Switching Regulator Constant Current

Logbook by Timoteo Volante

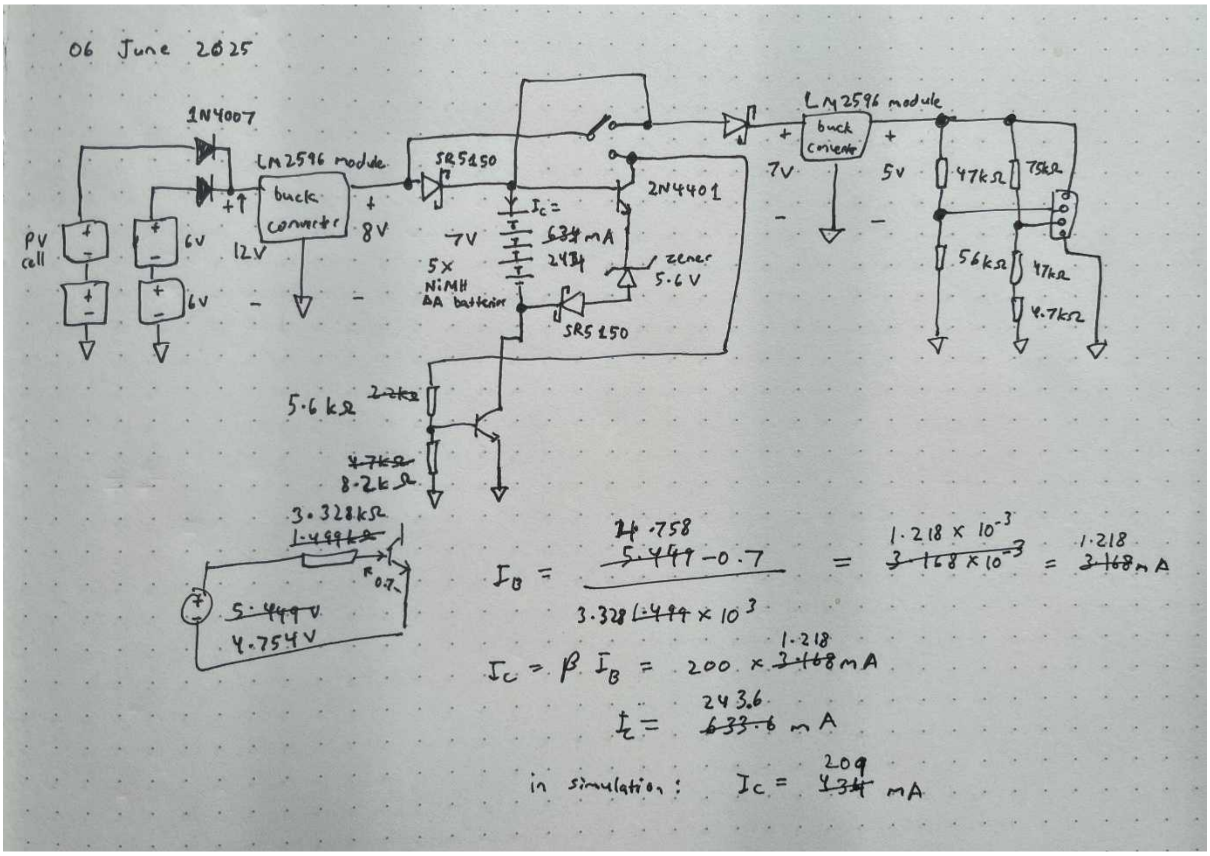
09/06June/25-

-Redesigned the charger to be a constant current trickle charging with a higher voltage input to the buck converter to charge the iPhone.

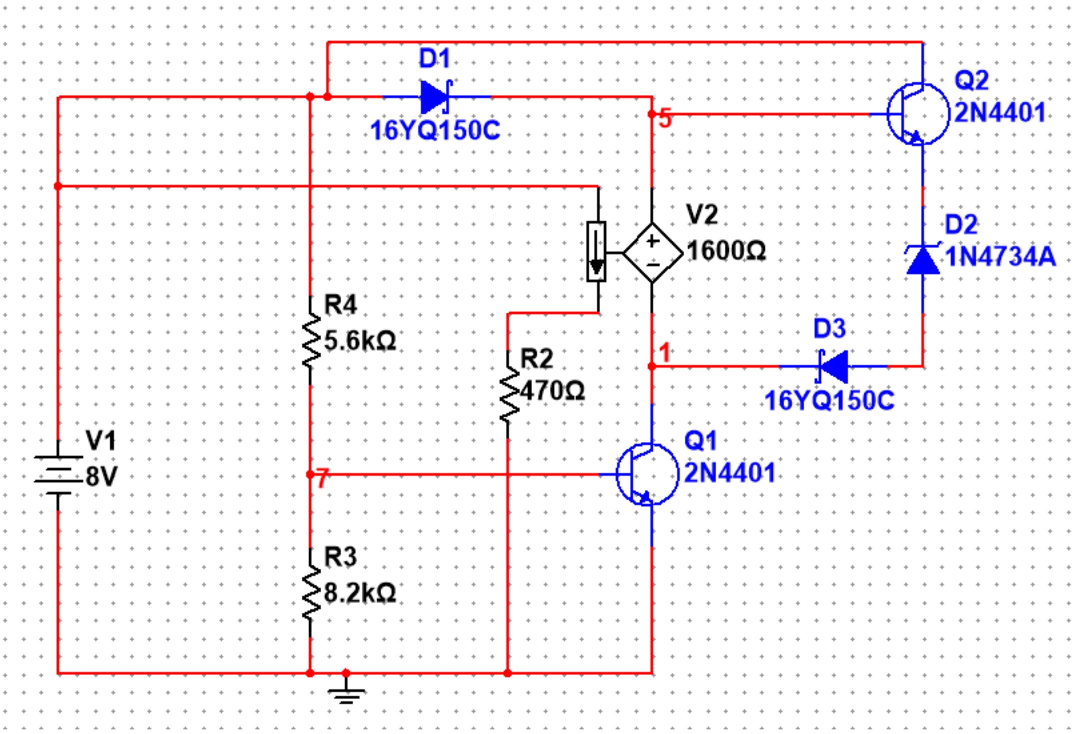
-Planned to make it on a PCB, add a SoC display, replace USB A to C, and add terminal blocks so battery holder and PV cells could be replaced.

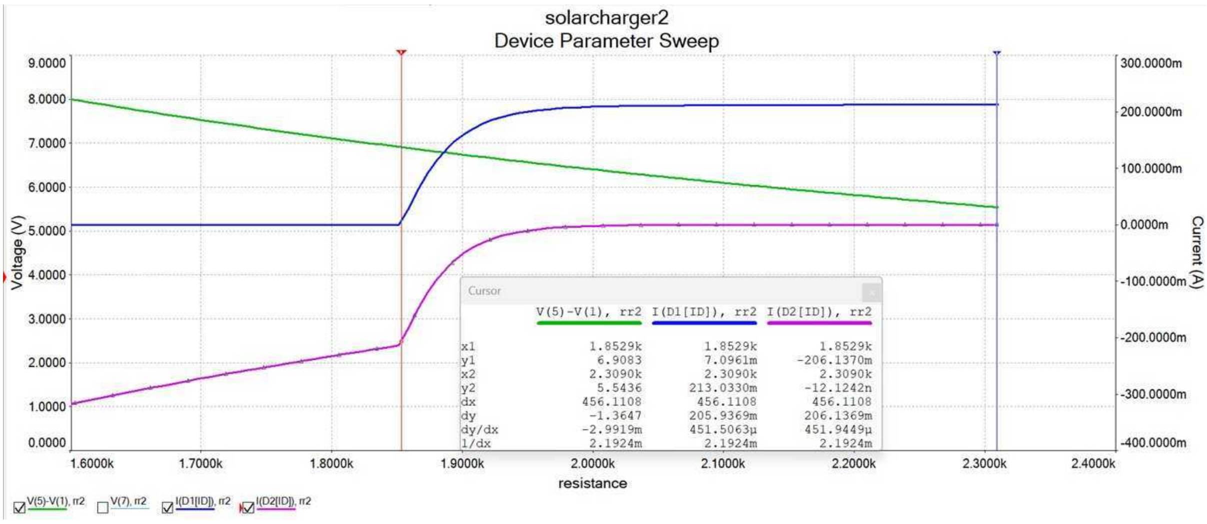
-Planned on using ATtiny85 and reflective LCD for the SoC display.

Battery voltage →Mapper (potential divider) → ATtiny85 → LCD display



-Simulated the constant current charger in NI Multisim using a current dependent voltage source as the battery with the parameter sweep of R2 for range from 7 V to 5.5 V.





PCB sites for instant quote: https://www.pcbuniverse.com/pcbu-quoteNEW.php

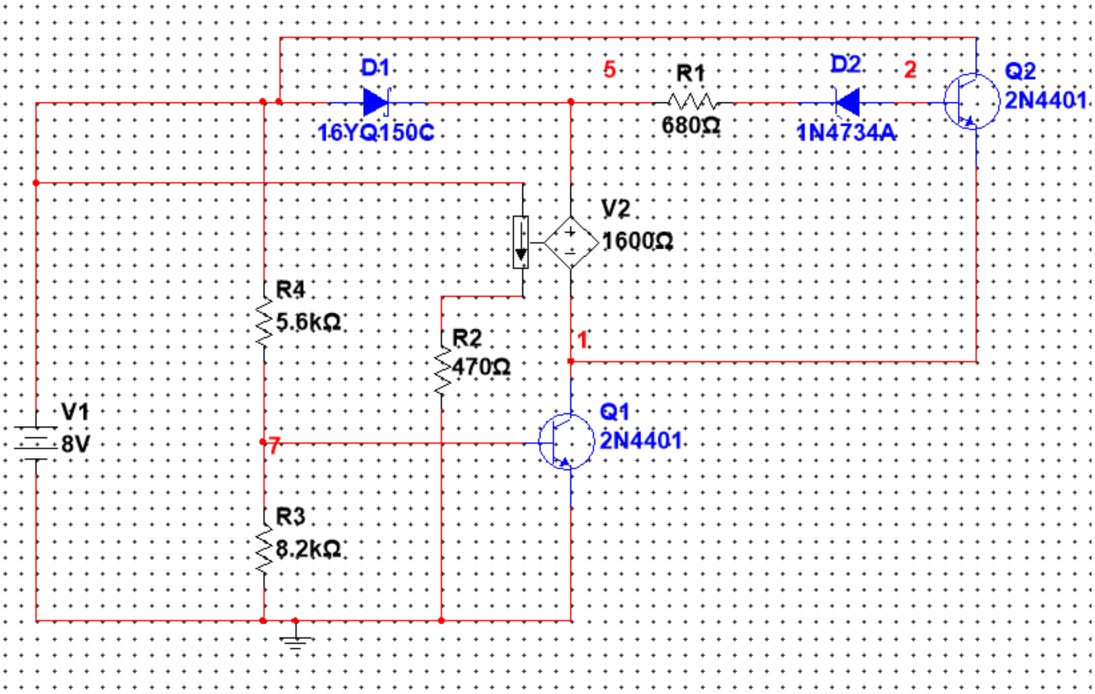
ATtiny85 LCD display example: http://www.technoblogy.com/show?WNM

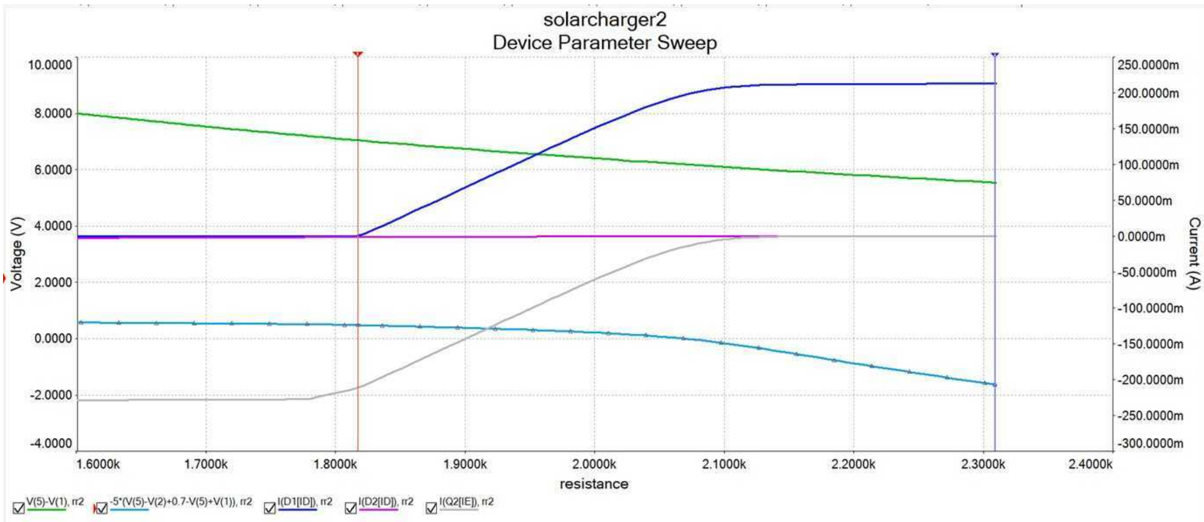
10/06June/25 -

-Looked for components from the internet (Mouser and Amazon).

DollaTek 2Pcs 7-Pin 0.66 inch OLED Display Module 64x48 LCD Screen SPI for Arduino AVR STM32: https://www.amazon.co.uk/DollaTek-Display-Module-Screen-Arduino/dp/B07QDR78H4/ref=asc_df_B07QDR78H4?mcid=792ccf9338b931ce8fd4d1fe4550c9d8&hvocijid=10082752697921516361-B07QDR78H4-&hvexpln=74&tag=googshopuk-21&linkCode=df0&hvadid=696285193871&hvpos=&hvnetw=g&hvrand=10082752697921516361&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1006671&hvtargid=pla-2281435176698&psc=1&gad_source=1

-Redesigned the drive circuit for the overcharge protection.





Cursor

	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D1[ID]), rr2	I(D2[ID]), rr2	I(Q2[IE]), rr2
x1	1.8167k	1.8167k	1.8167k	1.8167k	1.8167k
y1	7.0457	476.9625m	744.4316µ	-1.0979m	-211.4141m
x2	2.3088k	2.3088k	2.3088k	2.3088k	2.3088k
y2	5.5439	-1.6347	213.0322m	-2.8559n	-54.1694n
dx	492.1212	492.1212	492.1212	492.1212	492.1212
dy	-1.5018	-2.1117	212.2878m	1.0979m	211.4140m
dy/dx	-3.0516m	-4.2909m	431.3730µ	2.2310µ	429.5975µ
1/dx	2.0320m	2.0320m	2.0320m	2.0320m	2.0320m

11/06June/25 -

-Charged AA Eneloop batteries using the previous charger.

-Ordered components from Mouser and Amazon.

-Battery voltages after charging: 1.357, 1.358, 1.358, 1.359

-Charged batteries for full 2 days uninterrupted.

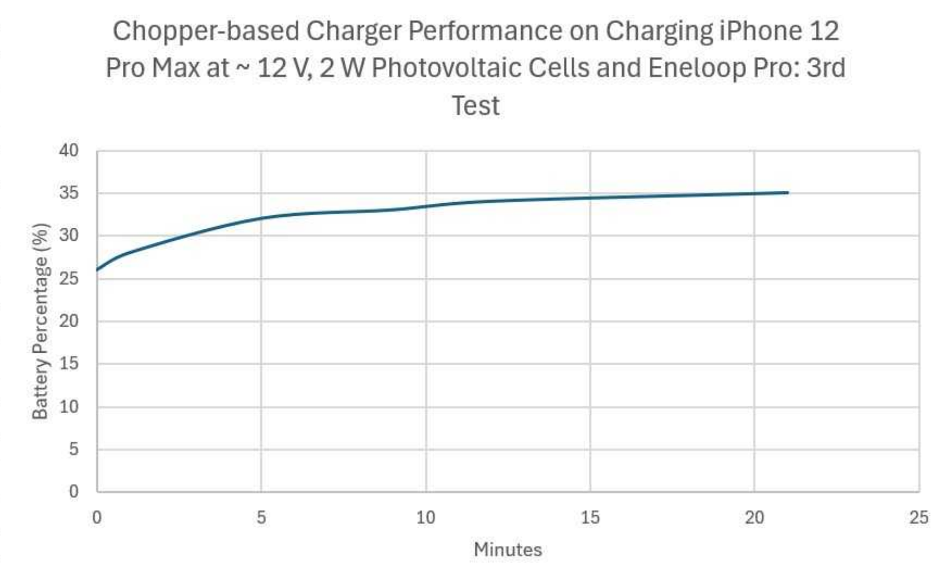
19/06June/25 -

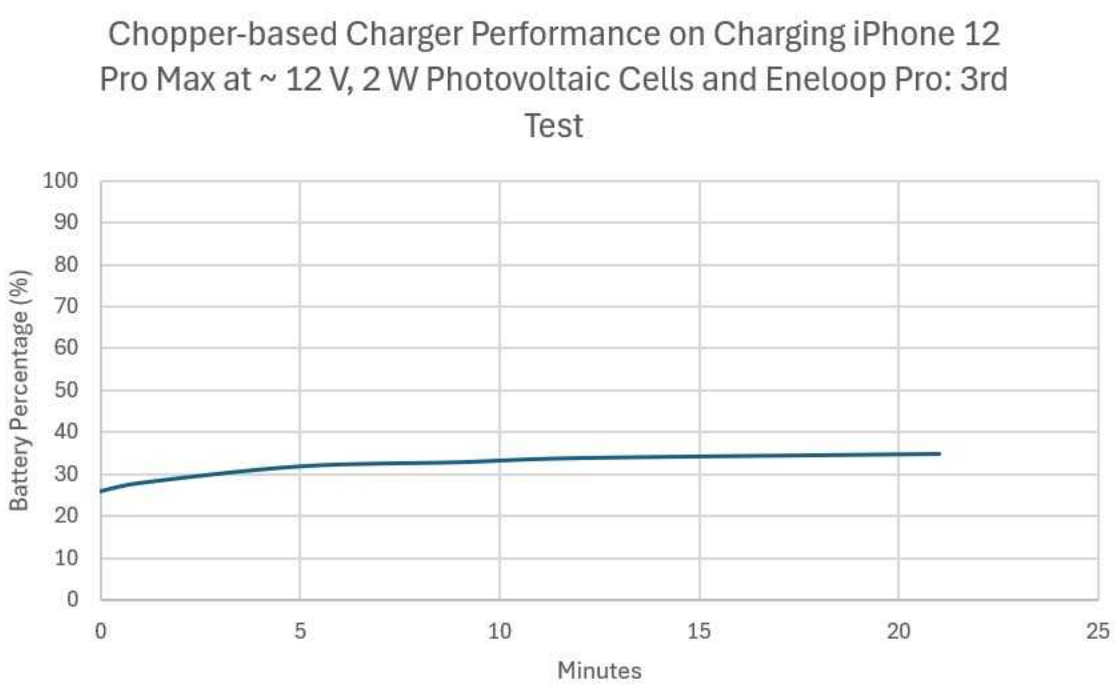
-Charged iPhone and gathered data.

* 9% increased for 21 minutes.

