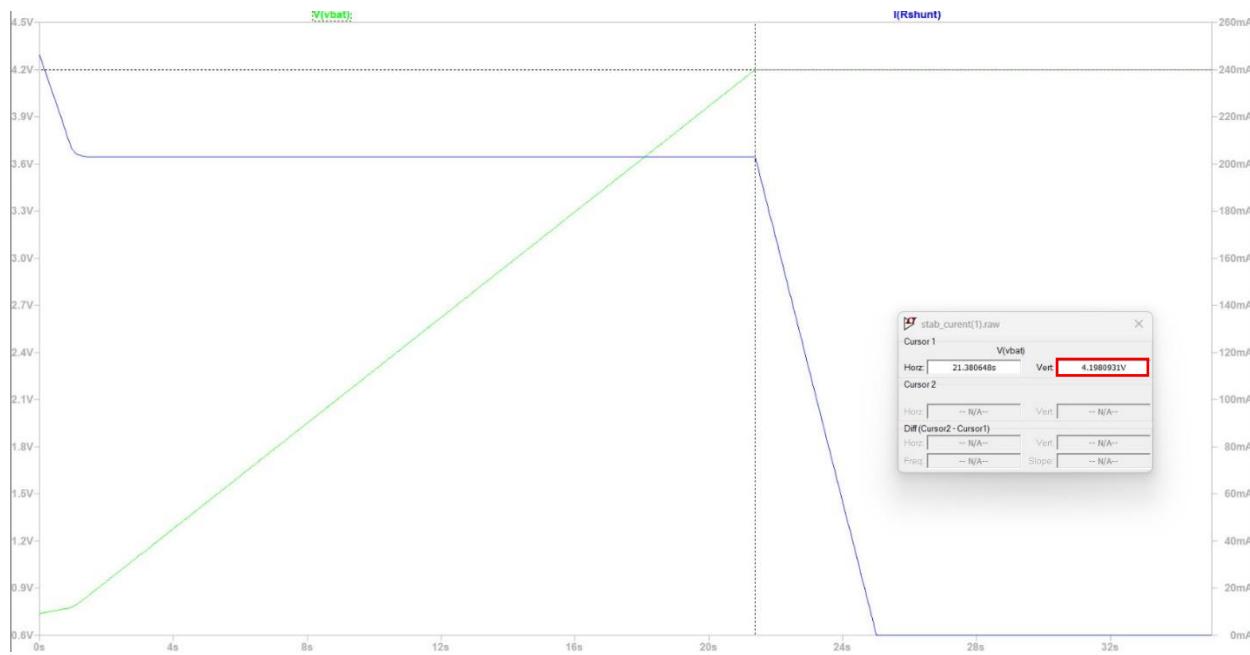
Since the slope ($\frac{dV}{dt}$) is constant, it follows that the current delivered by the LT3080 was also constant during this period. The circuit limited the current to protect the battery.

2. Threshold Reaching and Voltage Limitation (CV) – horizontal line

- **Visual observation:** The slope suddenly stops and the graph becomes a horizontal line
- **Value:** The graph indicates a cap at **4.2V**.
- **Explanation:** At this point, the battery voltage has reached the reference threshold set by the resistive divider and the U3 op amplifier. The circuit switched from current mode to voltage limiting mode.

Conclusion: The graph demonstrates the efficiency of the surge protection loop. Regardless of the elapsed time, the voltage on the battery never exceeds the critical value of **4.2V**, thus preventing the risk of overcharging.

BATTERY VOLTAGE AND CURRENT



The blue curve represents the temporal evolution of the charging current crossing the shunt resistance (R_{Shunt}), measured in milliampers (right vertical axis). The chart can be segmented into three distinct stages of operation:

1. Constant Current Stage (DC Regime)

- Visual description:** The graph shows a horizontal line, held constant at about **205 mA**.
- Explanation:** During this interval, the battery is discharged. The current control loop, managed by the U2 comparator $V_{bat} < 4.2V$ (LM339), is active. The comparator notices the tendency of the current to increase and reduce the voltage on the SET pin of the **LT3080 regulator** to keep the current fixed at the predefined value. The LT3080 regulator compensates for the continuous variation in battery impedance during charging.

2. Transition Point

- Correlation:** This point coincides with when the green curve (battery voltage) reaches the critical threshold of **4.198V**.
- Phenomenon:** The switch of control between the two reaction loops takes place. The current loop (U2) is deactivated, and the voltage loop (U3 - LM741) takes control of the regulator.

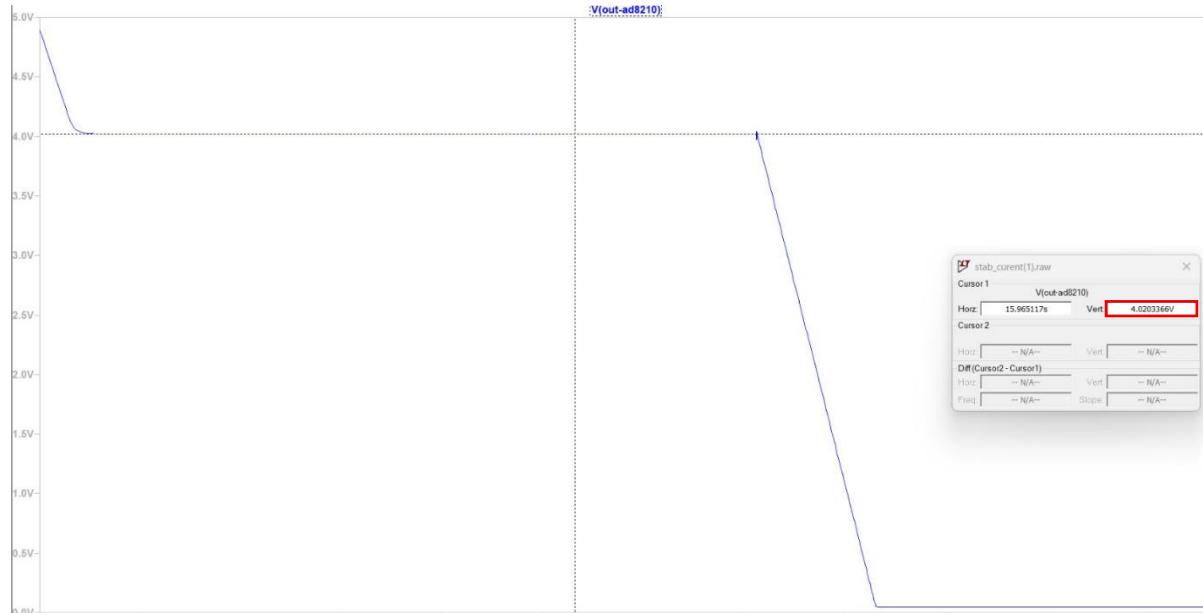
3. Downward Ramp (Transition to Resume)

- **Visual description:** The current decreases linearly from 205 mA to 0 mA.
- **Meaning:** The circuit progressively reduces the current to keep the voltage fixed at 4.2V, preventing oscillations.