2.815 x 0.09 = 0.253 Ah → 0.253 / (21/60) = 0.723 A average charging rate

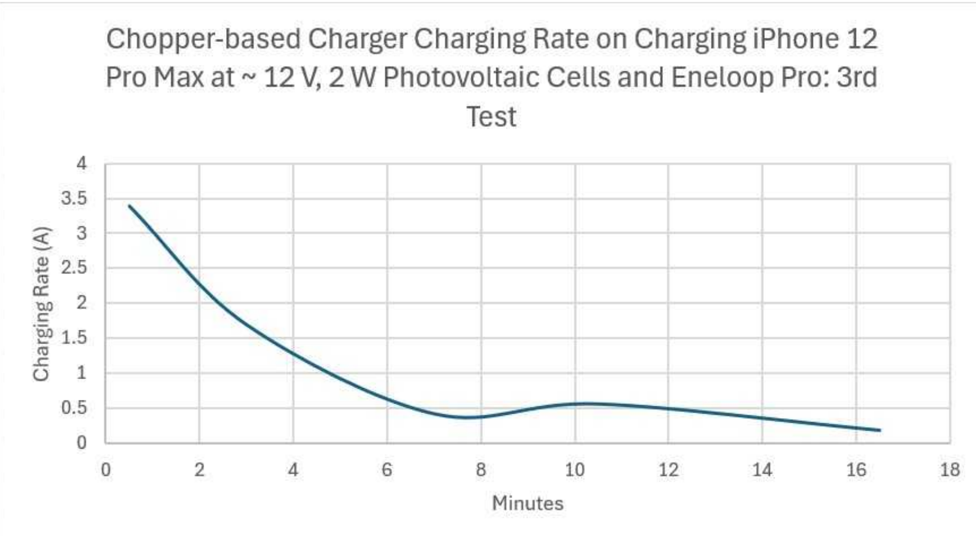
mins	Bat %
0	26
1	28
5	32
9	33
12	34
21	35





Formula to calculate current: 2.815 x (% change / (change in time in min/ 60))

mins	current
0.5	3.38
3	1.69
7	0.422
10.5	0.563
16.5	0.188



15/07July/25-

-Watched KiCad 7.0 tutorial: https://www.youtube.com/watch?v=3FGNw28xBr0 .

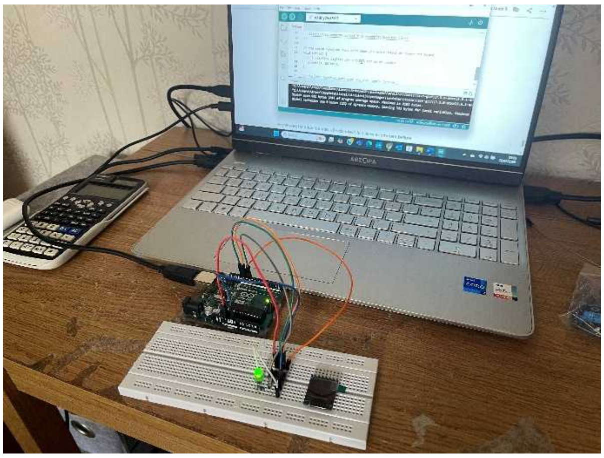
-Adjustable buck converter lm2596: https://www.onsemi.com/download/data-sheet/pdf/lm2596-d.pdf

17/07July/25-

-Read https://www.instructables.com/How-to-Program-an-Attiny85-From-an-Arduino-Uno/ .

22/07July/25-

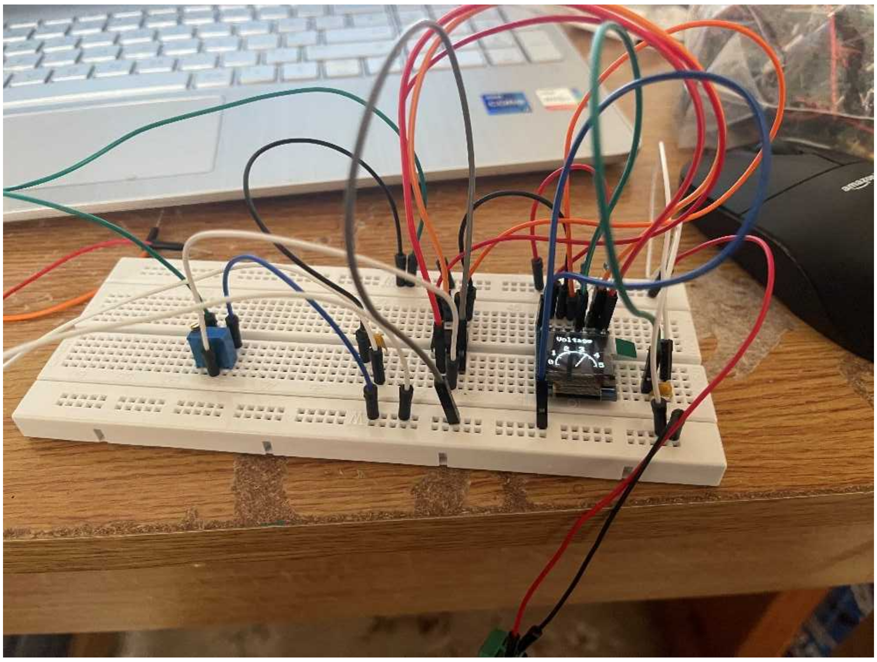
-Set up the Arduino to program the Attiny85: burnt the bootloader and uploaded a simple sketch Blink.



-White 0.66 inch OLED Display Module 64x48: https://static.rapidonline.com/pdf/61-6335_v1.pdf .

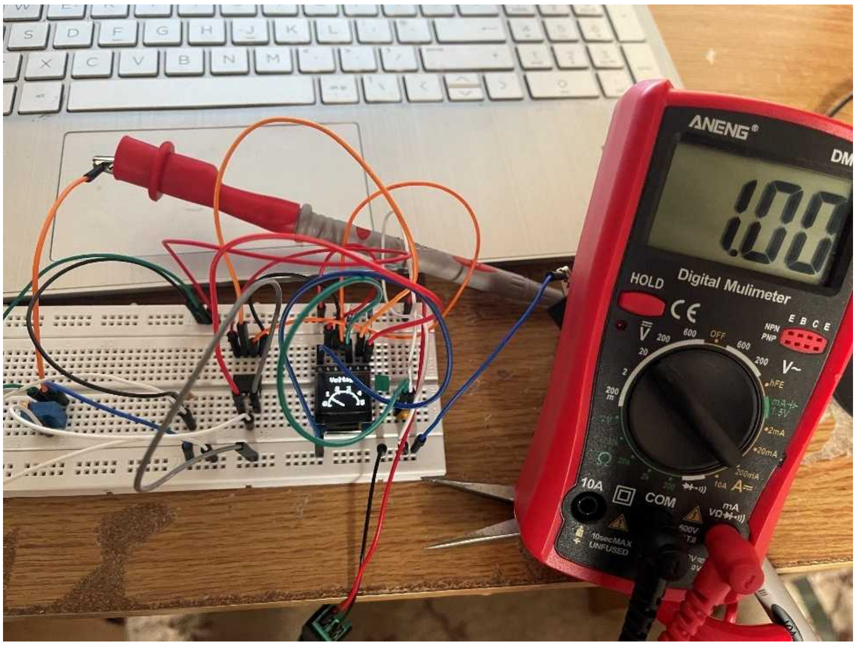
23/07July/25 -

-Tested the voltmeter display.



27/07July/25 -

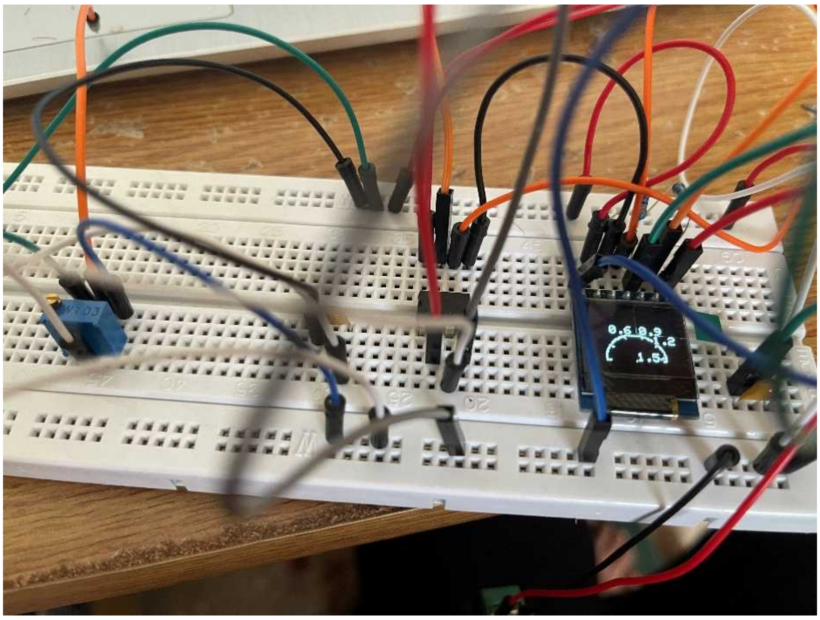
-Checked the voltmeter’s accuracy.



29/07July/25-

-Changed the readings to read the exact voltage of each AA battery.

-Planned to divide the battery holder voltage by 1.5 (1.5k and 1k voltage divider).



31/07July/25 -

-Constructed the buck converter.

-Tested the buck converter with the AA battery charger circuit on breadboard.

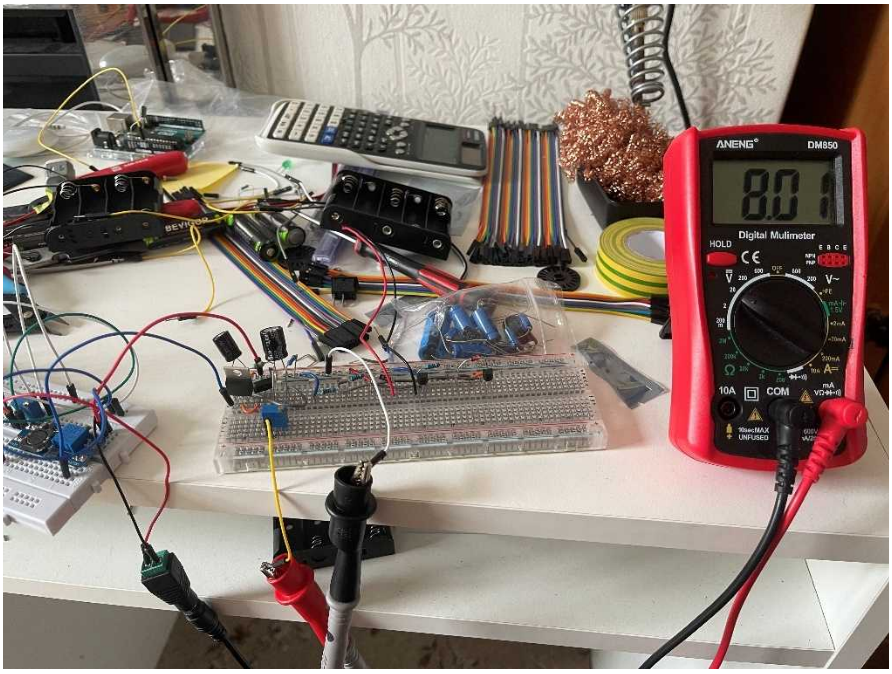
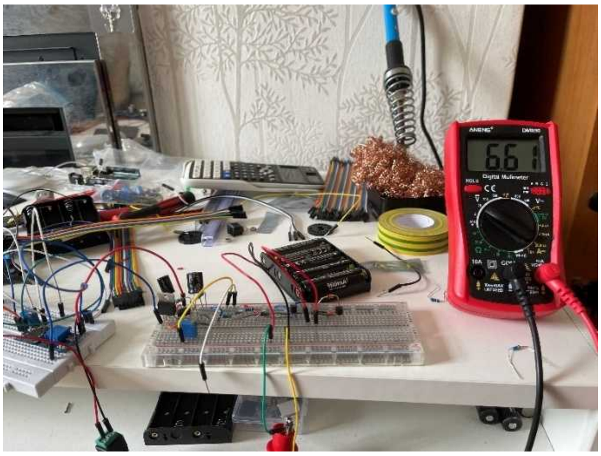
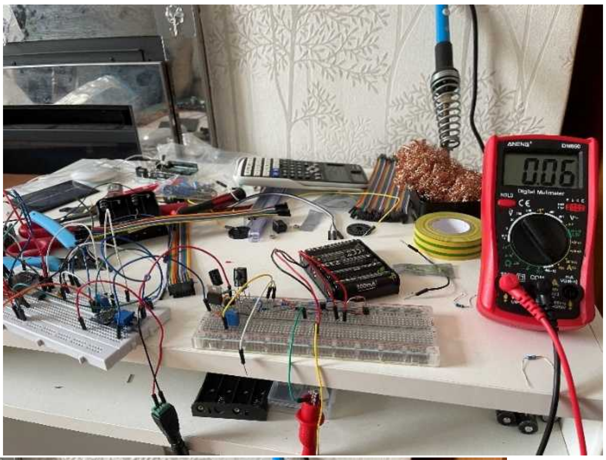


Figure: buck converter 8 V


6.61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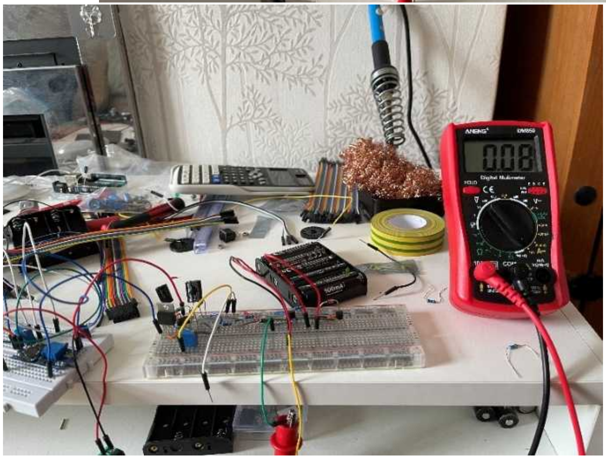
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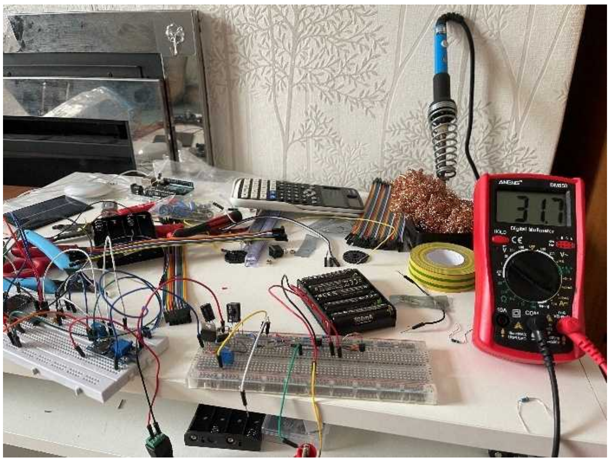
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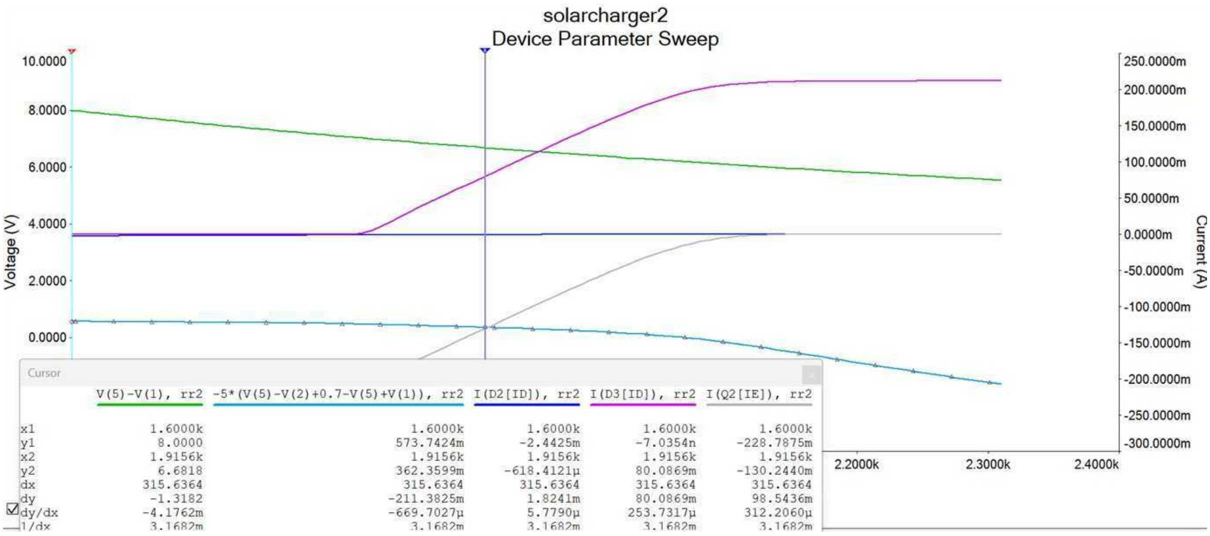
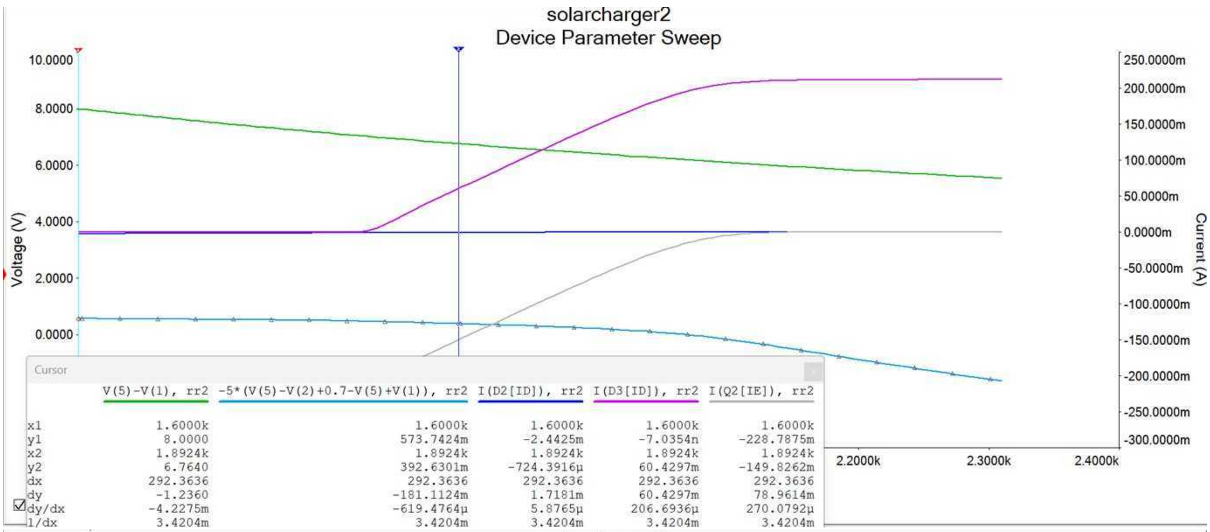
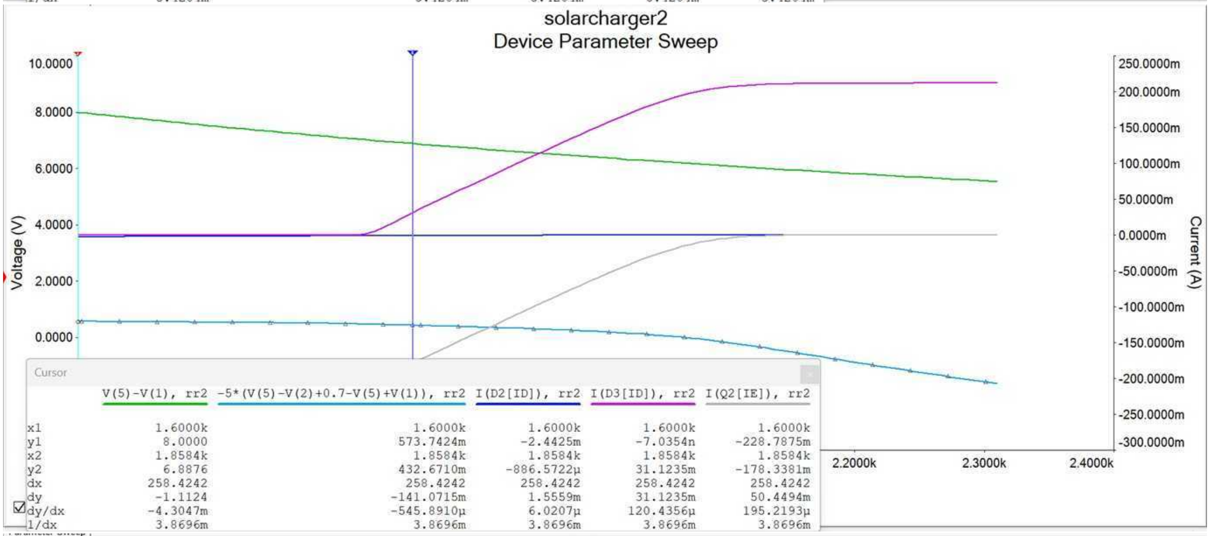
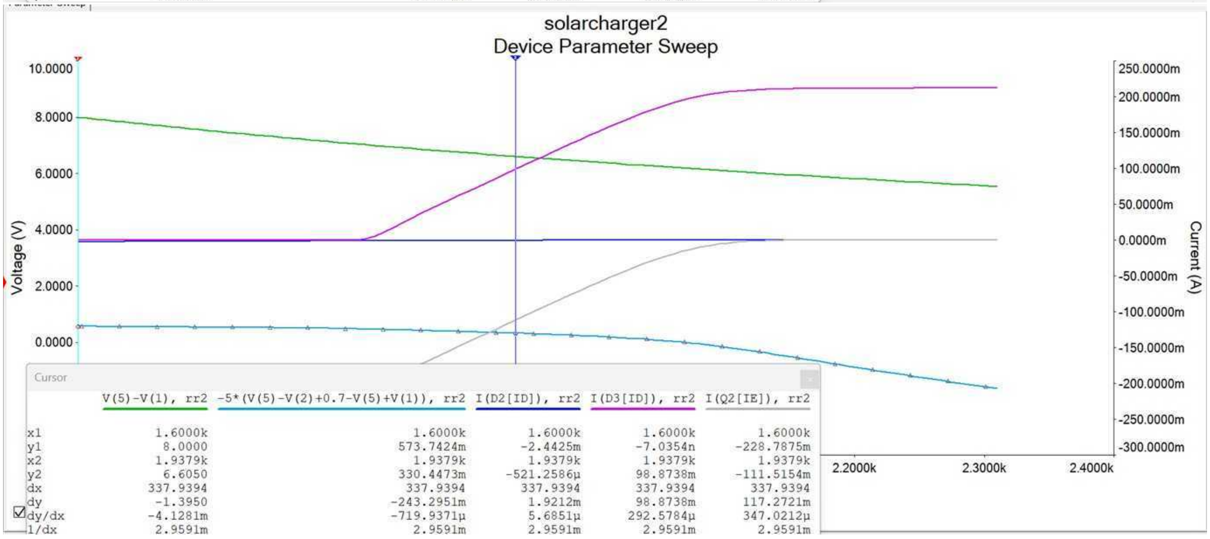