4. Shutdown Mode (Cut-off / Saturation)

- **Description:** The current becomes 0 mA.
- **Explanation:** In the simulation, because the supply voltage (LT3080) and the battery voltage equalized to 4.2V, there is no longer any potential difference to generate current ($I = \Delta U/R$).

OUTPUT FROM AD8210:



Although the unit of measurement on the vertical axis is Volts (4.02V), this signal actually represents the Current.

- **The AD8210** is a current amplifier with a fixed gain (usually 20V/V).
- It reads the small voltage drop on the shunt resistor and multiplies it by 20.
- **Calculation:**

$$V_{citată} = 4.02V$$

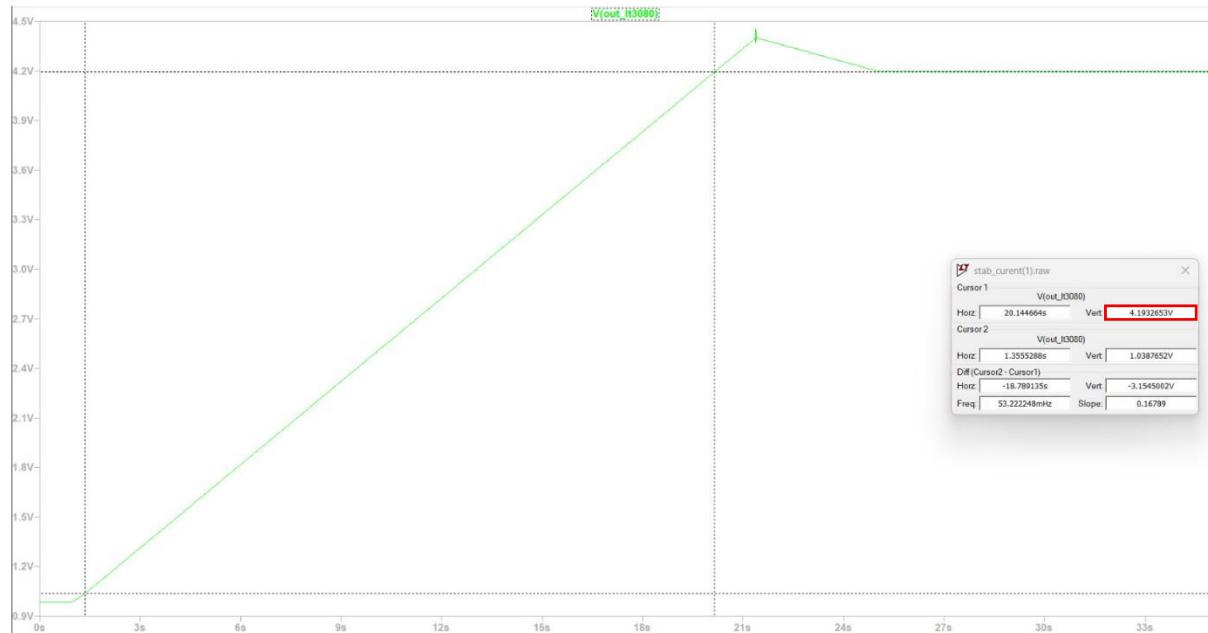
$$I_{real} = \frac{4.02V}{20 \text{ (Câștig)}} = 0.201A (201mA)$$

- **Conclusion:** The graph shows that the circuit charges the battery with a constant current of 200mA.

2. Chart shape analysis

- **Horizontal Bearing:** The line is straight at **4.02V**.
 - **Meaning:** This is the Constant Current (DC) phase. The regulator keeps the current at 200mA, regardless of the battery voltage. This confirms that the loop with the **LM339** works.
- **Downward Slope:** The line descends linearly to zero.
 - **Significance:** This is when the battery reached 4.2V. The current decreases in a controlled manner.
- **Zero:**
 - **Meaning:** Charging has stopped.

OUTPUT FROM LT3080:



1. Linear ramp (dynamic adaptation)

- The voltage increases linearly from approx. 1.0V to 4.2V.
- **Why?:** This is the Constant Current (DC) phase.
 - As the battery charges, its internal voltage increases.
 - In order to be able to still push the same current (200mA) into the battery, the LT3080 regulator is forced to increase its own output voltage.

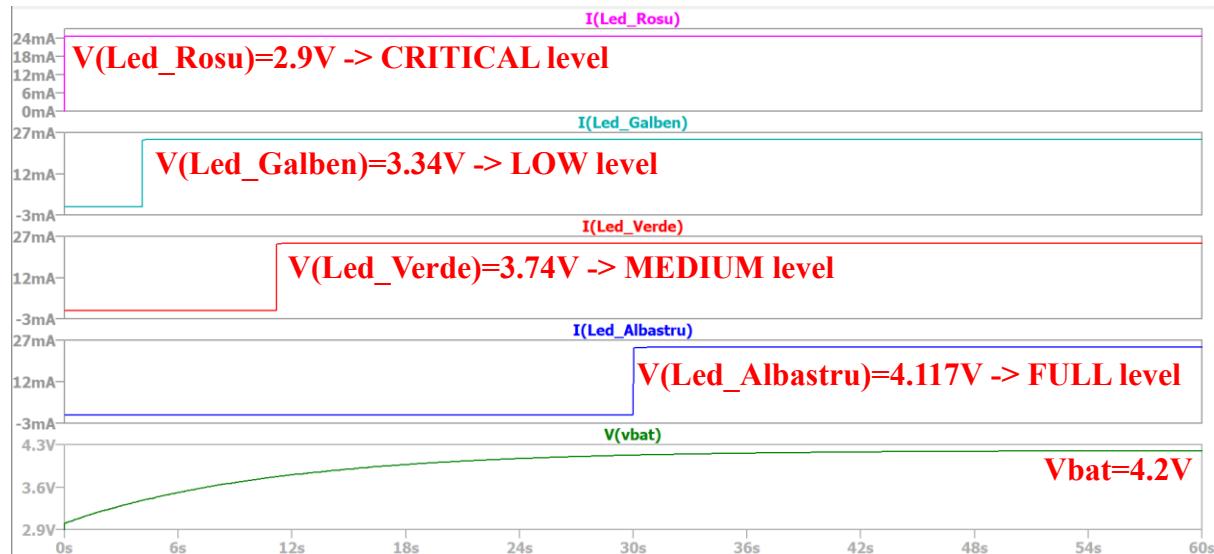
2. "The Spike"

- A small peak just before the line becomes horizontal. The voltage jumps a little above 4.2V and then comes back.
- **Explanation:** This is the transient response to changing the mode of control.
 - In that fraction of a second, the current loop (LM339) "lets go" of control, and the voltage loop (LM741) "takes" control.

3. Stable Landing

- The voltage remains fixed at a constant value (the cursor shows around 4.19V - 4.2V).
- **Why:** The regulator has entered **Constant Voltage (CV) mode**. No matter what the battery does now, the LT3080 won't let the voltage go up any further.

MEASURED THRESHOLD VALUES:



1. Green curve ($V(V_{bat})$) – reference

- This is the battery voltage that increases linearly over time (from <1V to 4.2V).
- It acts as an independent variable based on which decisions are made to turn on LEDs.

2. Colored Steps (LEDs) - Sequential Activation

The colored lines (Blue, Red, Turquoise, Pink) represent the current through the 4 LEDs.

- **OFF status:** When the line is at 0mA, the LED is off.
- **ON Status:** When the line jumps to ~14mA, the LED lights up.

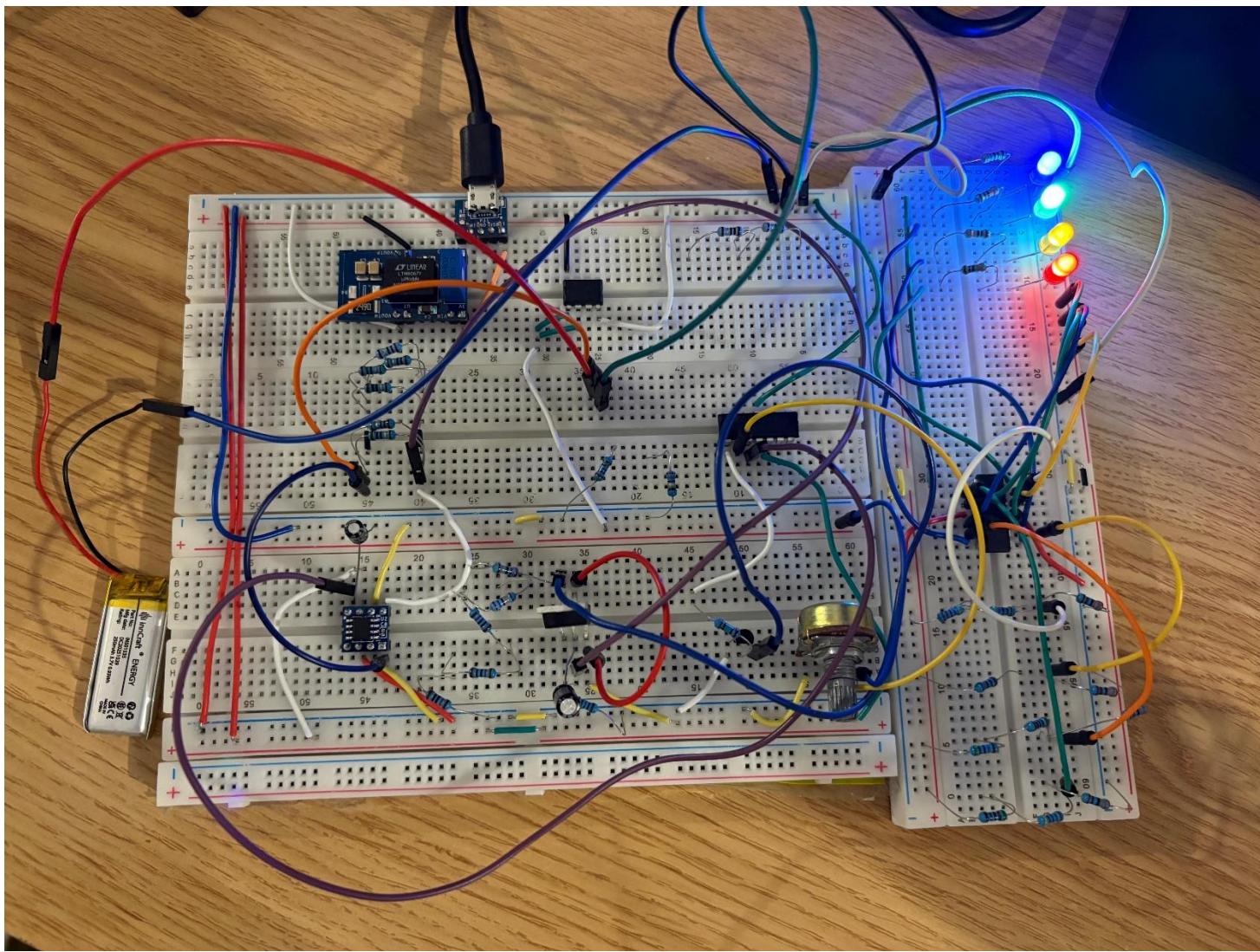
3. LED Current Validation

- The graph shows a current of about **14mA** through each LED lit.

- The 470Ω resistors limit the current so as not to burn the LEDs, but ensuring sufficient brightness.

SOLVING THE THEME ON PHYSICAL ASSEMBLY

COMPLETE ASSEMBLY:



Description of Visible Components in the Prototype

The image captures a complex experimental setup, made on two interconnected breadboards, configured to simulate the charging and discharging process of a **3.8V battery**.

1. Power and Stabilization Section (Top)

- LT3080 regulator:** It can be seen on the upper left, mounted in a capsule that allows heat dissipation. It acts as a fine tuning element for the output voltage.
- AD8210 Monitor:** Centrally placed, this current monitoring IC is connected to read the signal from the shunt resistors (the equivalent resistance obtained is 2.3Ω).
- Power:** On the right side, a **micro-USB module** provides the voltage input, and on the top a **Li-Ion/LiFePO4 battery** is connected via red and black wires.

2. Load and Measure Resistances

According to the test configuration, instead of the battery (or in parallel with it for discharge tests), the following groups of resistors are visible:

- **Discharge Load:** A group of resistors of 10Ω mounted to simulate the current draw in the battery, allowing the stability of the circuit under load to be tested.
- **Measurement divider:** For precise monitoring of parameters, the following are installed:
 - **A resistance of 270Ω**
 - **A resistance of 22Ω**
- They are used for **measuring voltage drop** and determining current through load resistors, providing the necessary data to the monitoring amplifier.