solarcharger2
Device Parameter Sweep
Voltage (V)
Current (A)
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
250.0000m
200.0000m
150.0000m
100.0000m
50.0000m
0.0000m
-50.0000m
-100.0000m
-150.0000m
-200.0000m
-250.0000m
-300.0000m
2.2000k
2.3000k
2.4000k
Cursor
V(5)-V(1), rr2
-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2
I(D2[ID]), rr2
I(D3[ID]), rr2
I(Q2[IE]), rr2
x1 1.6000k 1.6000k 1.6000k 1.6000k 1.6000k
y1 8.0000 573.7424m -2.4425m -7.0354n -228.7875m
x2 1.9156k 1.9156k 1.9156k 1.9156k 1.9156k
y2 6.6818 362.3599m -618.4121µ 80.0869m -130.2440m
dx 315.6364 315.6364 315.6364 315.6364 315.6364
dy -1.3182 -211.3825m 1.8241m 80.0869m 98.5436m
dy/dx -4.1762m -669.7027µ 5.7790µ 253.7317µ 312.2060µ
1/dx 3.1682m 3.1682m 3.1682m 3.1682m 3.1682m


solarcharger2
Device Parameter Sweep
Voltage (V)
Current (A)
Cursor
V(5)-V(1), rr2
-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2
I(D2[ID]), rr2
I(D3[ID]), rr2
I(Q2[IE]), rr2
x1 1.6000k 1.6000k 1.6000k 1.6000k 1.6000k
y1 8.0000 573.7424m -2.4425m -7.0354n -228.7875m
x2 1.8924k 1.8924k 1.8924k 1.8924k 1.8924k
y2 6.7640 392.6301m -724.3916µ 60.4297m -149.8262m
dx 292.3636 292.3636 292.3636 292.3636 292.3636
dy -1.2360 -181.1124m 1.7181m 60.4297m 78.9614m
dy/dx -4.2275m -619.4764µ 5.8765µ 206.6936µ 270.0792µ
1/dx 3.4204m 3.4204m 3.4204m 3.4204m 3.4204m


solarcharger2
Device Parameter Sweep
Voltage (V)
Current (A)
Cursor
V(5)-V(1), rr2
-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2
I(D2[ID]), rr2
I(D3[ID]), rr2
I(Q2[IE]), rr2
x1 1.6000k 1.6000k 1.6000k 1.6000k 1.6000k
y1 8.0000 573.7424m -2.4425m -7.0354n -228.7875m
x2 1.8584k 1.8584k 1.8584k 1.8584k 1.8584k
y2 6.8876 432.6710m -886.5722µ 31.1235m -178.3381m
dx 258.4242 258.4242 258.4242 258.4242 258.4242
dy -1.1124 -141.0715m 1.5559m 31.1235m 50.4494m
dy/dx -4.3047m -545.8910µ 6.0207µ 120.4356µ 195.2193µ
1/dx 3.8696m 3.8696m 3.8696m 3.8696m 3.8696m


solarcharger2
Device Parameter Sweep
Voltage (V)
Current (A)
Cursor
V(5)-V(1), rr2
-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2
I(D2[ID]), rr2
I(D3[ID]), rr2
I(Q2[IE]), rr2
x1 1.6000k 1.6000k 1.6000k 1.6000k 1.6000k
y1 8.0000 573.7424m -2.4425m -7.0354n -228.7875m
x2 1.9379k 1.9379k 1.9379k 1.9379k 1.9379k
y2 6.6050 330.4473m -521.2586µ 98.8738m -111.5154m
dx 337.9394 337.9394 337.9394 337.9394 337.9394
dy -1.3950 -243.2951m 1.9212m 98.8738m 117.2721m
dy/dx -4.1281m -719.9371µ 5.6851µ 292.5784µ 347.0212µ
1/dx 2.9591m 2.9591m 2.9591m 2.9591m 2.9591m

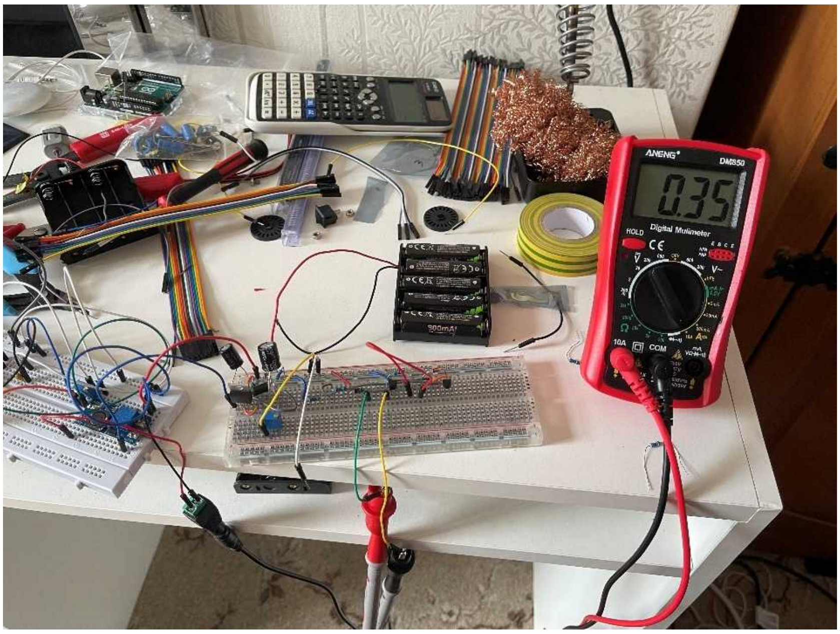
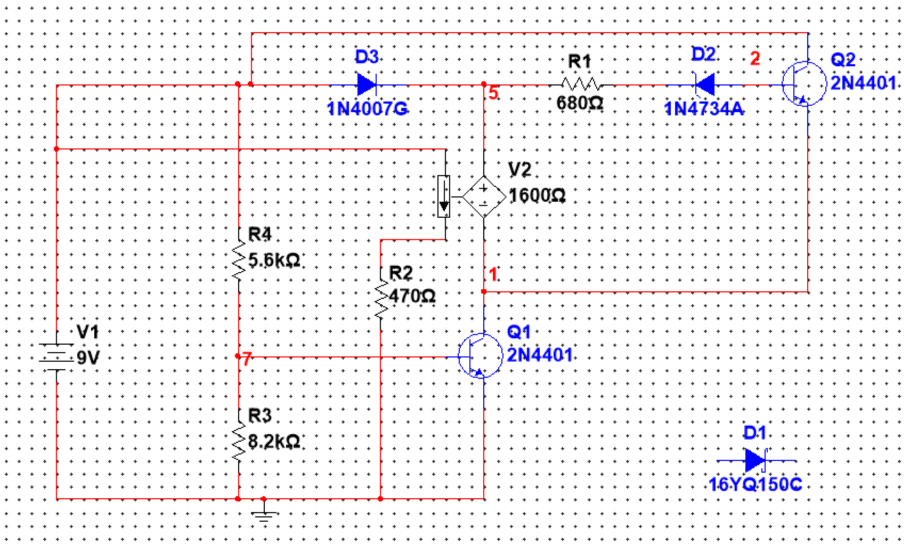
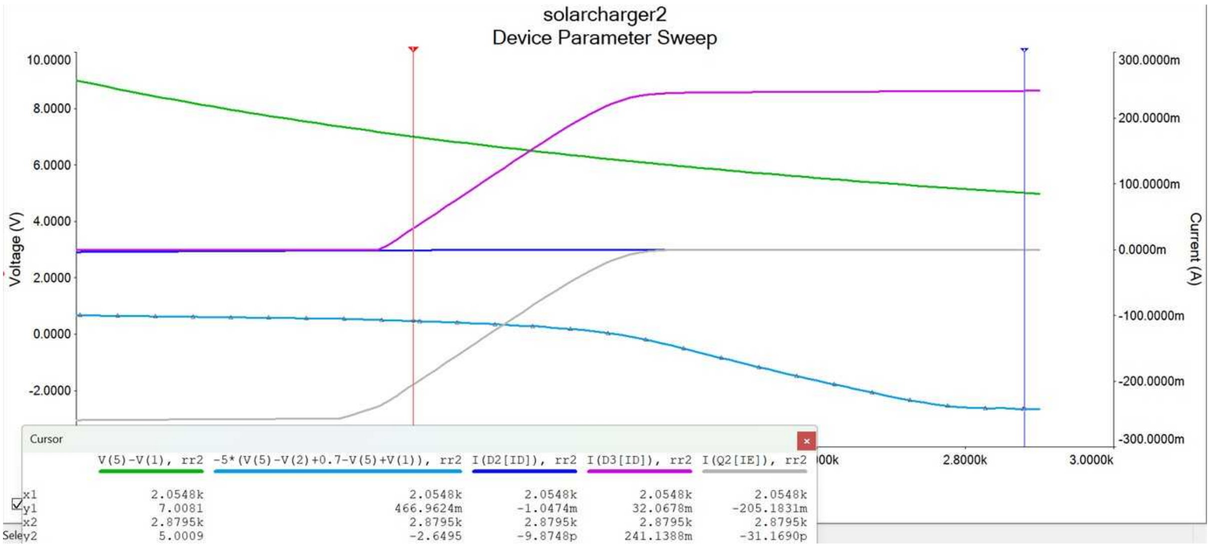


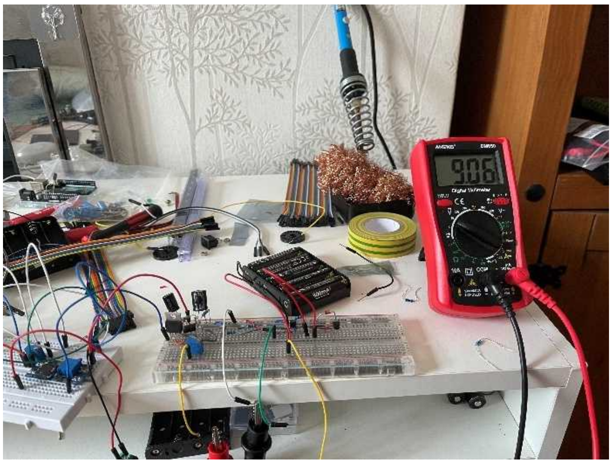
Figure: Without load. Ic = 350 mA

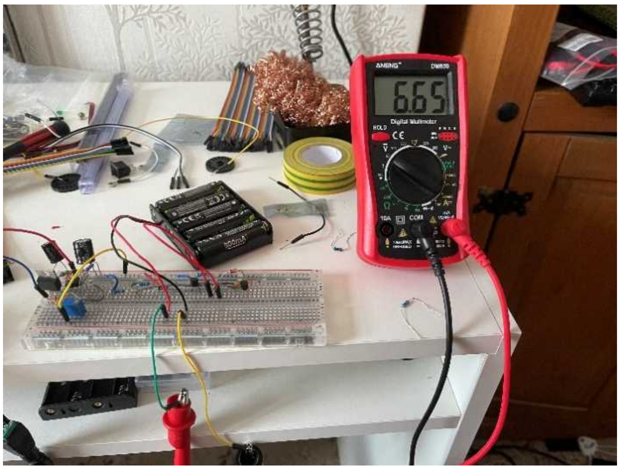
-Changed the output voltage of the buck converter to 9 V instead of 8 V.

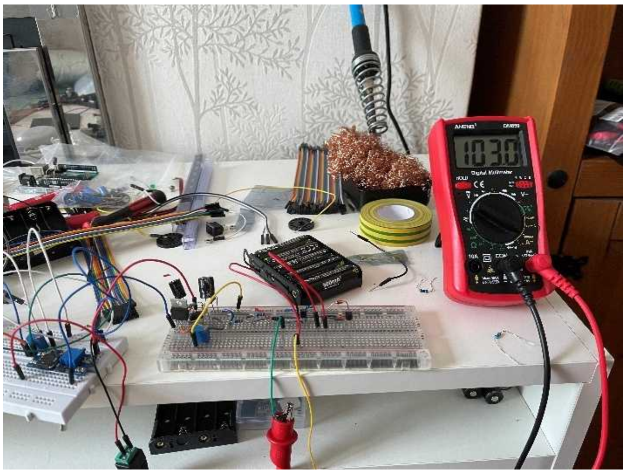




-Tested the 9V to the charger.



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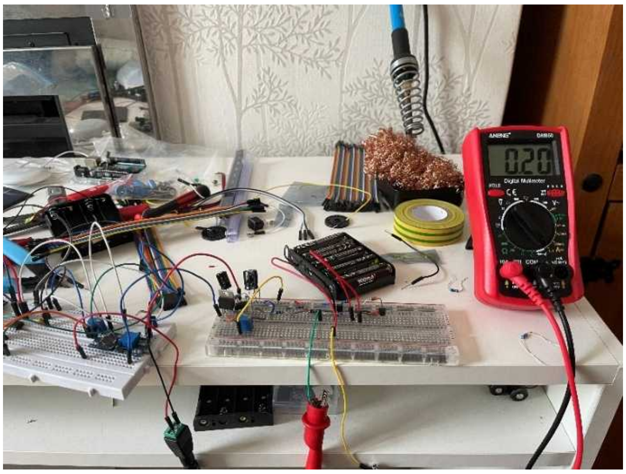
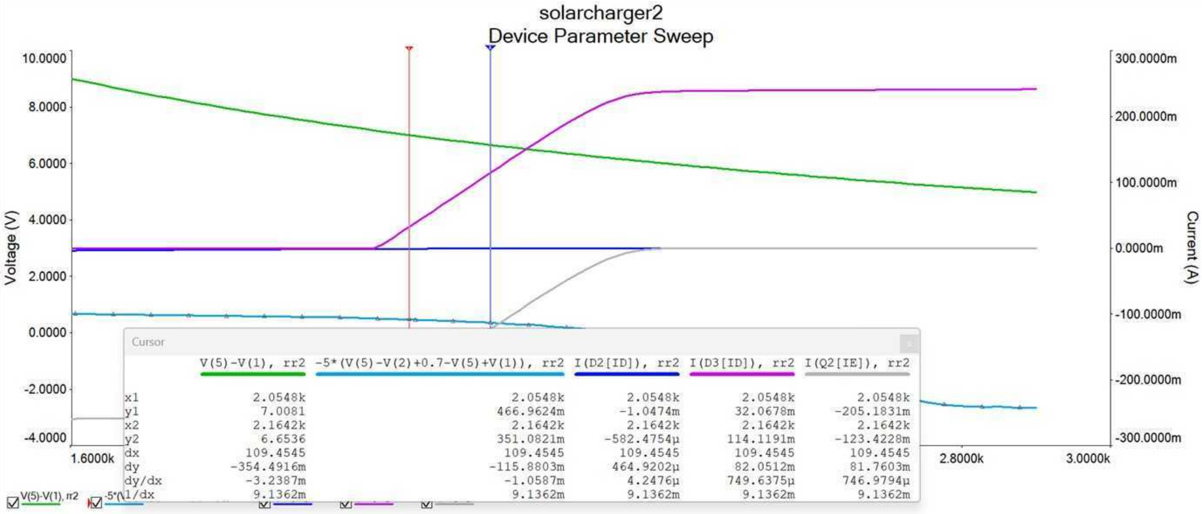

020


solarcharger2
Device Parameter Sweep
Voltage (V)
Current (A)
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
-2.0000
-4.0000
300.0000m
200.0000m
100.0000m
0.0000m
-100.0000m
-200.0000m
-300.0000m
1.6000k
2.8000k
3.0000k
Cursor
V(5)-V(1), rr2 | -5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2 | I(D2[ID]), rr2 | I(D3[ID]), rr2 | I(Q2[IE]), rr2
x1 2.0548k 2.0548k 2.0548k 2.0548k 2.0548k
y1 7.0081 466.9624m -1.0474m 32.0678m -205.1831m
x2 2.1642k 2.1642k 2.1642k 2.1642k 2.1642k
y2 6.6536 351.0821m -582.4754µ 114.1191m -123.4228m
dx 109.4545 109.4545 109.4545 109.4545 109.4545
dy -354.4916m -115.8803m 464.9202µ 82.0512m 81.7603m
dy/dx -3.2387m -1.0587m 4.2476µ 749.6375µ 746.9794µ
1/dx 9.1362m 9.1362m 9.1362m 9.1362m 9.1362m
V(5)-V(1), rr2