3. Interfață de Afisare (Bargraph)

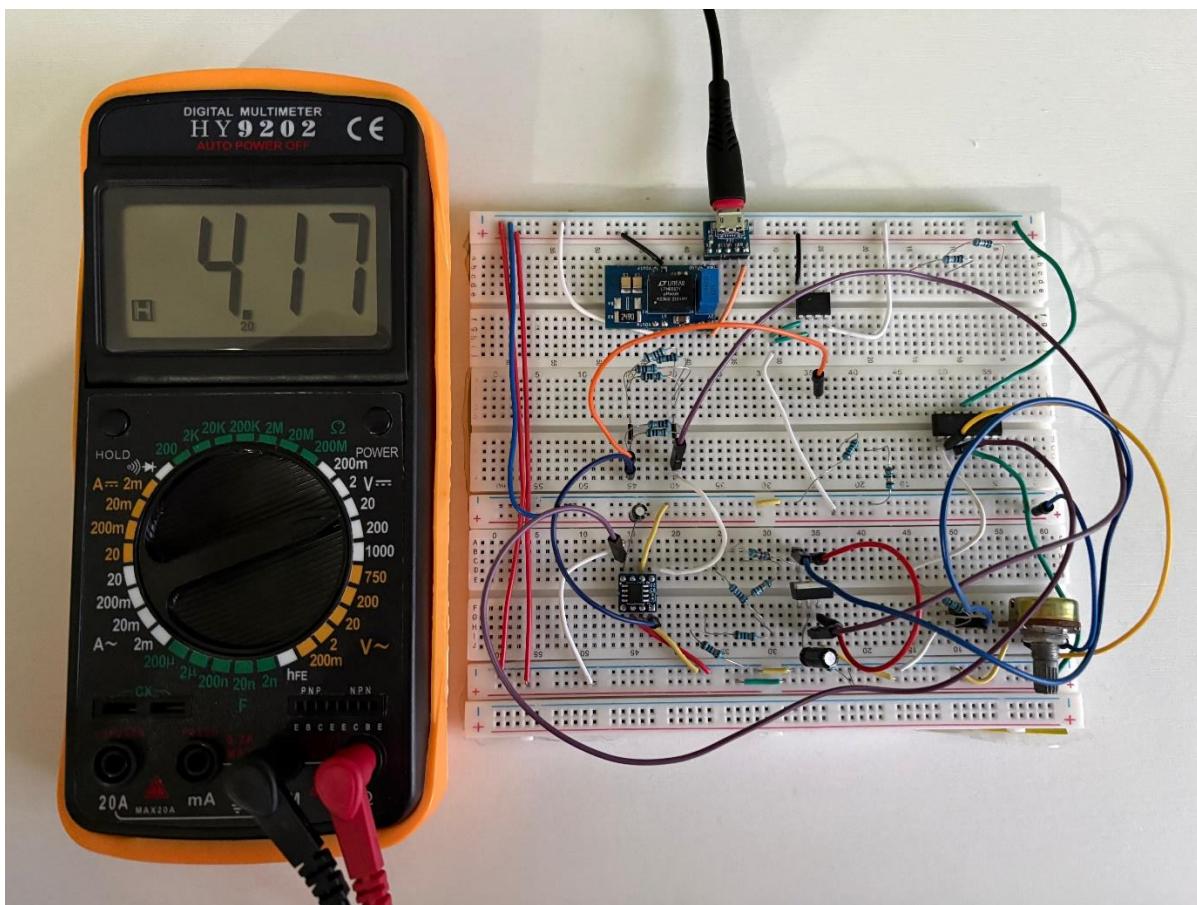
At the bottom of the mount, on the second breadboard, is the visual diagnostic system:

- **LED String:** 4 colored LEDs (Red, Yellow, Green, Blue) that are powered by dedicated limiting resistors.
- **Current status:** In the photo, the LEDs are on, indicating that the level monitoring system (Bargraph) is active and detects a maximum voltage on the circuit.

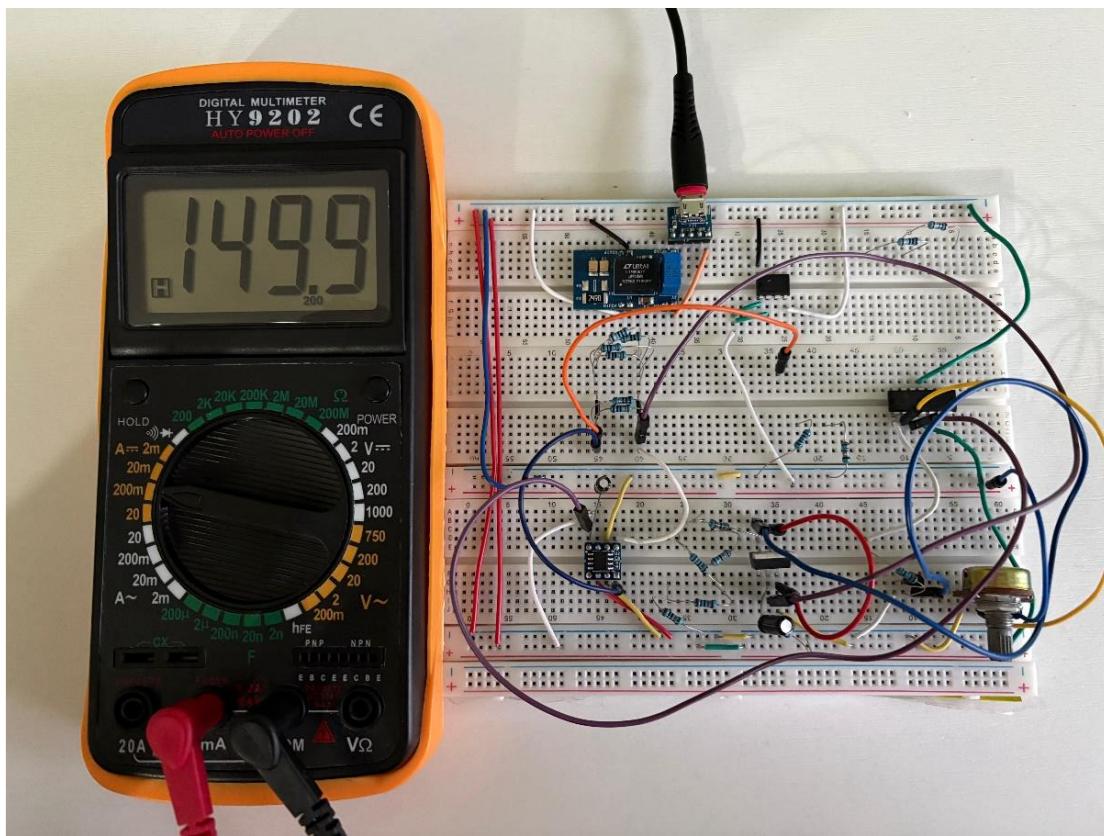
4. Control Element

- **Potentiometer:** Placed at the bottom left of the first board, it serves to adjust the reference thresholds or the output voltage of the LT3080 stabilizer, thus limiting the current to different values (maximum 150mA).
- **Wiring:** A color organization of jumper wires is observed to differentiate data lines from power lines, facilitating quick circuit troubleshooting.

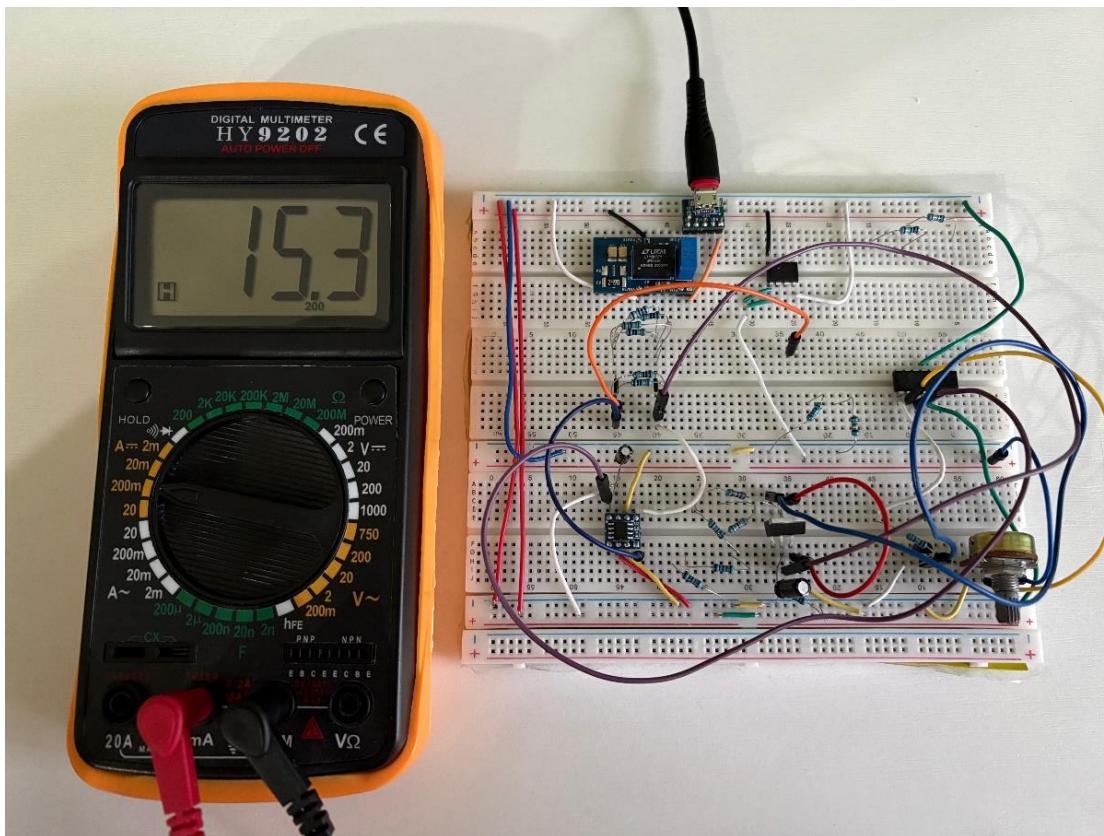
OUTPUT VOLTAGE ON LOAD RESISTORS



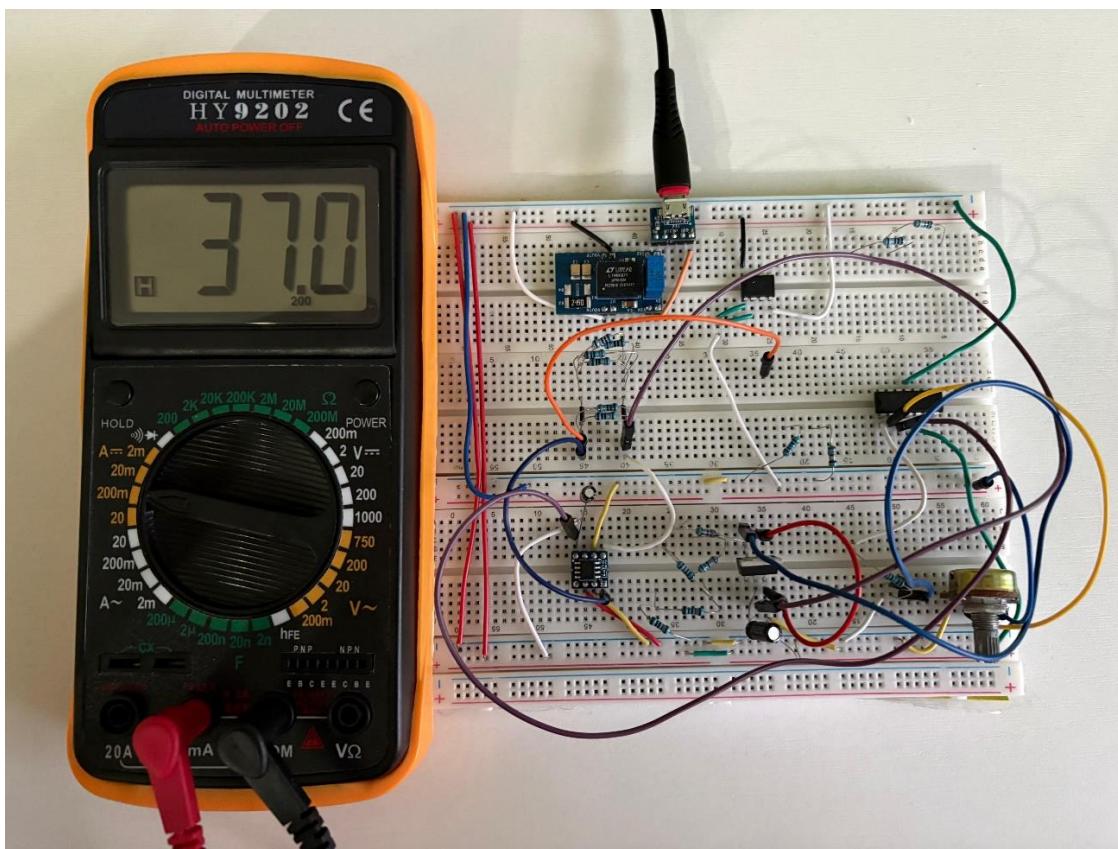
CURRENT ON THE 22Ω RESISTOR (POTENTIOMETER OPEN TO MAXIMUM)