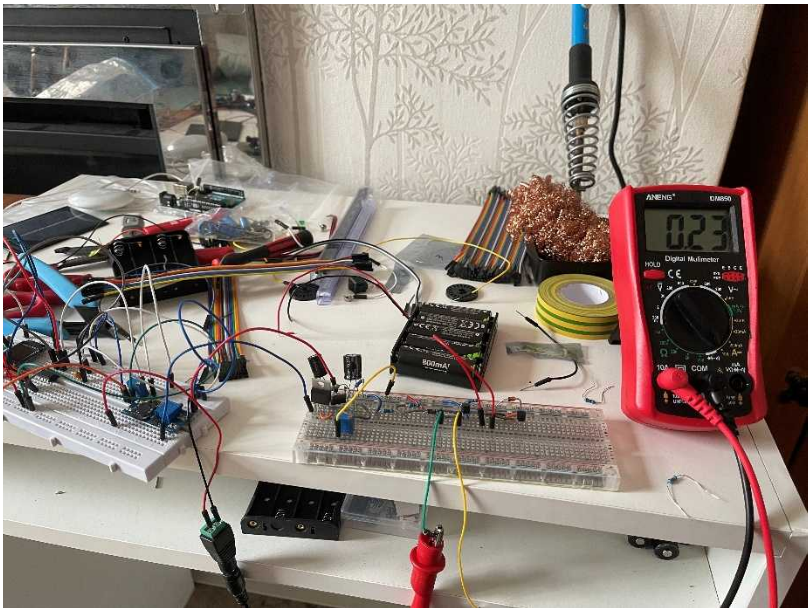
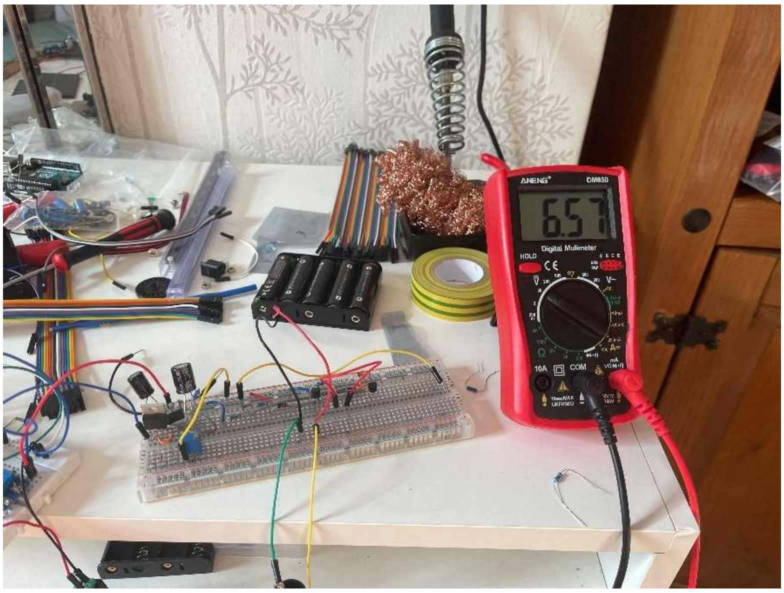
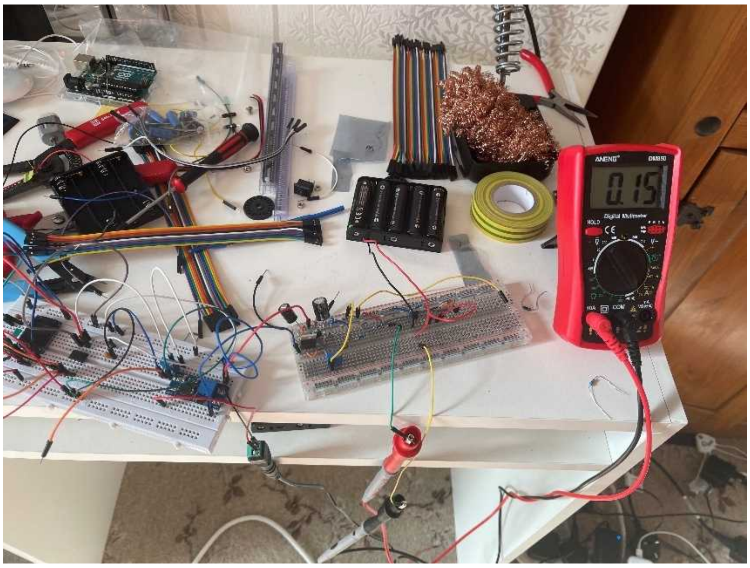


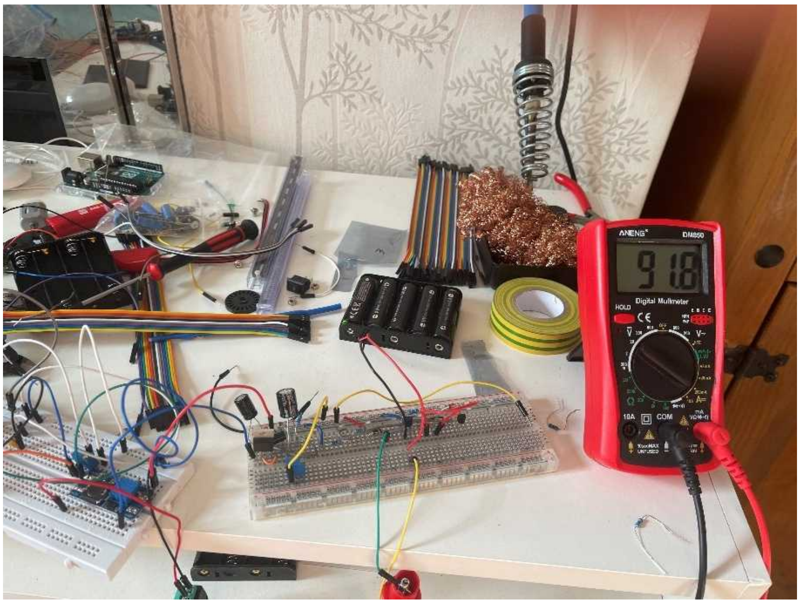
Figure: without load Ic = 230 mA

Different battery holder voltage:

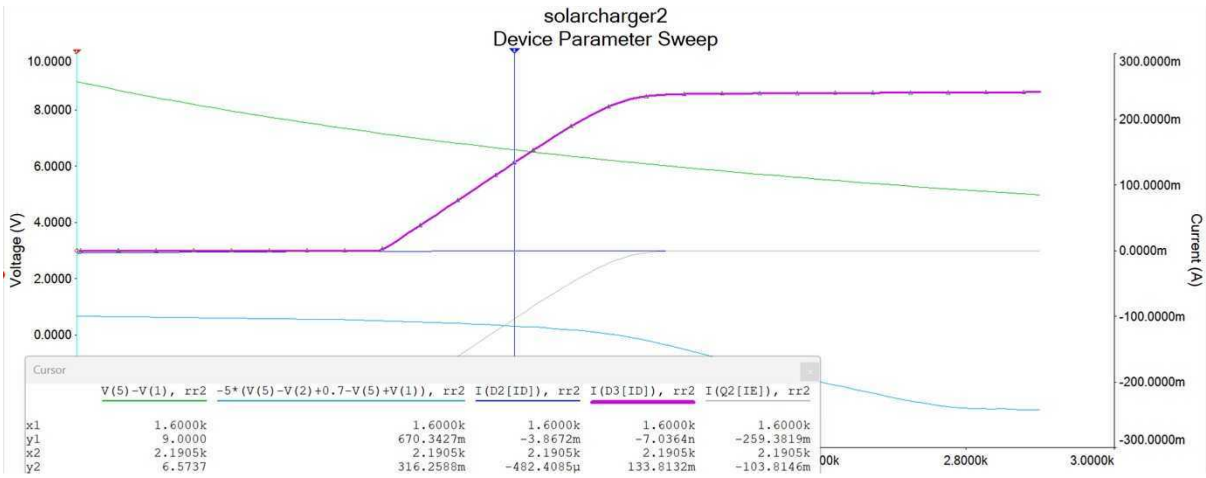




ANENG
DM850
0.15
Digital Multimeter
HOLD



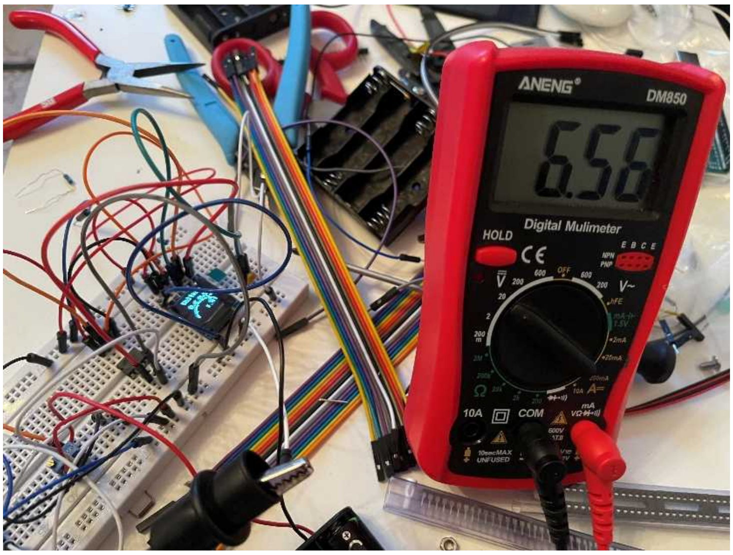
ANENG
DM850
91.8
Digital Multimeter
HOLD
10A
COM

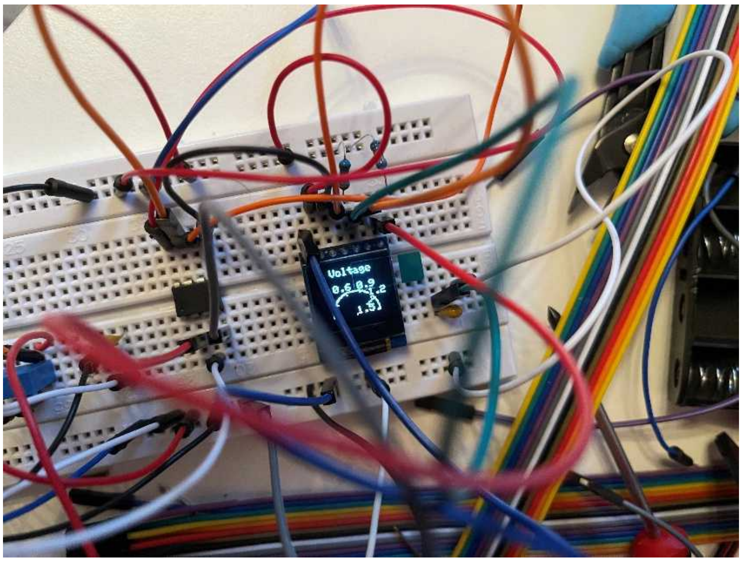


solarcharger2
Device Parameter Sweep
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
Voltage (V)
300.0000m
200.0000m
100.0000m
0.0000m
-100.0000m
-200.0000m
-300.0000m
Current (A)
Cursor
V(5)-V(1), rr2
-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2
I(D2[ID]), rr2
I(D3[ID]), rr2
I(Q2[IE]), rr2
x1 1.6000k 1.6000k 1.6000k 1.6000k 1.6000k
y1 9.0000 670.3427m -3.8672m -7.0364n -259.3819m
x2 2.1905k 2.1905k 2.1905k 2.1905k 2.1905k
y2 6.5737 316.2588m -482.4085μ 133.8132m -103.8146m
2.8000k
3.0000k

-Tested the voltmeter with the battery holder.

6.56 /5 = 1.312 V per battery





-Might have fried the pin by accidently inputting 6.56 V.

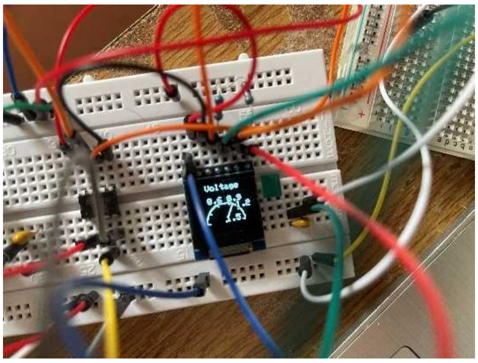
-Will replace and test tomorrow.

01/08Aug/25-

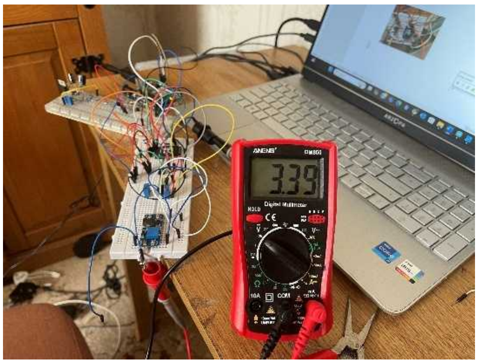
-Replaced the attiny85 with a new one, and reburnt and reflashed it.

-Checked a 5V input.

5/5 = 1 V per battery

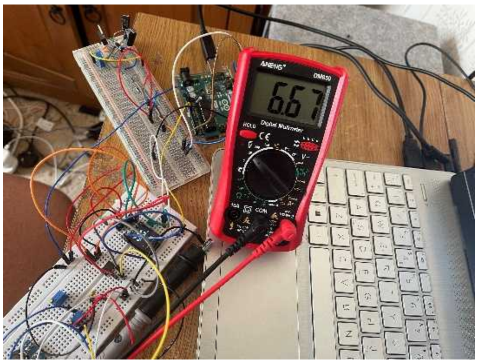


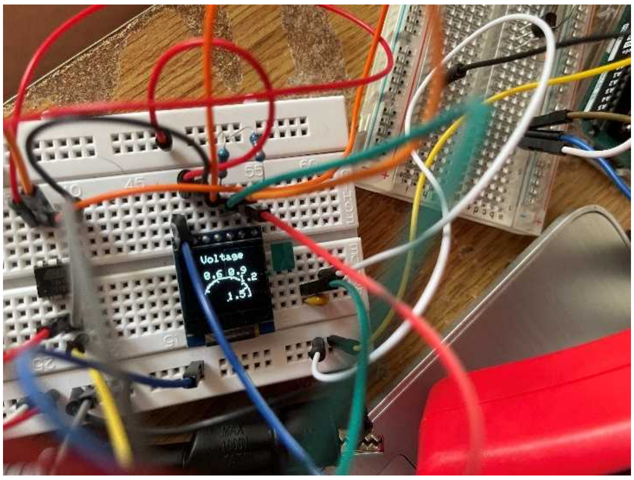
3.39 x 1.5 = 5.09 V



-Tested 6.67 V battery holder.

6.67/5 = 1.33 V





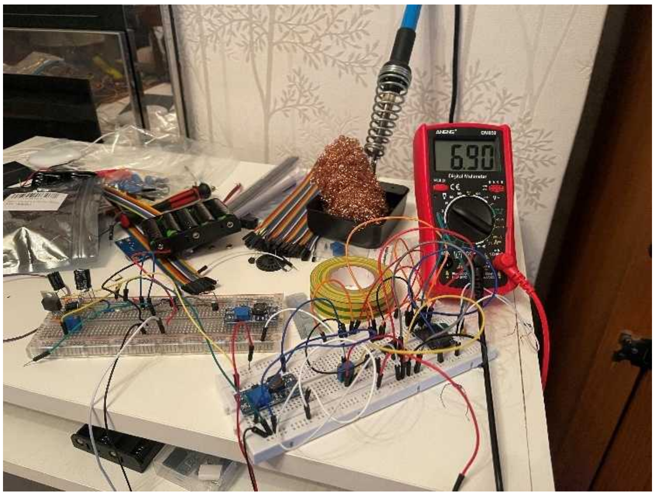
-Tested the current drawn for the display circuit.

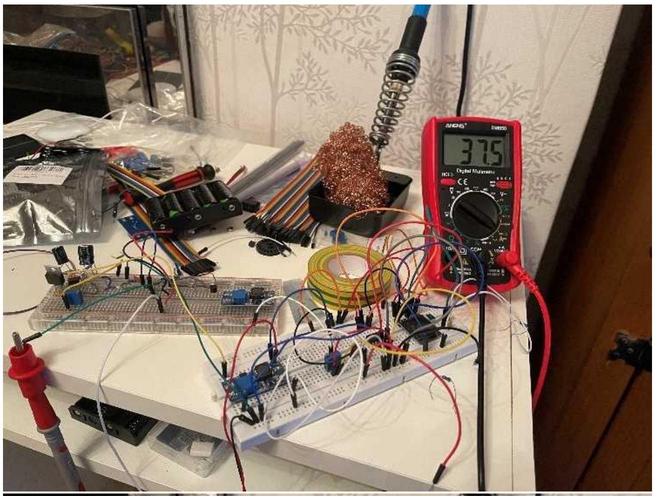
15.8mA current drawn from the supply by the display and attiny85.

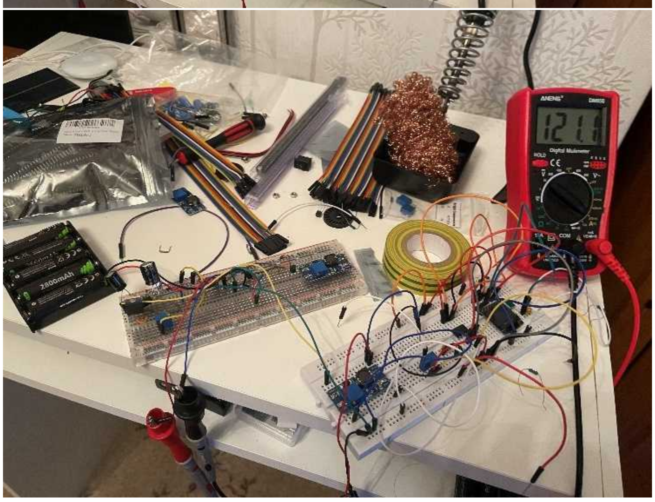
0.6mA current drawn from the battery holder into the ADC of attiny85.

-Found out I connected the wire for the overcharge protection circuit the wrong way which shorted it. Fixed the connection.

-Tested the current values again.



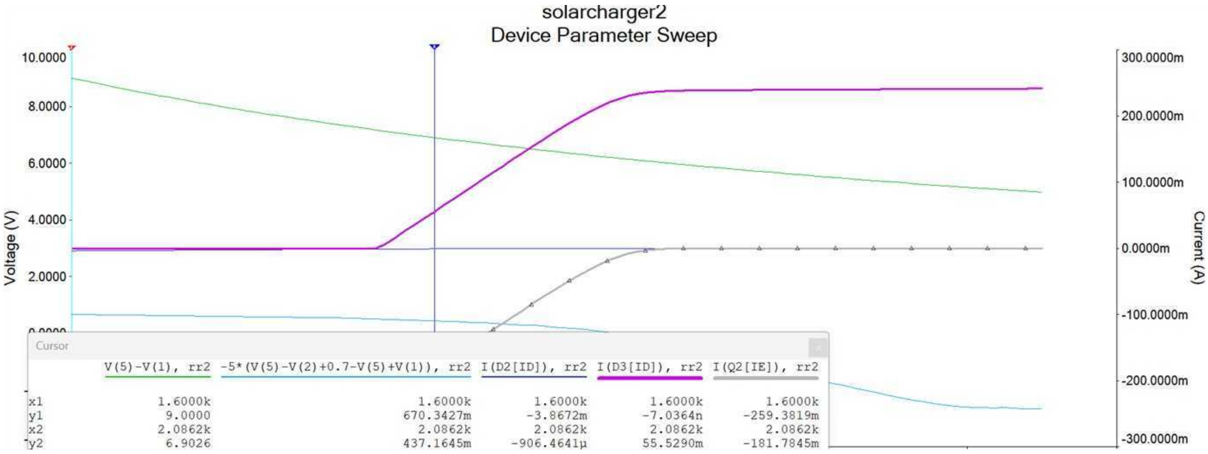




Battery holder voltage = 6.9 V

Current going into the battery holder = 37.5 mA

Current going into the overcharge protection circuit = 121.1 mA

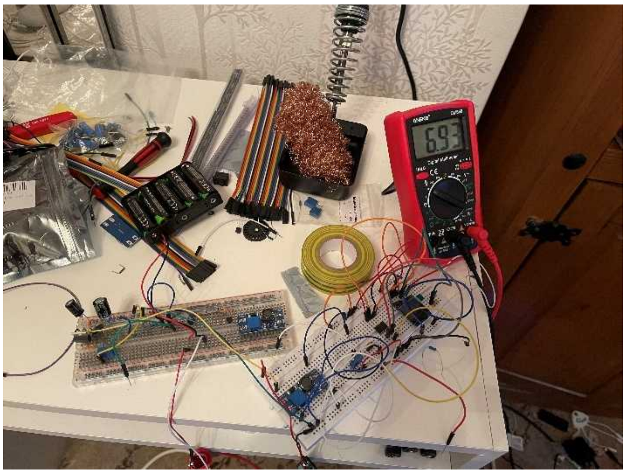


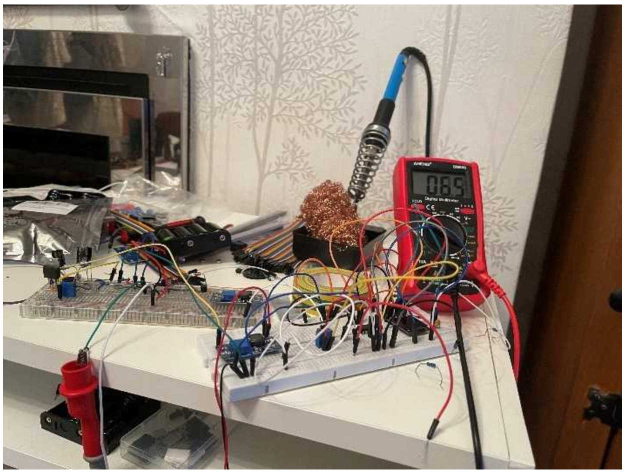
Simulation:

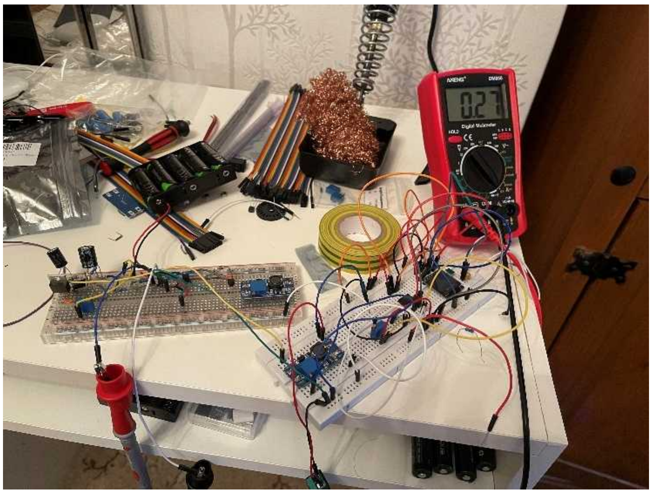
Current going into the battery holder = 55.5 mA

Current going into the overcharge protection circuit = 181.8 mA

-Charged it more to test the current going into the battery holder becoming close to zero.