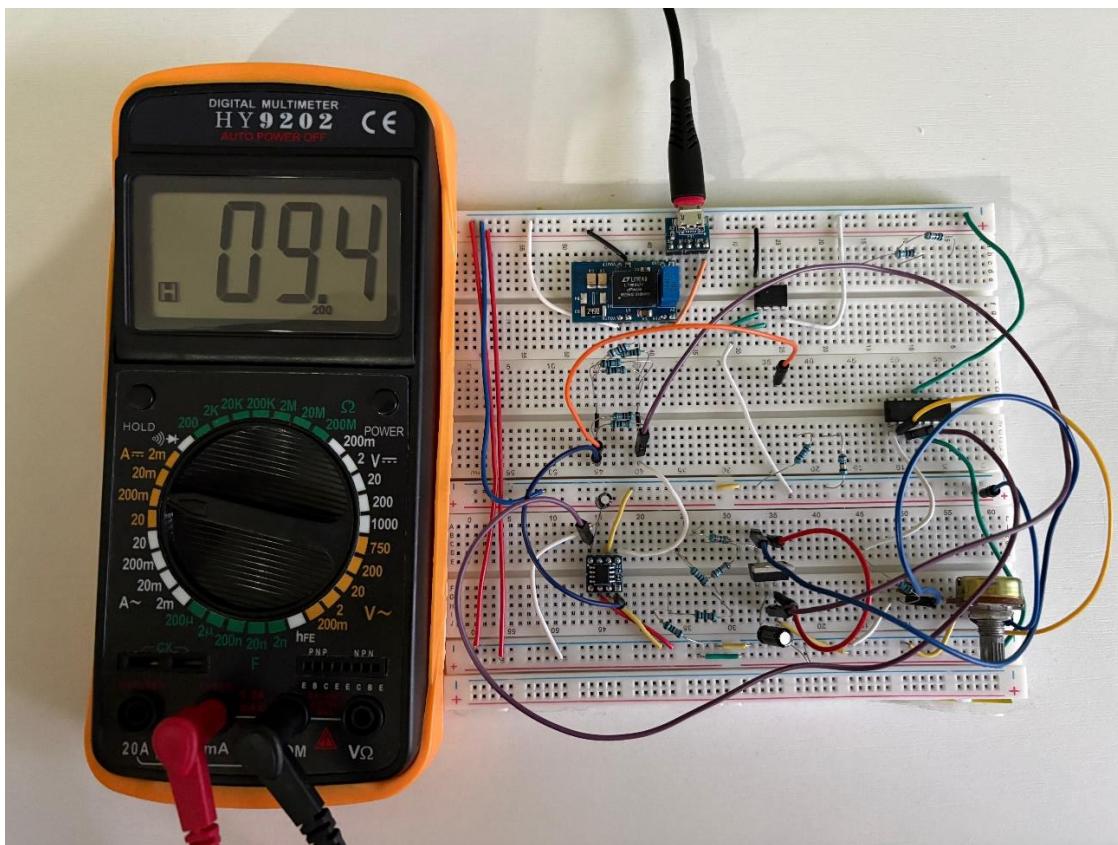
CURRENT ON 270Ω RESISTOR (POTENTIOMETER OPEN TO MAXIMUM)



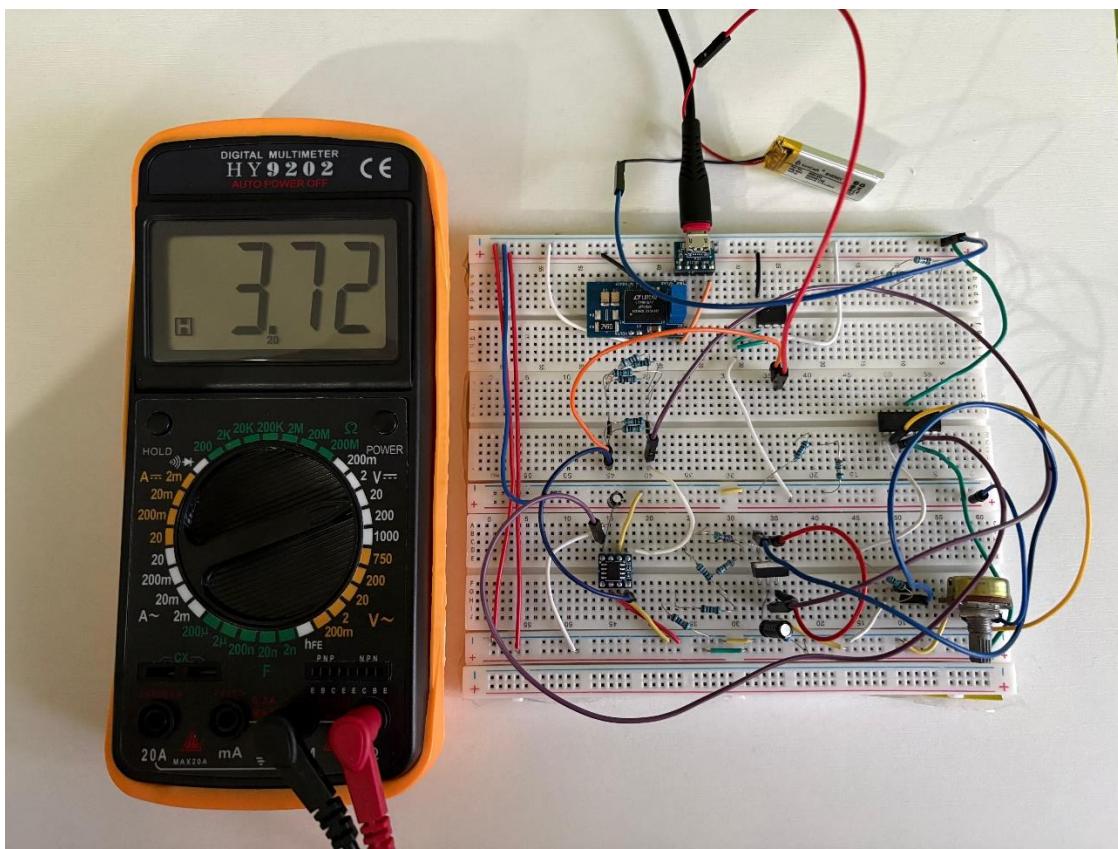
CURRENT ON 22Ω RESISTOR (MAXIMUM POTENTIOMETER CLOSED)