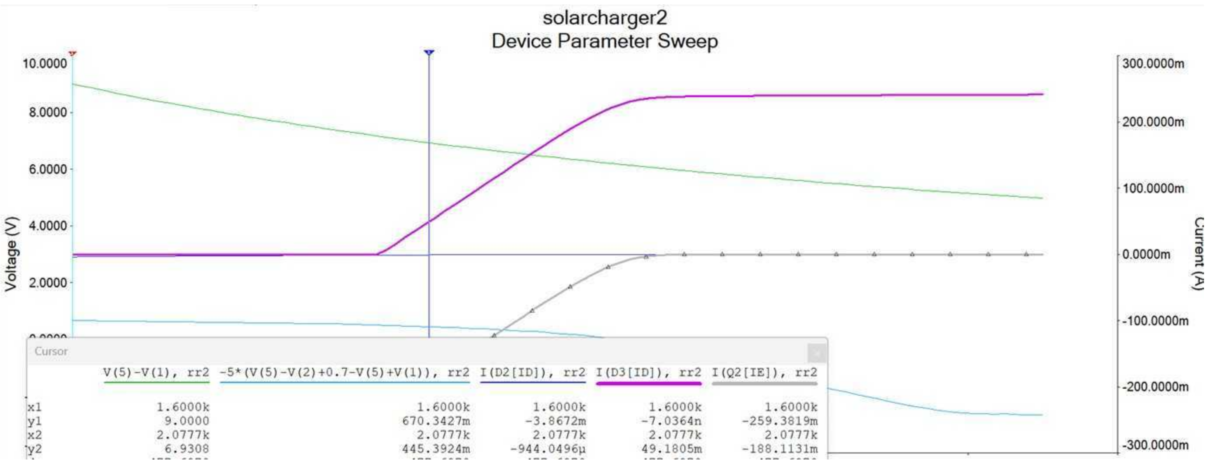




Battery holder voltage = 6.93 V

Current going into the battery holder = 6.5 mA

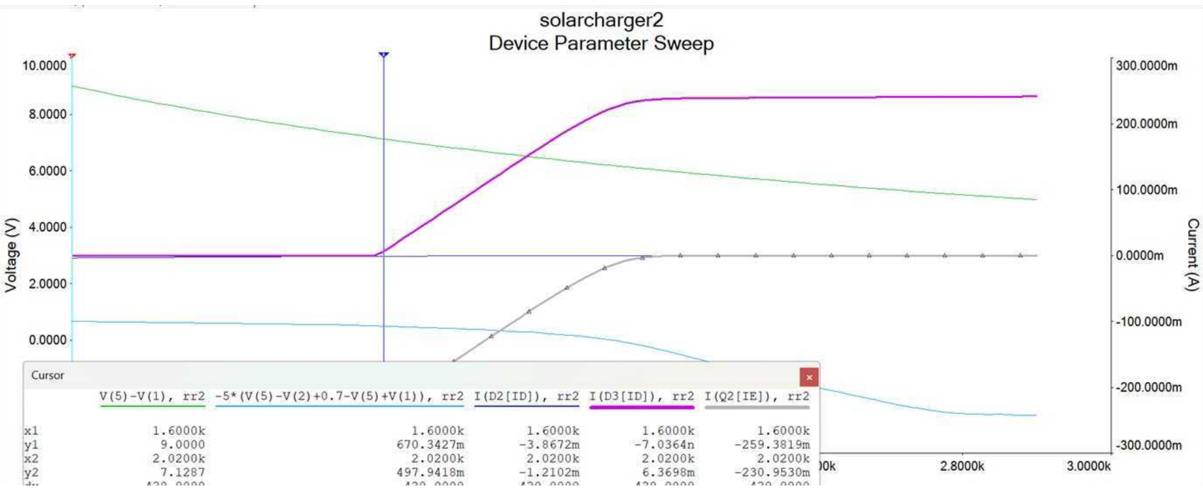
Current going into the overcharge protection circuit = 270 mA



Simulation:

Current going into the battery holder = 49.2 mA

Current going into the overcharge protection circuit = 188.1 mA



* Possible shift of the graph to the right. The test could have happened in “the event” pointed out in the figure above, and not in the first graph.

Problem: display won’t work properly because of grounding issues. The ground of the battery holder is different from the ground of the charger.

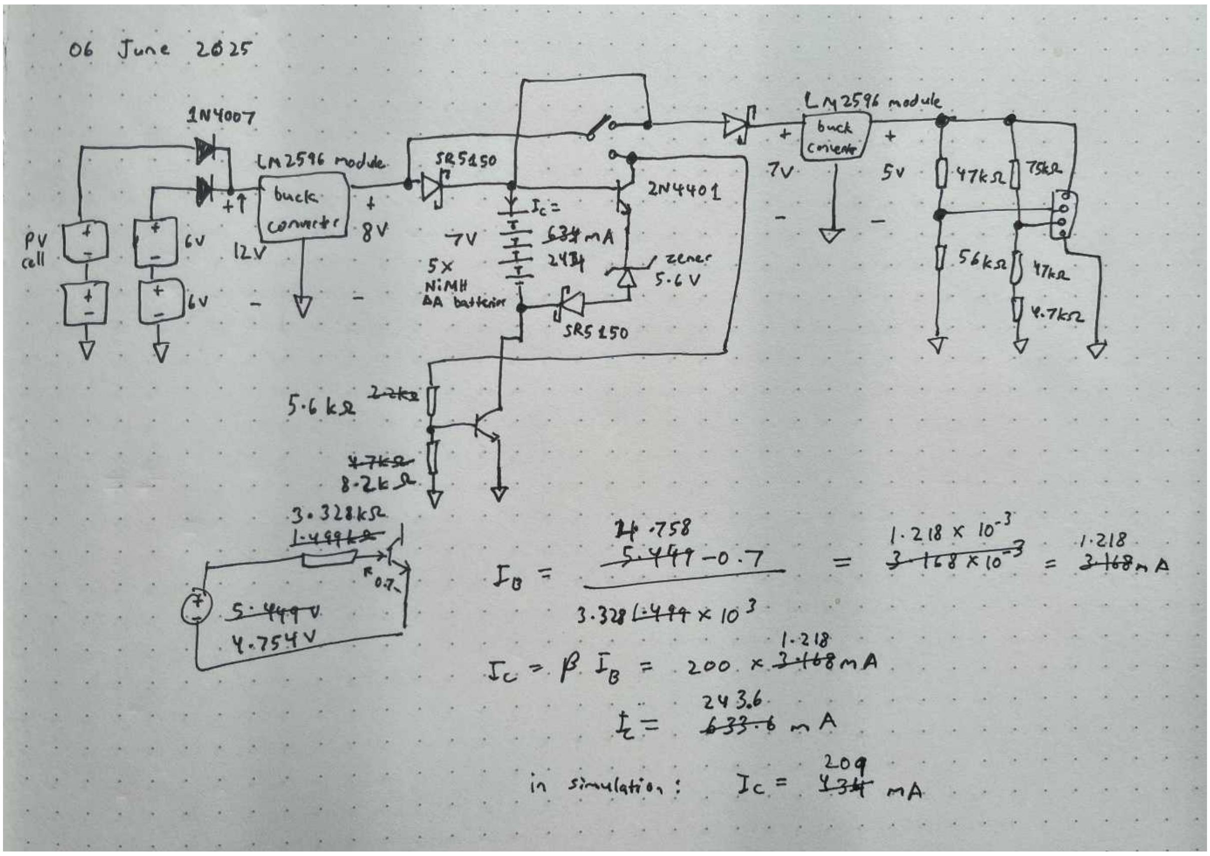
02/08Aug/25 -

-Tested the no load current.

Current going into the battery holder = 220 mA

Current going into the overcharge protection circuit = 0 A

*Consistent with simulation.



Vb = 9* (8.2/(8.2+5.6)) =5.3478 V

Ib = (5.3478-0.7)/ 3.328*10^3 = 1.3966*10^-3

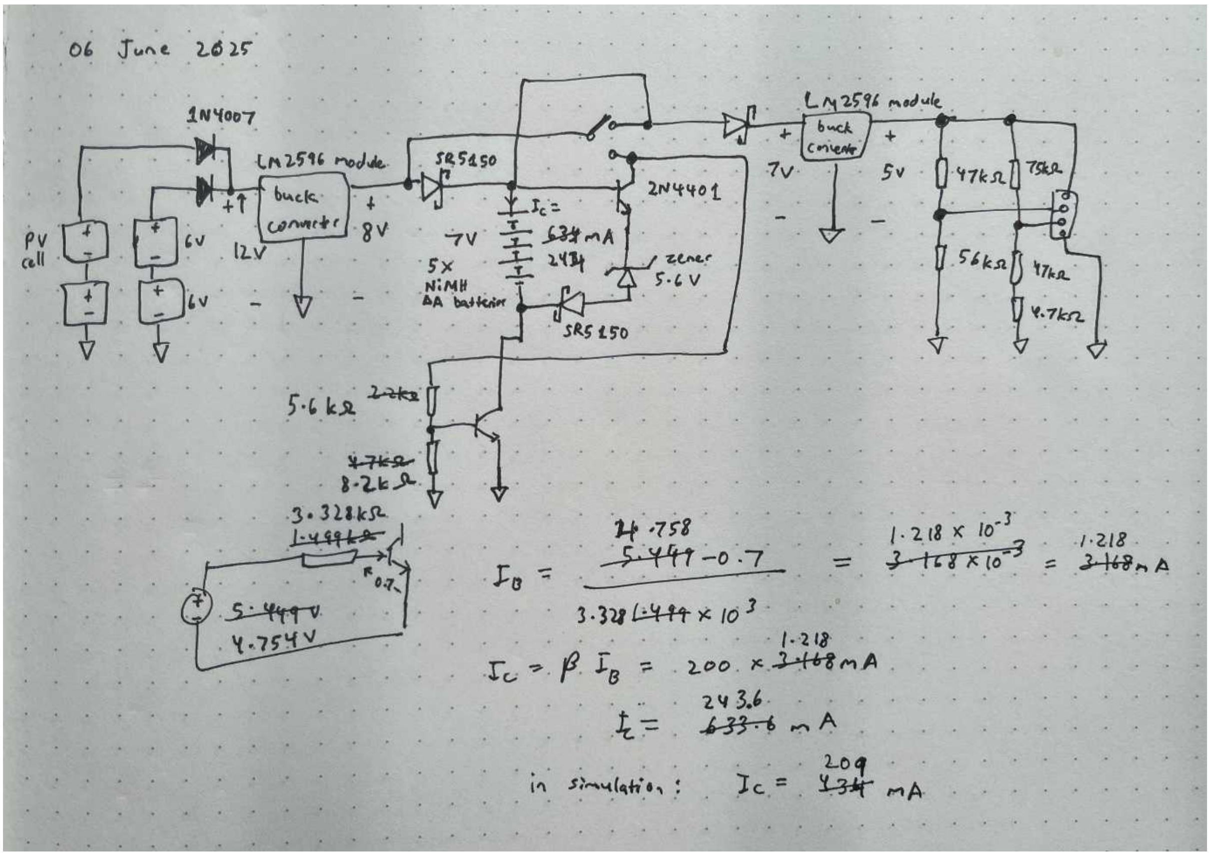
Ic = B*Ib = 0.2793 A = 279 mA

*Consistent with theoretical predictions.

*0.2-ohm resistor is needed to ground the battery holder to make it able to charge with the PV cells without burning. (five 1 ohm resistors in parralel)

P =(I^2)*R = 1*0.2 = 0.2 W < 0.25 W   assuming voltage drop of 0.2 V

07/08Aug/25 -



*Maybe the reason why it is not charging iPhone was because most current goes into the battery instead of the usb c.

-Fixed this by adding an additional diode pointed by the image above.

Without the diode: 0.12 A into the usb c

0.25 A charging current into the battery holder without iPhone

0.05 A going out the battery holder while charging iPhone

-Added the diode: did not affect the outcome.

-Removed the diode.

-Replaced voltage divider resistors with the 10k variable resistors and set it to D- = 2.8 V

D+ = 2 V.

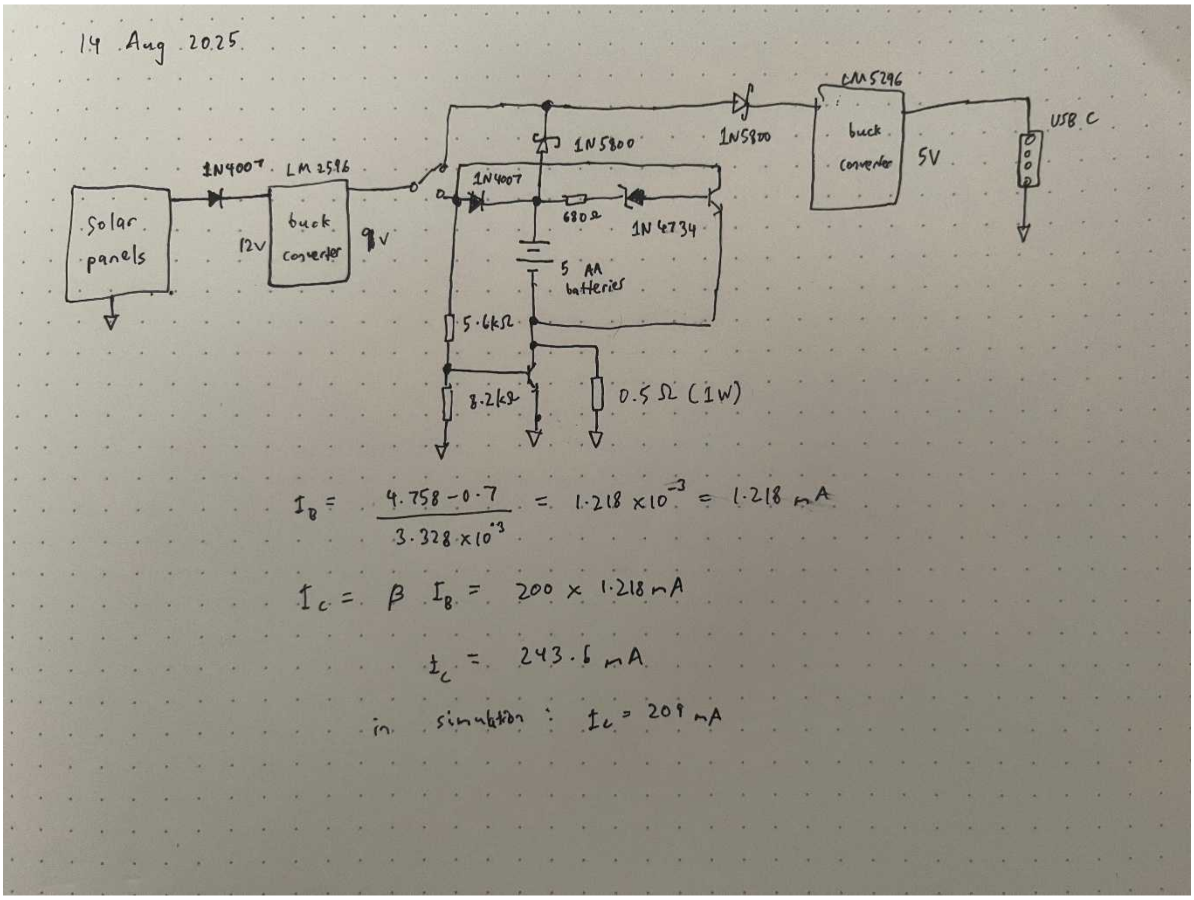
*Measured current into the usb c: 0.12 A

11/08Aug/25-

Data pin voltages: https://blog.voltaicsystems.com/phones-and-ipads-usb-pin-voltages/

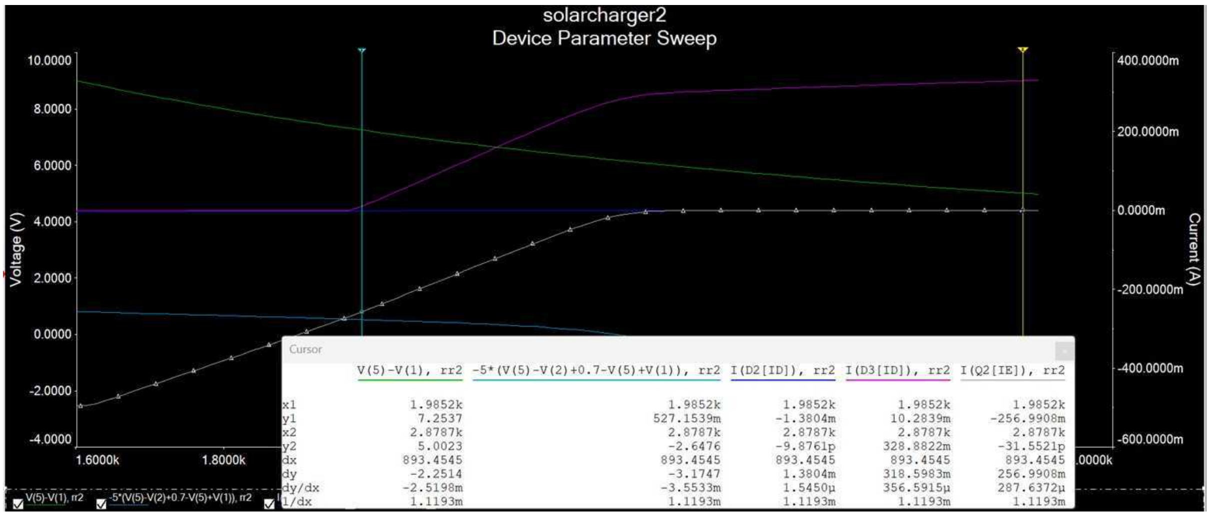
-Re-added the diode.

14/08Aug/25-

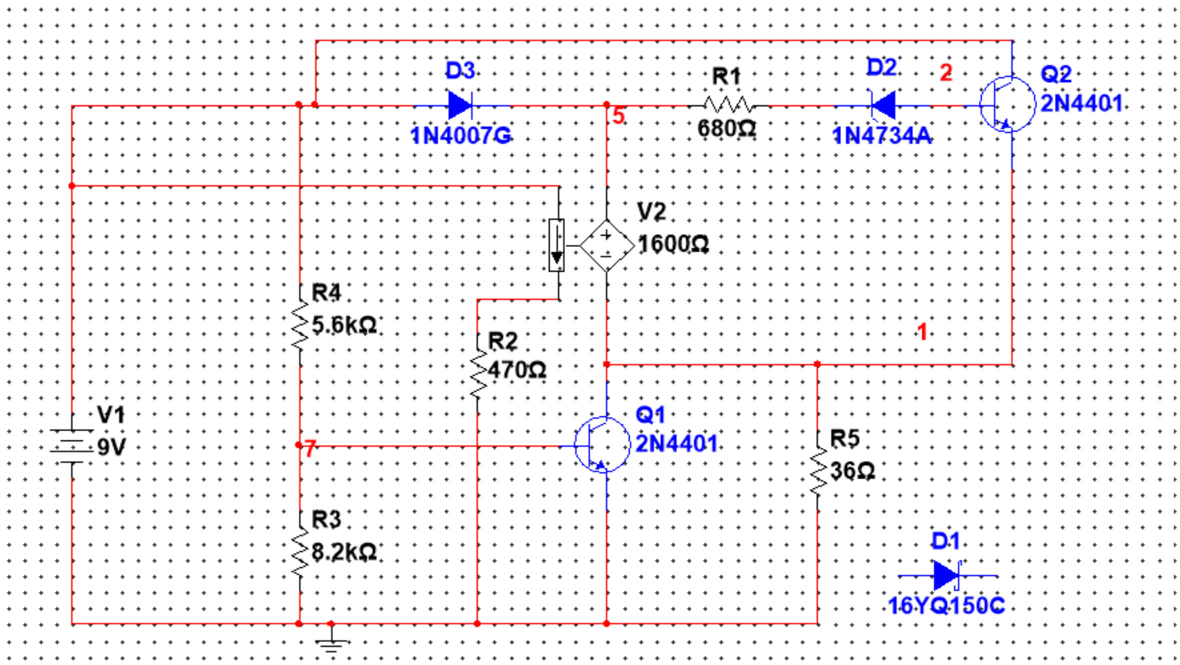


-Redesigned the connection for the switch.