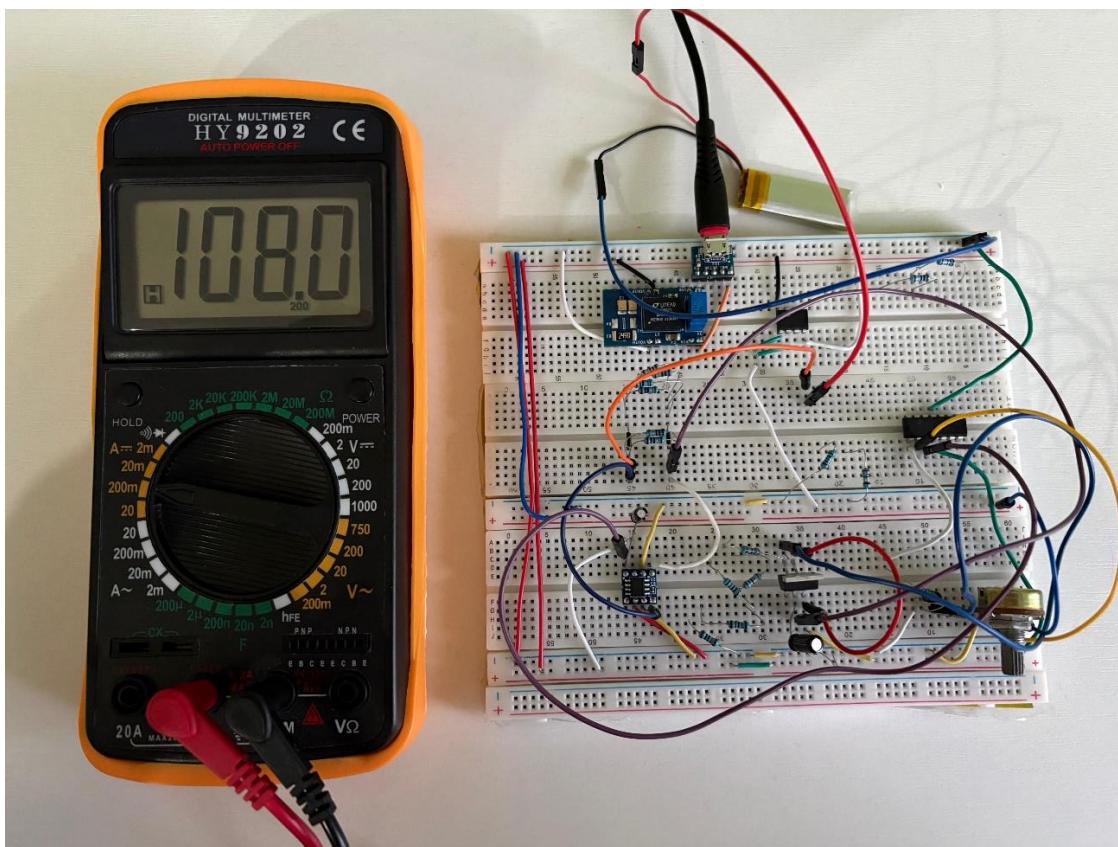
CURRENT ON 270Ω RESISTOR (MAXIMUM POTENTIOMETER CLOSED)



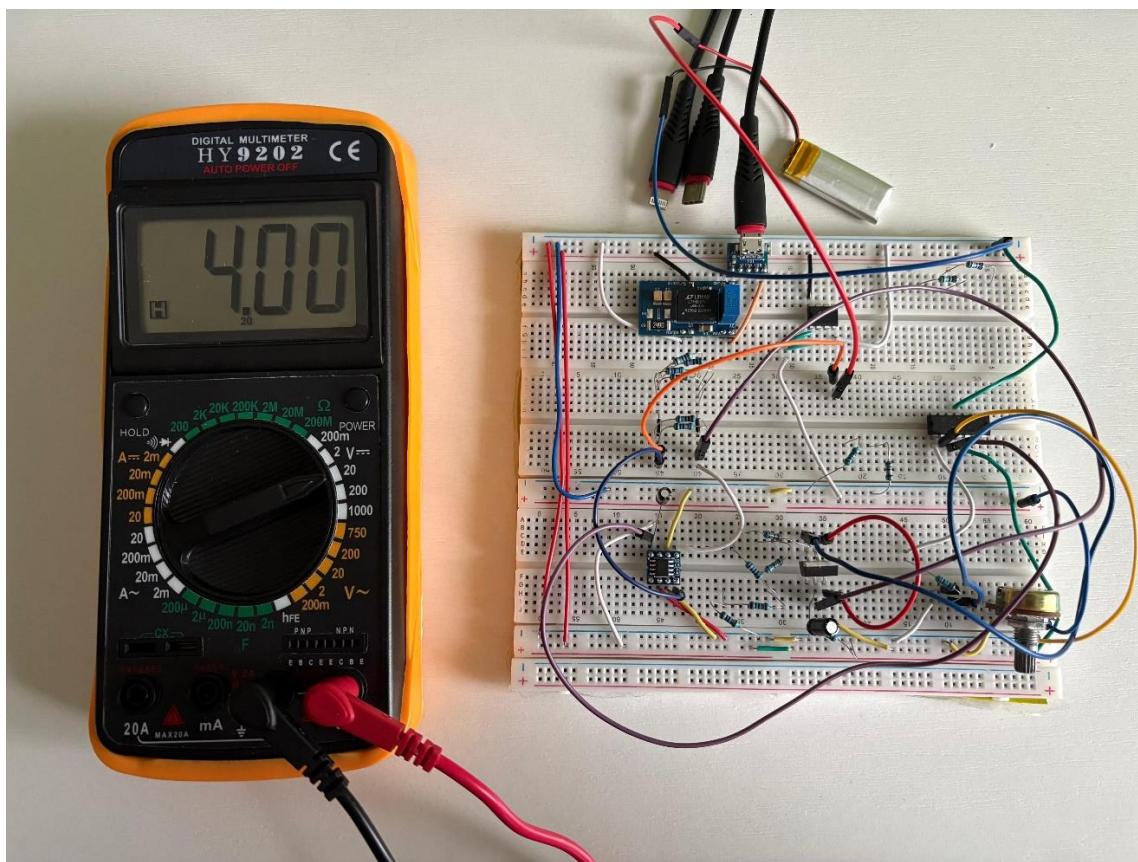
BATTERY CONNECTED TO THE CIRCUIT (DISCHARGED BATTERY = 3.72V)



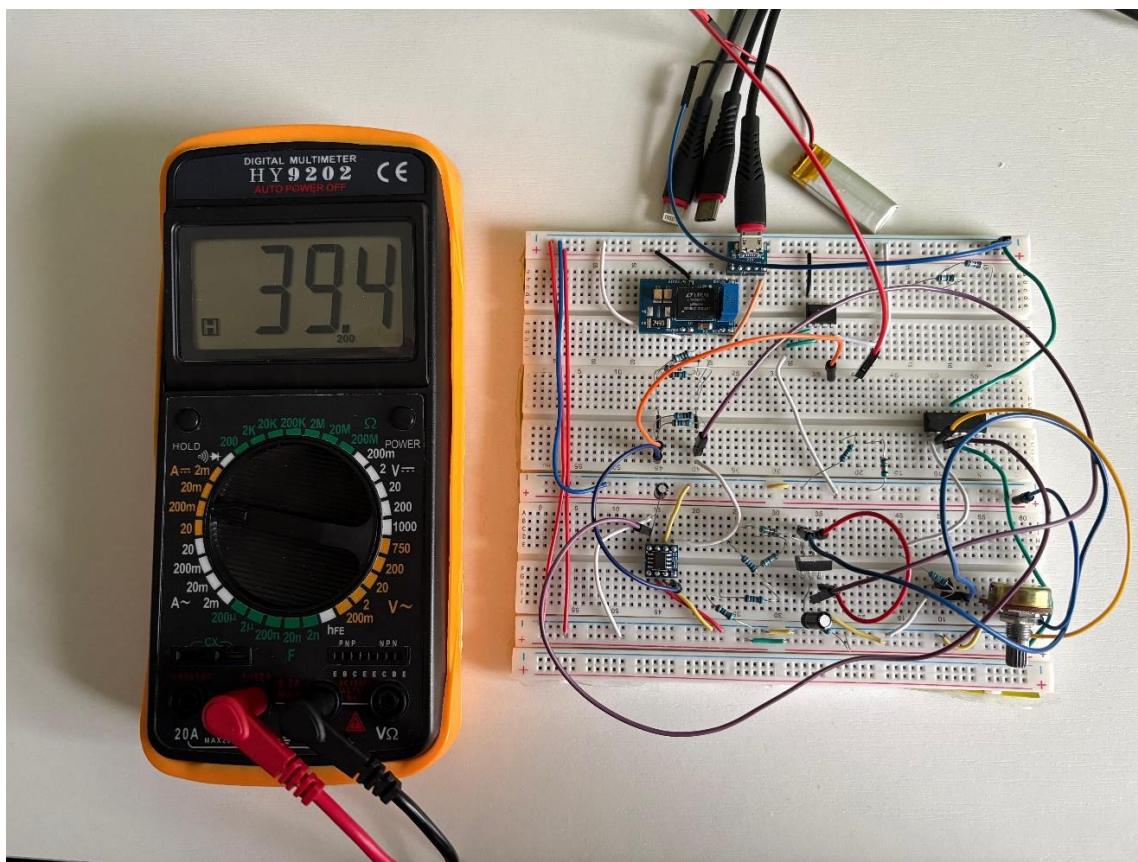
BATTERY CONNECTED IN THE CIRCUIT (CURRENT = 108mA at 3.72V)



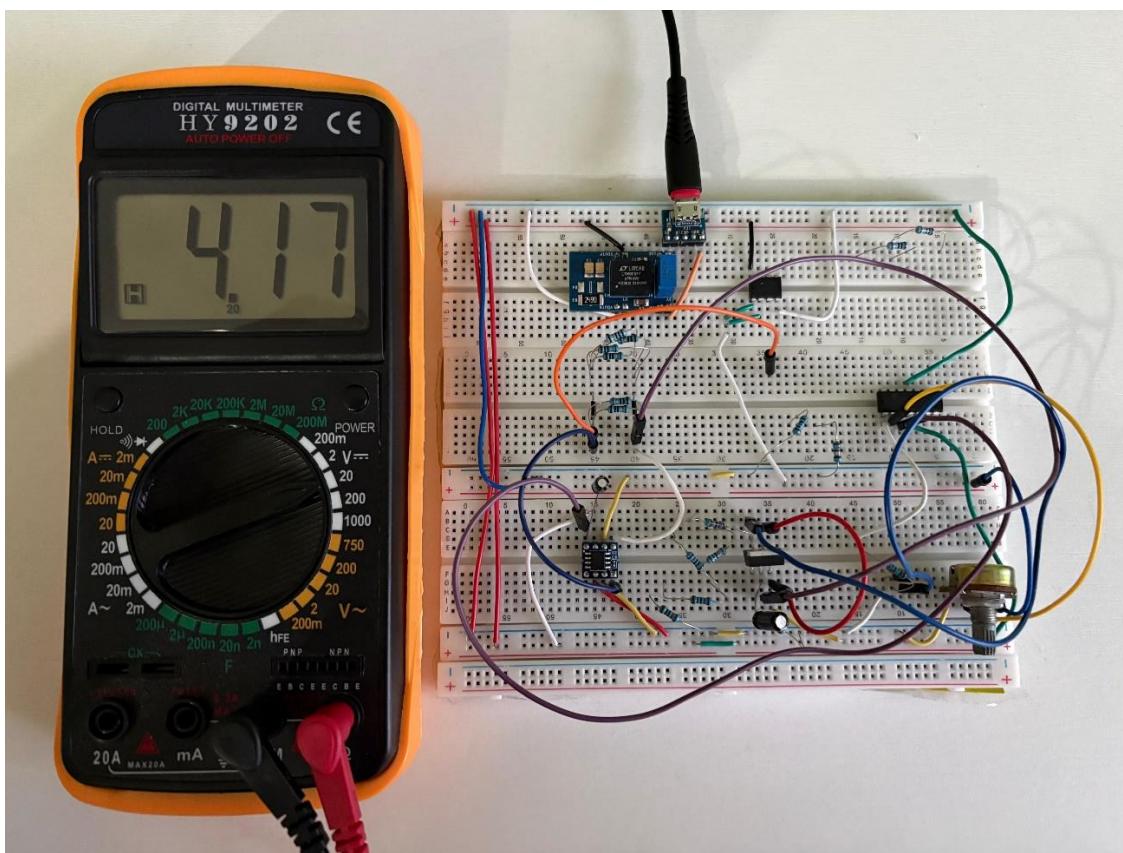
BATTERY CONNECTED IN THE CIRCUIT (BATTERY AT HALF = 4V)



BATTERY CONNECTED TO THE CIRCUIT (CURRENT = 39.4mA at 4V)



BATTERY CONNECTED IN THE CIRCUIT (BATTERY CHARGED = 4.17V)



BATTERY CONNECTED IN THE CIRCUIT (CURRENT = 12.1mA at 4V)