-Reconnected the breadboard circuit.



	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D2[ID]), rr2	I(D3[ID]), rr2	I(Q2[IE]), rr2
x1	1.9852k	1.9852k	1.9852k	1.9852k	1.9852k
y1	7.2537	527.1539m	-1.3804m	10.2839m	-256.9908m
x2	2.8787k	2.8787k	2.8787k	2.8787k	2.8787k
y2	5.0023	-2.6476	-9.8761p	328.8822m	-31.5521p
dx	893.4545	893.4545	893.4545	893.4545	893.4545
dy	-2.2514	-3.1747	1.3804m	318.5983m	256.9908m
dy/dx	-2.5198m	-3.5533m	1.5450µ	356.5915µ	287.6372µ
1/dx	1.1193m	1.1193m	1.1193m	1.1193m	1.1193m



-Resimulated with a pulldown resistor.

Ic = 298 mA at battery voltage of 6 V (1.2 V per battery)

-Tested the aa charger:

0.11 A protection current

22 mA charging current

6.52 V battery holder voltage

Simulation:

91 mA protection current

0.146 A charging current

-Replaced the transistors:

0.10 A protection current

44 mA charging current

-The 9V line is 8.70 V, re-adjusted it to 9.10 V.

-Tested it again:

0.12 A protection current

Initial: 104mA → final: 88 mA charging current

6.59 V battery holder voltage

Simulation:

0.108 protection current

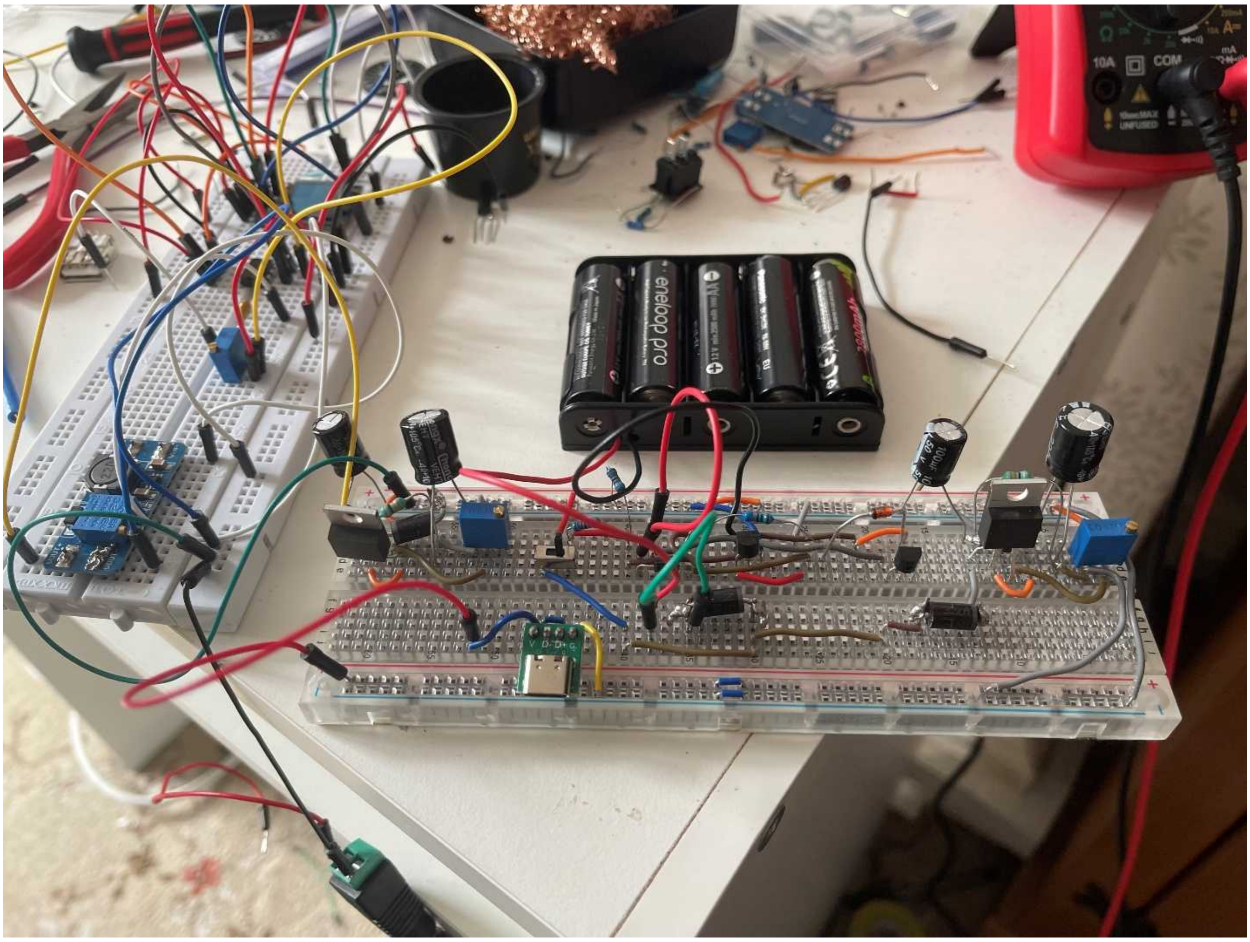
0.129 A charging current

-Tested the iPhone charger:

90 mA charging current

6 mA contribution from battery holder

29 mA contribution from the 12 V source



15/08Aug/25 -

-Tested the output current of the buck converter:

I = 0.4 A

V = 9 V

R = 7.5 ohm

This confirms the buck converter cant output enough current.

The multimeter should be working as I tested it can go beyond 1 A when connected across a battery.

-Replaced the DIY buck converters with the buck converter modules:

0.14 A usb c output

12 mA AA charging

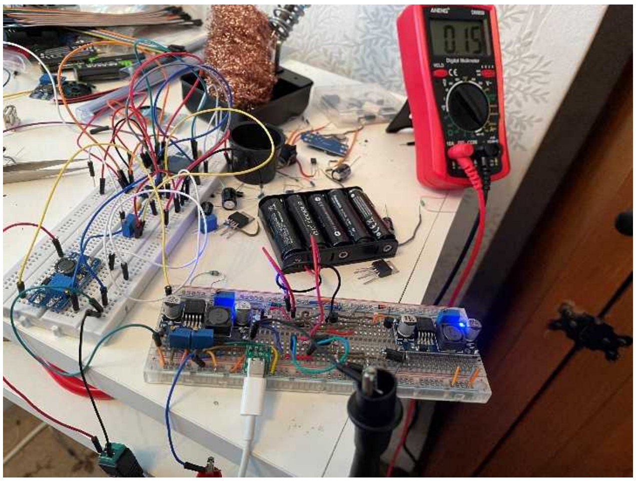
0.11 A protection current

-Replaced the shorted D+ and D- with the D- = 2.75 V and D+ = 2 V:

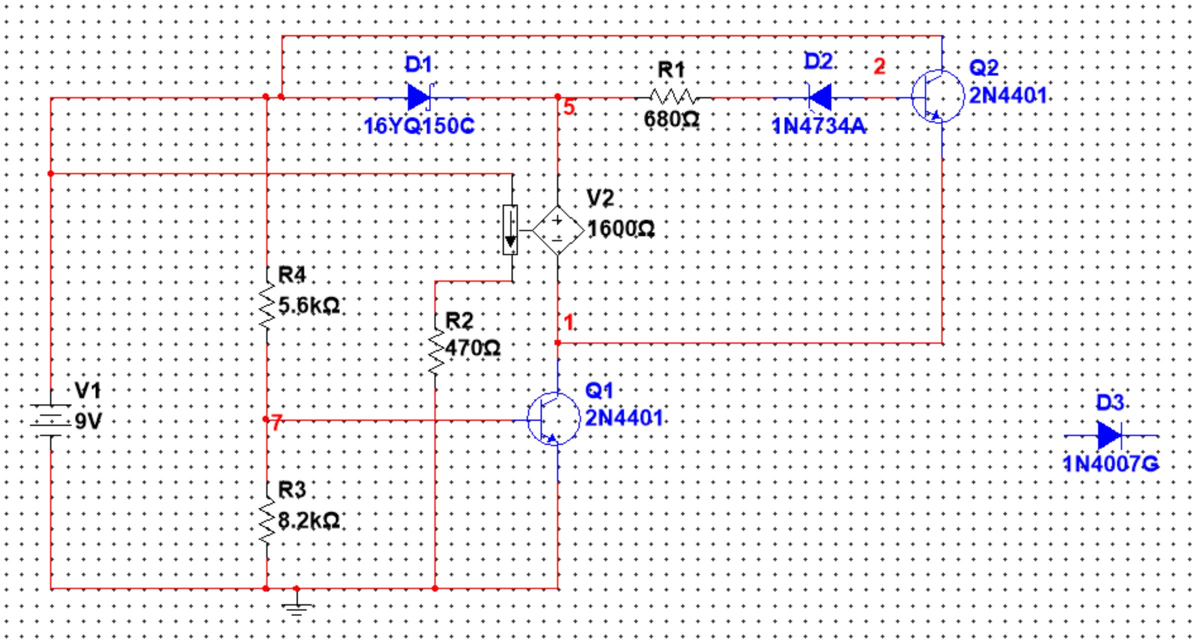
0.20 A usb c output

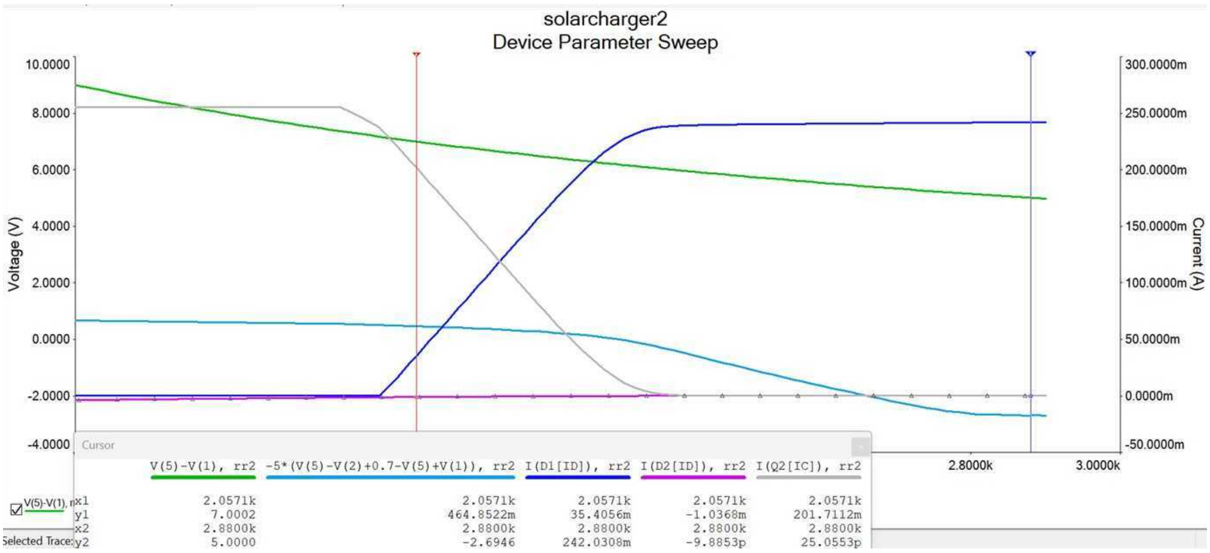
-Charged another iPhone:

0.15 A usb c output



-Replaced the normal diode with Schottky diode:





-Tested the new circuit:

6.52 V battery holder

0.11 A protection current

14 mA charging current into battery holder

	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D1[ID]), rr2	I(D2[ID]), rr2	I(Q2[IC]), rr2
x1	2.0571k	2.0571k	2.0571k	2.0571k	2.0571k
y1	7.0002	464.8522m	35.4056m	-1.0368m	201.7112m
x2	2.2080k	2.2080k	2.2080k	2.2080k	2.2080k
y2	6.5218	290.5816m	148.0025m	-418.9780µ	90.1563m

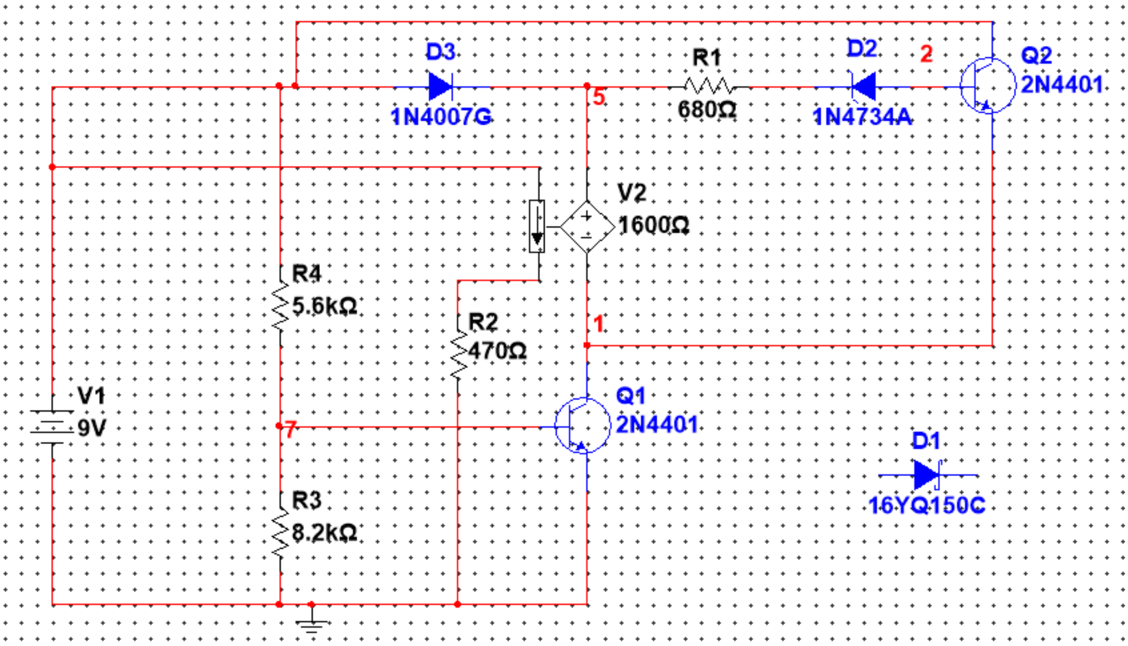
The discrepancy was most likely due to the battery holder current going into the 5 V buck converter.

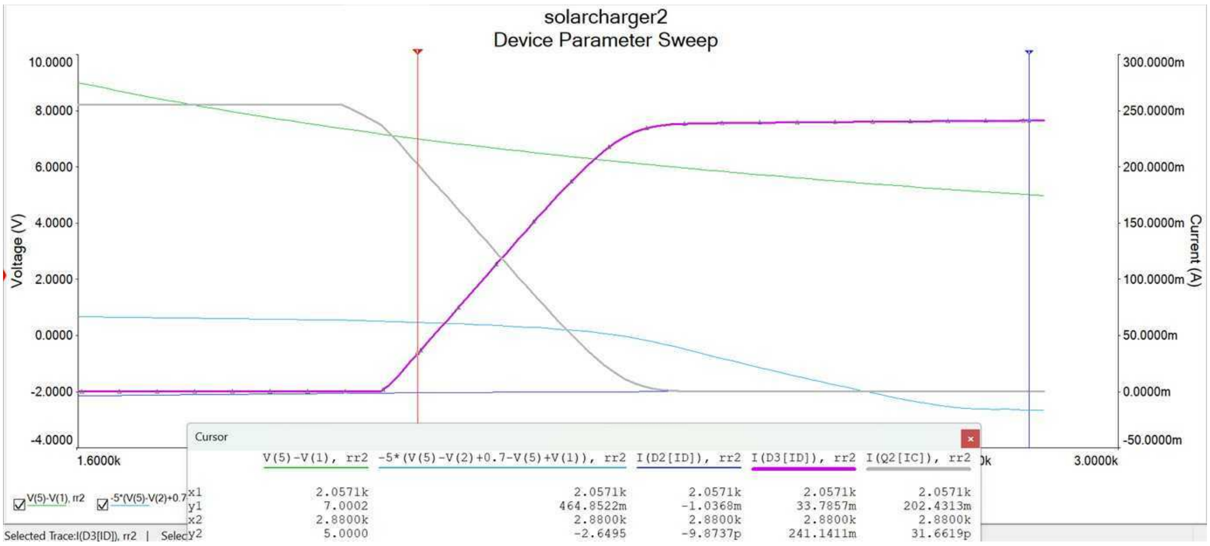
-Tested it again:

-50 mA charging current into the battery holder

-Realised it did not follow the original protection circuit diagram.

-Reverted the design.





-Tested the aa charger circuit again:

-67 mA going into the battery holder (67 mA going out the battery holder)

0.11 A protection current

Cursor

	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D2[ID]), rr2	I(D3[ID]), rr2	I(Q2[IC]), rr2
x1	1.6000k	1.6000k	1.6000k	1.6000k	1.6000k
y1	9.0000	670.3427m	-3.8672m	-7.0364n	255.5148m
x2	2.2083k	2.2083k	2.2083k	2.2083k	2.2083k
y2	6.5208	290.0871m	-417.8458µ	147.0271m	90.2427m

16/08Aug/25-

-Added the appropriate switches to the design and circuit.

6.54 V battery holder

80 mA going into the battery holder

180 mA protection current

	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D2[ID]), rr2	I(D3[ID]), rr2	I(Q2[IC]), rr2
x1	1.6000k	1.6000k	1.6000k	1.6000k	1.6000k
y1	9.0000	670.3427m	-3.8672m	-7.0364n	255.5148m
x2	2.2016k	2.2016k	2.2016k	2.2016k	2.2016k
y2	6.5408	300.3134m	-442.0884μ	142.0190m	95.2036m

Second reading:

10 mA going into the battery holder

200 mA protection current

-Tested charging iPhone:

0.12 A charging current into iPhone

0.43 A before the 12 V boost converter drawing from 5 V power source

0.16 A between the 12 boost and 9 V buck

0.14 A after the 9V buck

-Tested the 6.54 V battery across a 4.7 ohm:

6.54 / 4.7 = 1.39

Measured current = 1.55 A → multimeter confirmed to be working.

Problem might be the buck converter can't output enough current:

-Tested this by inputting the battery into the 5 V buck with a 2.2 ohm load (confirmed the battery can output at most 1.55 A):

5/ 2.2 = 2.27 A, only 0.9 A output → confirmed the hypothesis

-Removed the diode:

1.2 A output for 2.2 ohm

2.8 ohm → 5/ 2.8 = 1.79 A

Possible reason for the diode's low current capability:

Burnt from soldering

19/08Aug/25 -

-Tested the buck converter, battery and usb c circuit on another breadboard:

0.8 - 0.7 A output

This means the problem was the breadboard.

-Confirmed it charged 87 % to 91%.

-Reconnected the same circuit on this breadboard.

6.33 V battery holder

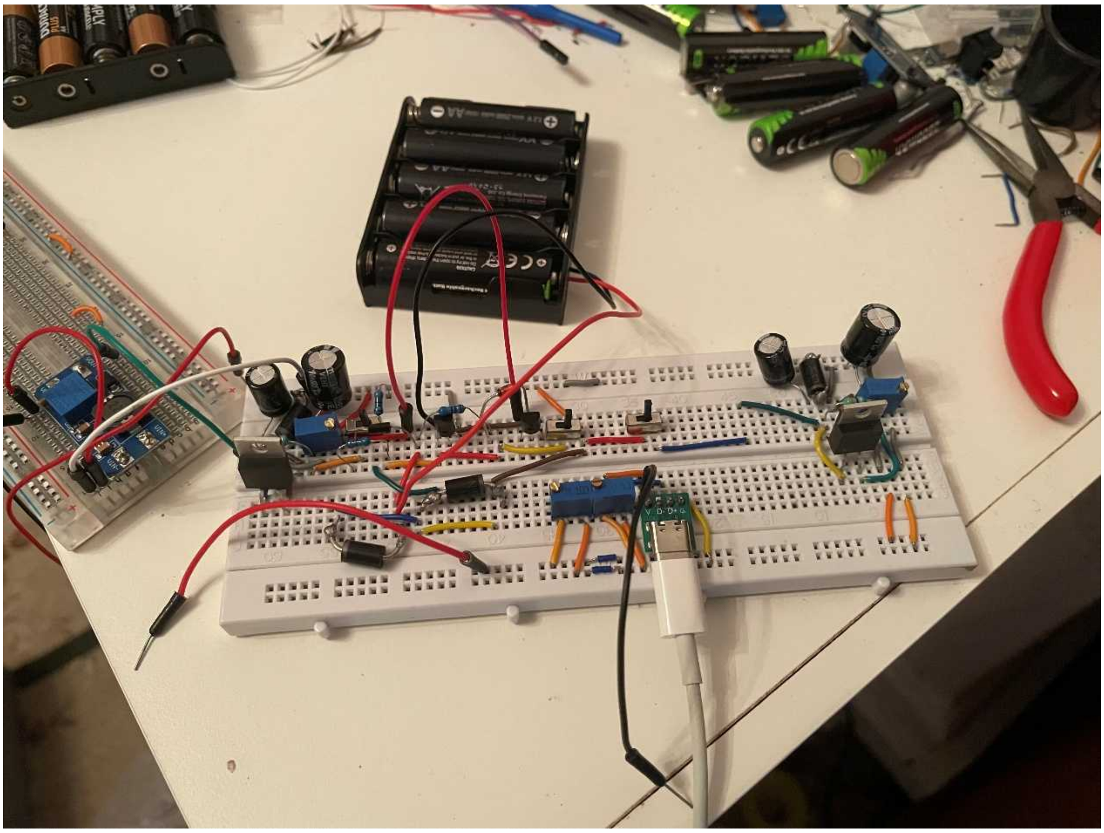
~0.40 A usb c output

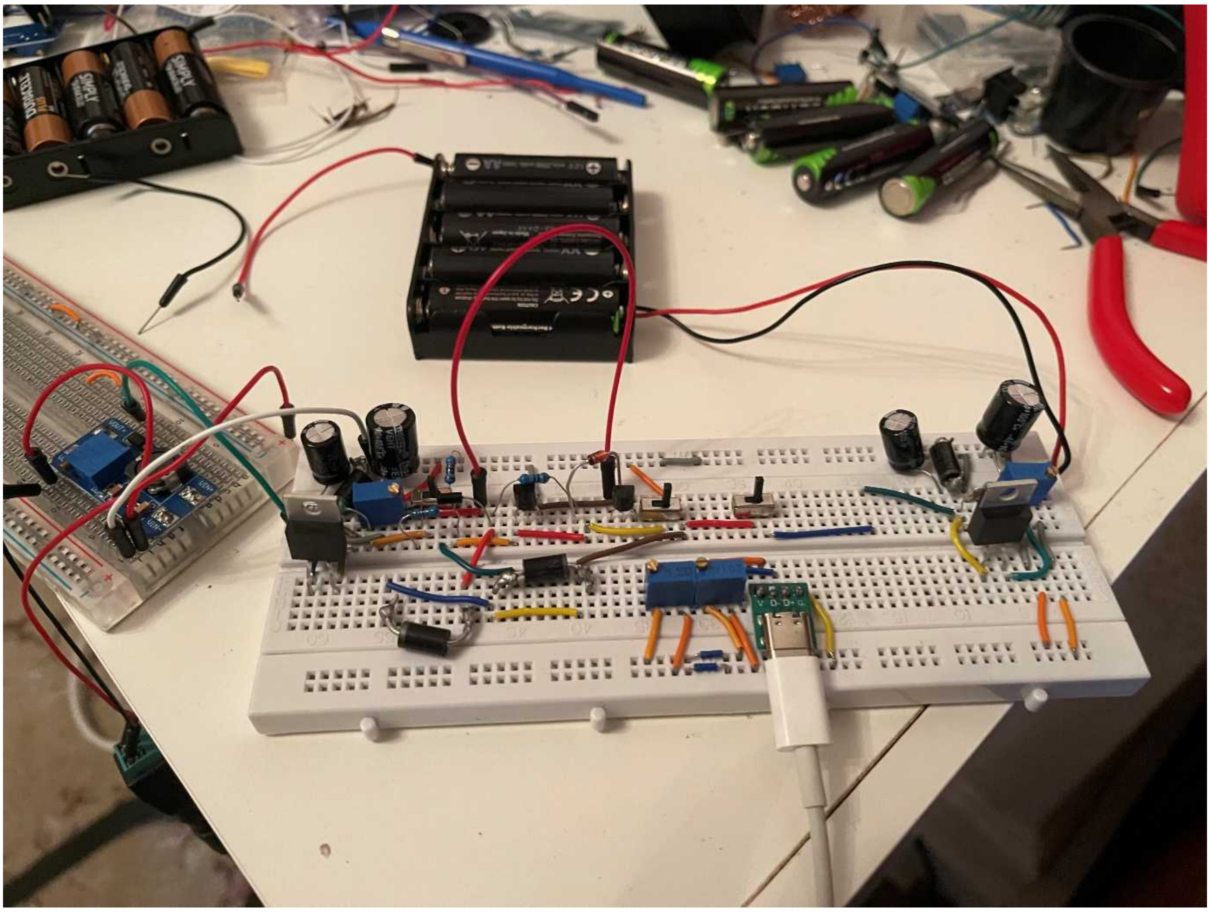
0.35 A usb c output without the grid source

Goes to 0.24 A at lowest voltage

81 % to 88 %

0.1 A is probably the absolute minimum to charge the iPhone
6.46 V battery holder
~0.40 A usb c output
~0.30 A usb c output without grid source





20/08Aug/25-

Testing charging AA batteries:

18:05 6.24 V starting battery voltage

15 mA going into the battery

0.22 A going into the protection circuit

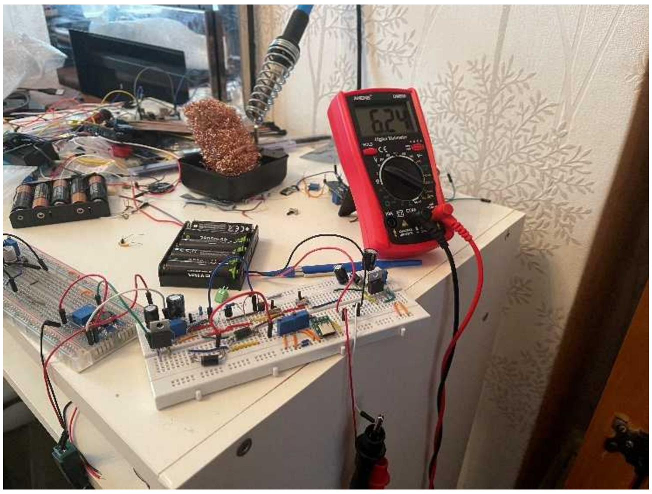
Cursor

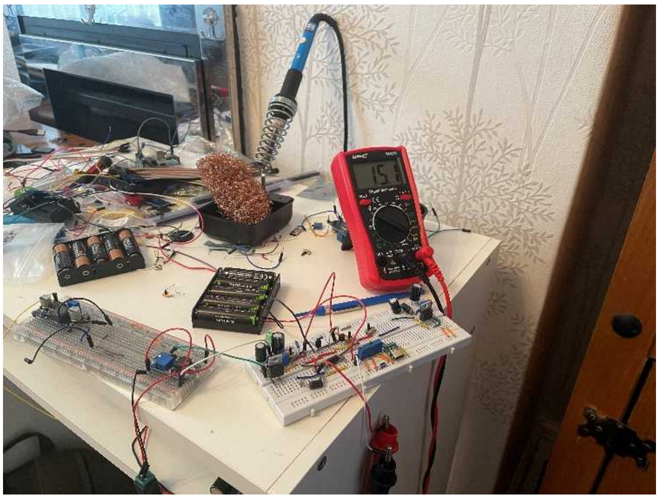
	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D2[ID]), rr2	I(D3[ID]), rr2	I(Q2[IC]), rr2
x1	1.6000k	1.6000k	1.6000k	1.6000k	1.6000k
y1	9.0000	670.3427m	-3.8672m	-7.0364n	255.5148m
x2	2.3072k	2.3072k	2.3072k	2.3072k	2.3072k
y2	6.2414	74.6272m	-118.3792µ	213.6141m	24.3283m
dx	707.1817	707.1817	707.1817	707.1817	707.1817
dy	-2.7586	-595.7155m	3.7488m	213.6141m	-231.1865m
dy/dx	-3.9008m	-842.3797µ	5.3010µ	302.0640µ	-326.9124µ
1/dx	1.4141m	1.4141m	1.4141m	1.4141m	1.4141m

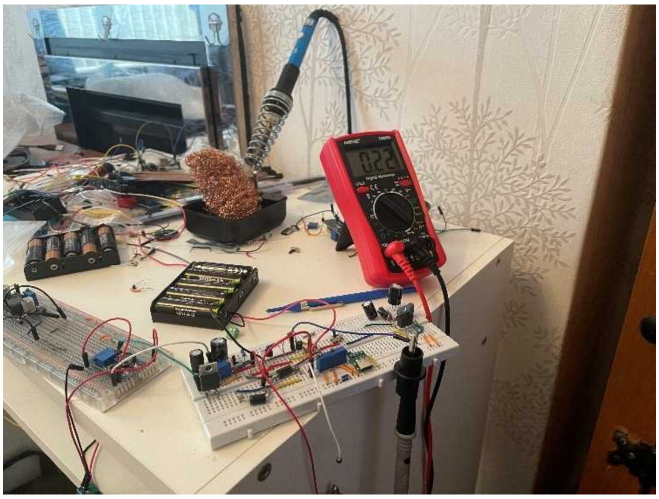
The actual response might be shifted right:

Cursor

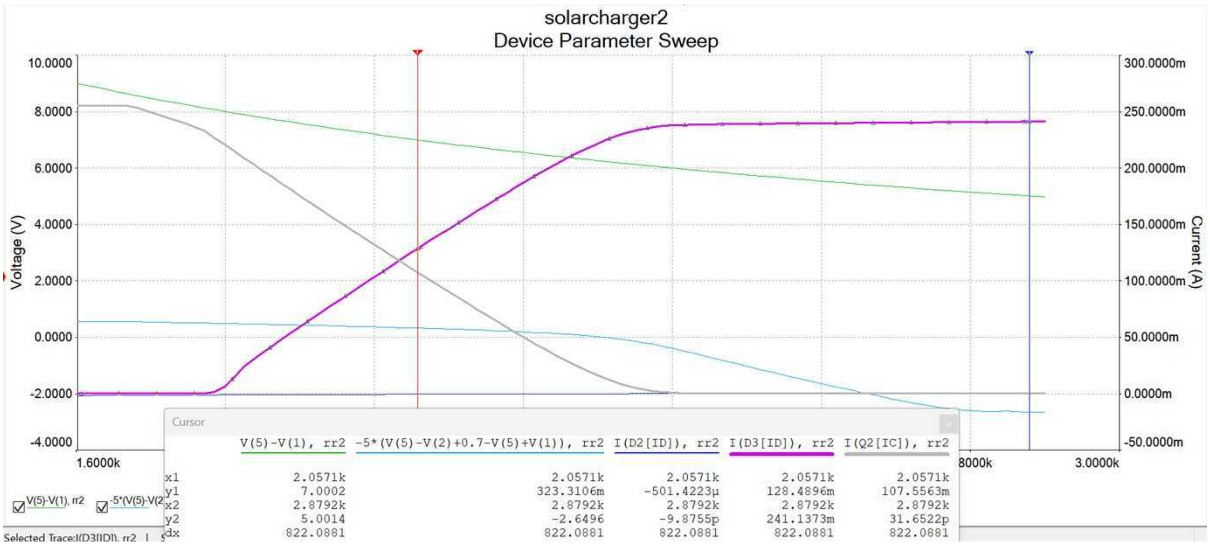
	V(5)-V(1), rr2	-5*(V(5)-V(2)+0.7-V(5)+V(1)), rr2	I(D2[ID]), rr2	I(D3[ID]), rr2	I(Q2[IC]), rr2
x1	1.6000k	1.6000k	1.6000k	1.6000k	1.6000k
y1	9.0000	670.3427m	-3.8672m	-7.0364n	255.5148m
x2	2.0317k	2.0317k	2.0317k	2.0317k	2.0317k
y2	7.0875	487.6993m	-1.1544m	14.9453m	221.1493m
dx	431.7441	431.7441	431.7441	431.7441	431.7441
dy	-1.9125	-182.6434m	2.7127m	14.9453m	-34.3655m
dy/dx	-4.4296m	-423.0363µ	6.2832µ	34.6160µ	-79.5968µ
1/dx	2.3162m	2.3162m	2.3162m	2.3162m	2.3162m







-Changed the protection circuit base resistor into 1.5k ohm to compensate for the shift.

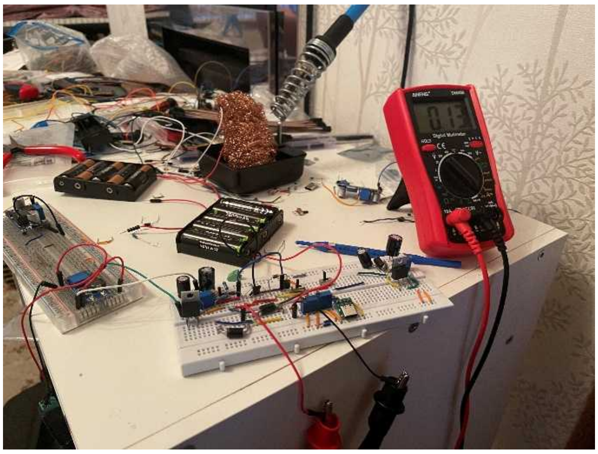


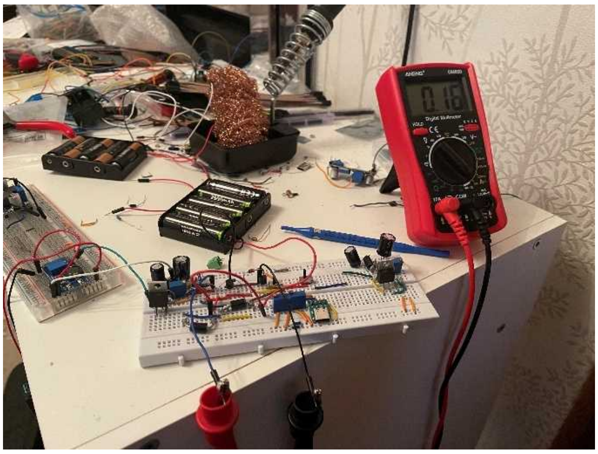
-Tested the AA charger circuit:

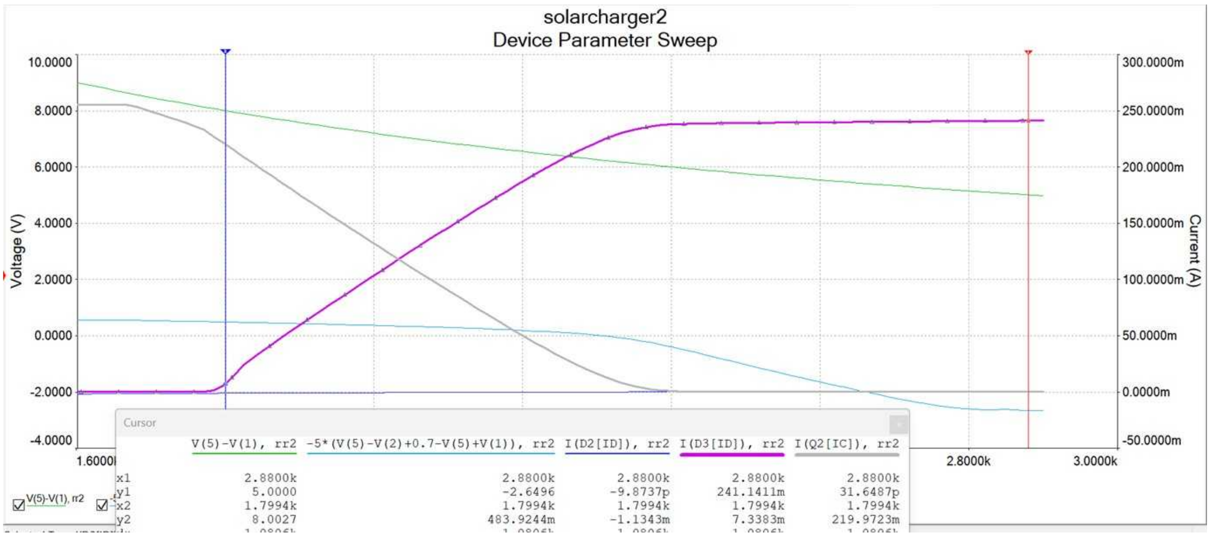
6.27 V battery

0.13 A going into the battery

0.16 A going into the protection circuit







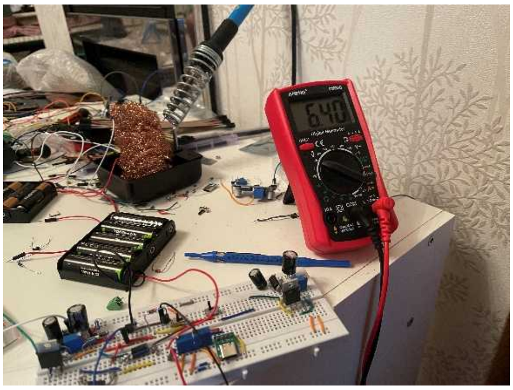
If the shift is just temporary, a problem of overcharging to 1.6 V would arise.

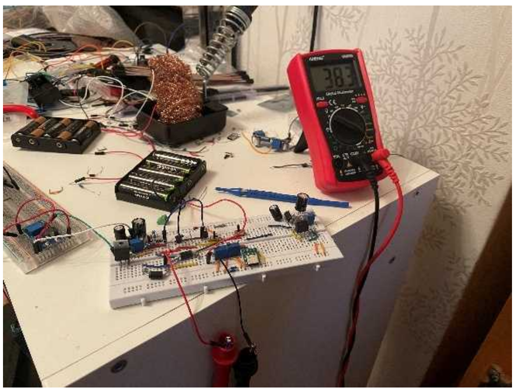
A consequence of increasing the resistance would be a way less steep slope so less response from the protection circuit.

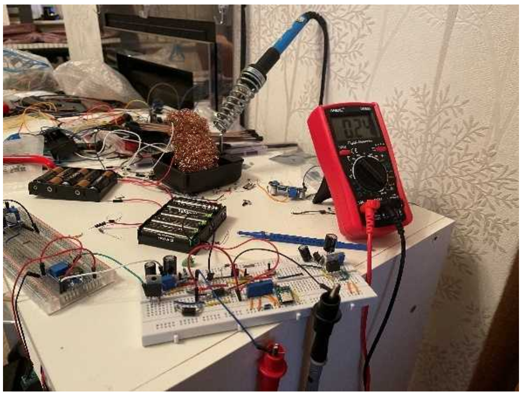
6.40 V battery

38 mA going into the battery

0.24 A going into the protection circuit



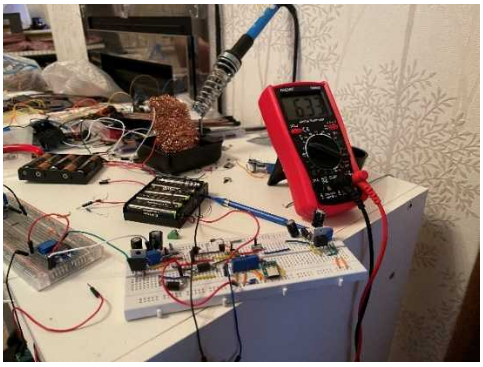


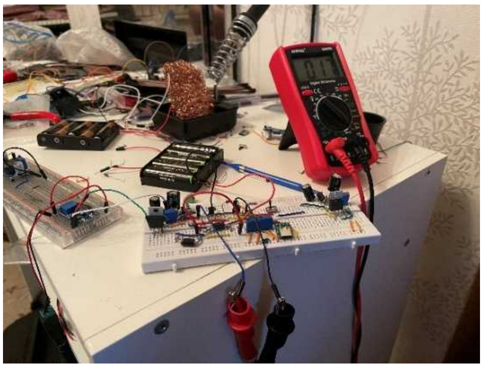


6.33 V battery

126 mA going into the battery

0.17 A going into the protection circuit

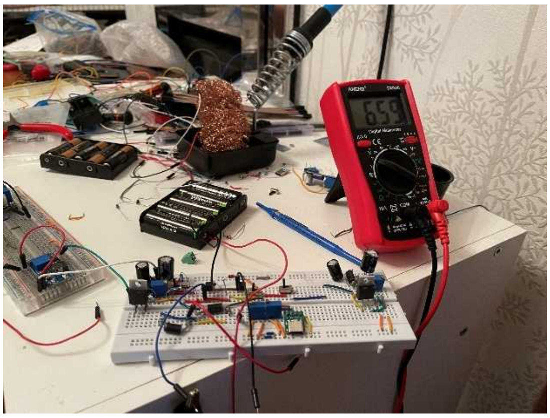


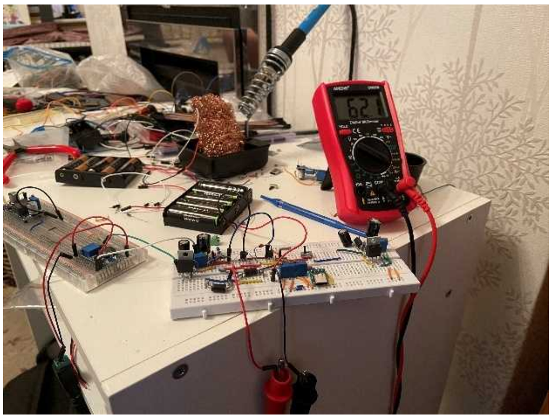


6.59 V

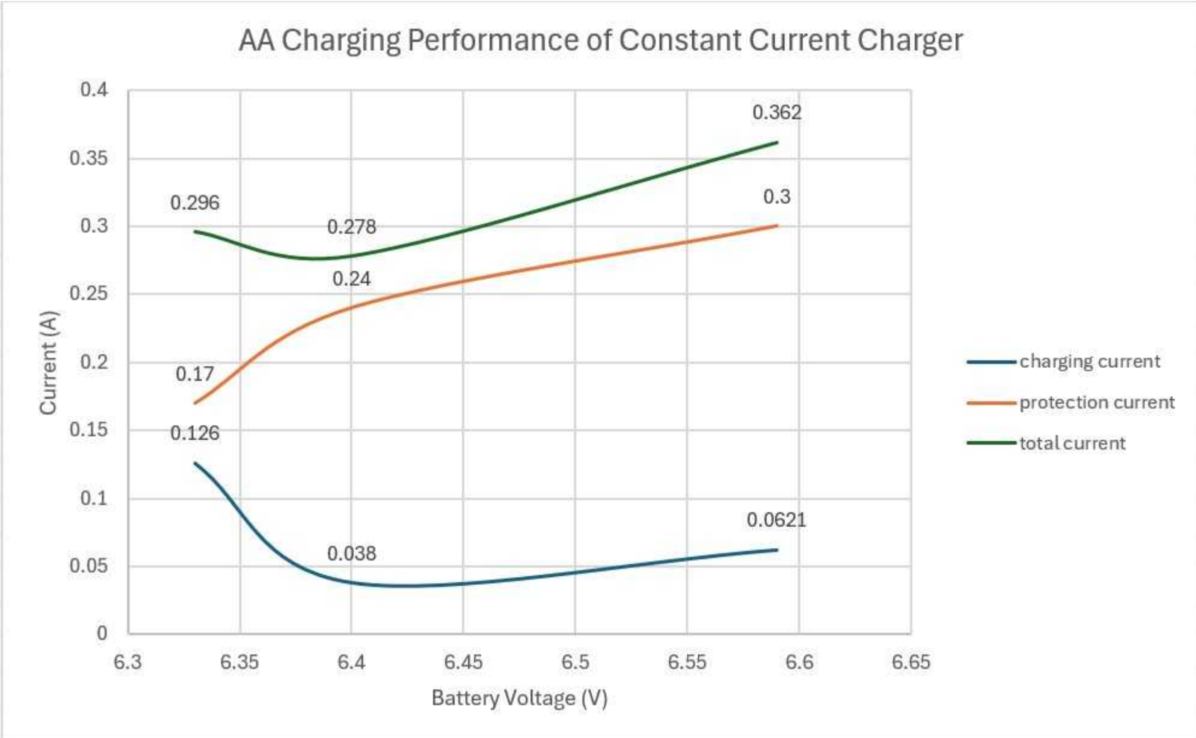
62.1 mA going into the battery

0.3 A going into the protection circuit

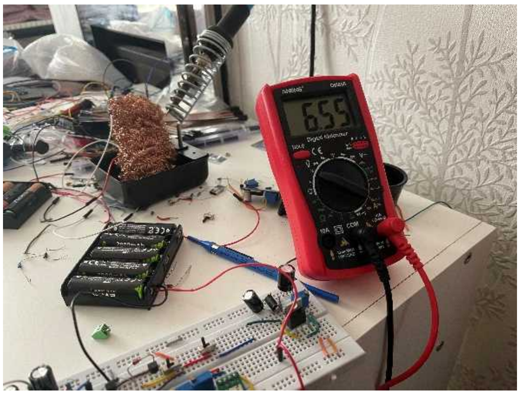


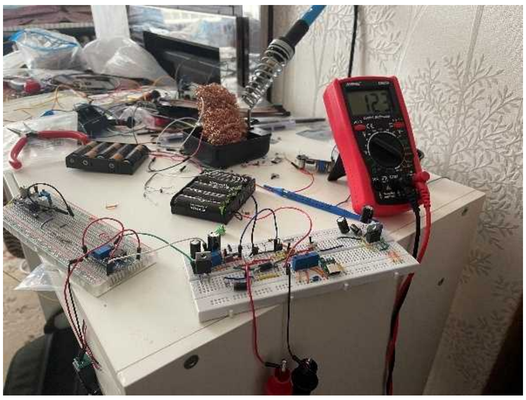


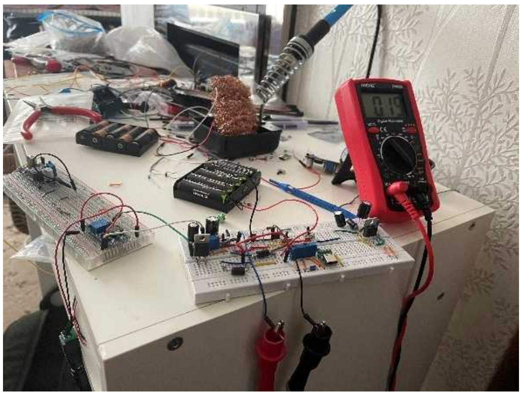
6.33	0.126	0.17	0.296
6.4	0.038	0.24	0.278
6.59	0.0621	0.3	0.362


AA Charging Performance of Constant Current Charger
Current (A)
Battery Voltage (V)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
6.3
6.35
6.4
6.45
6.5
6.55
6.6
6.65
0.362
0.296
0.278
0.3
0.24
0.17
0.126
0.038
0.0621
charging current
protection current
total current

21/08Aug/25 -





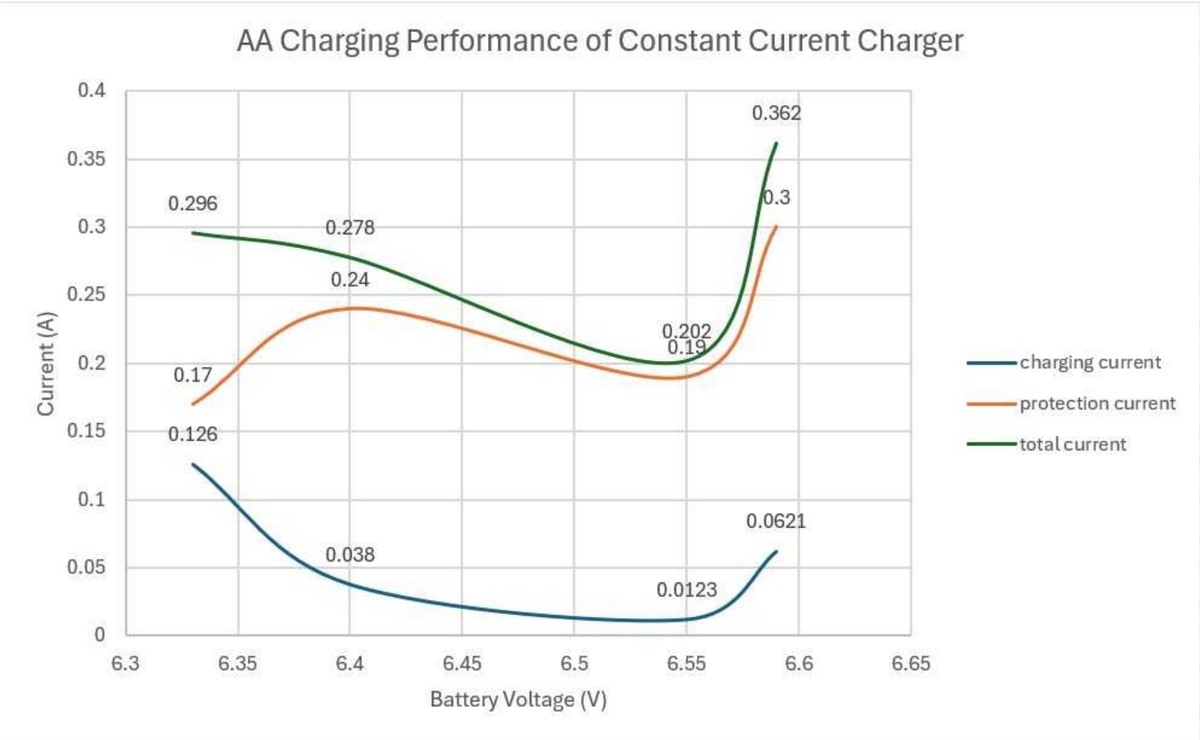


6.55 V

12.3 mA going into battery

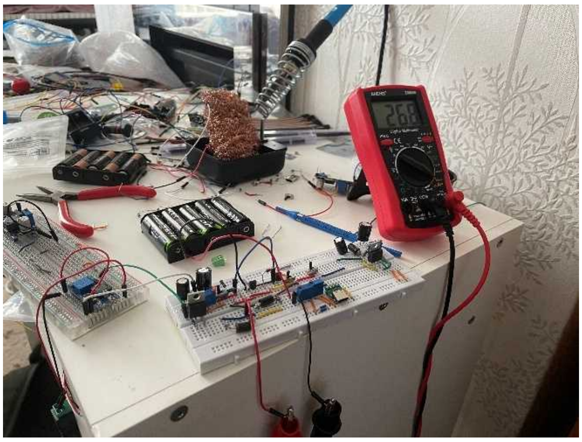
0.19 A going into protection circuit

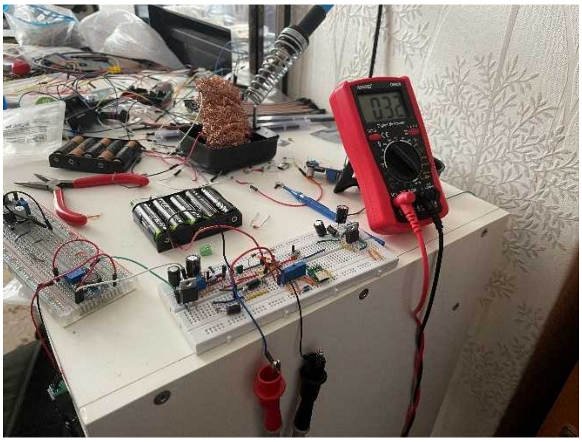
New graph would look like the one below:



It could just be an anomaly.

-Remeasured again:

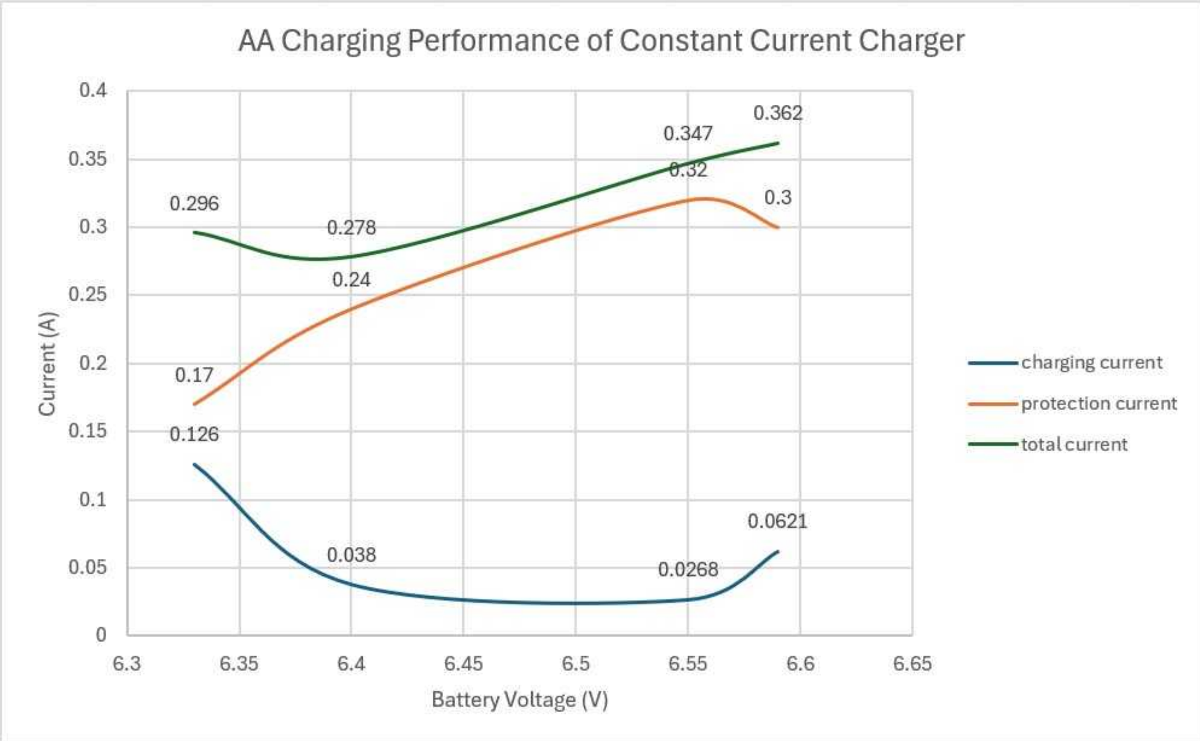




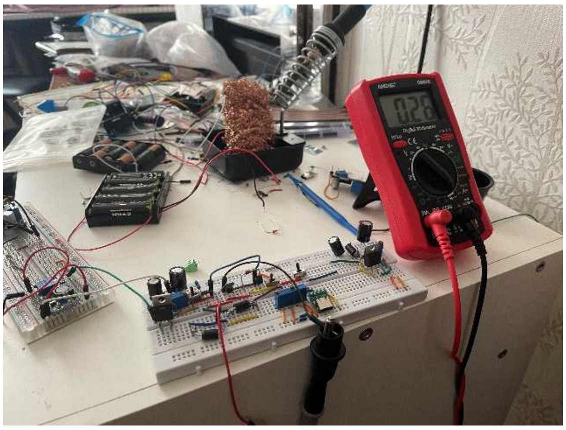
26.8 mA going into batt

0.32 A going into protect

6.33	0.126	0.17	0.296
6.4	0.038	0.24	0.278
6.55	0.0268	0.32	0.347
6.59	0.0621	0.3	0.362

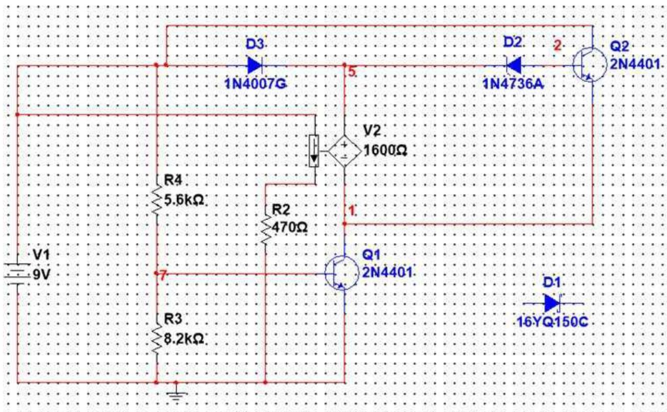


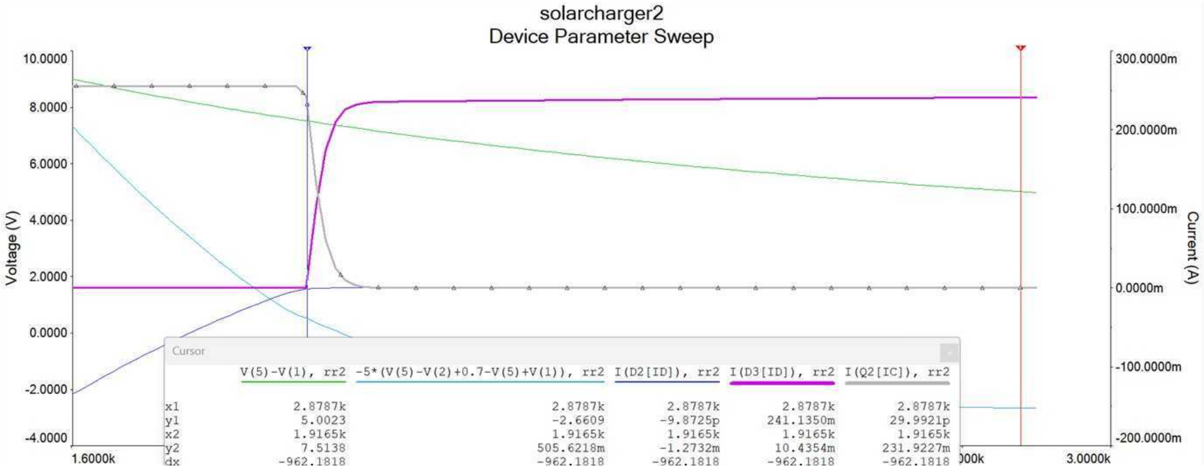
No load current: 0.26 A



23/08Aug/25 -

-Redesigned the protection circuit to no resistor and a 6.8 V Zener diode.





y2 7.0023 -935.0506m -235.0634n 235.9447m 12.7242µ

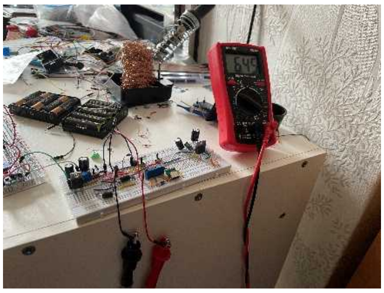
Made it 6.8 to compensate for the right shifting of the graph in the real circuit.

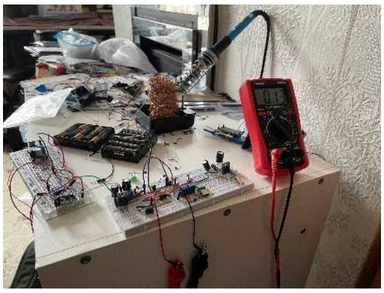
-Tested the circuit:

6.45 V battery

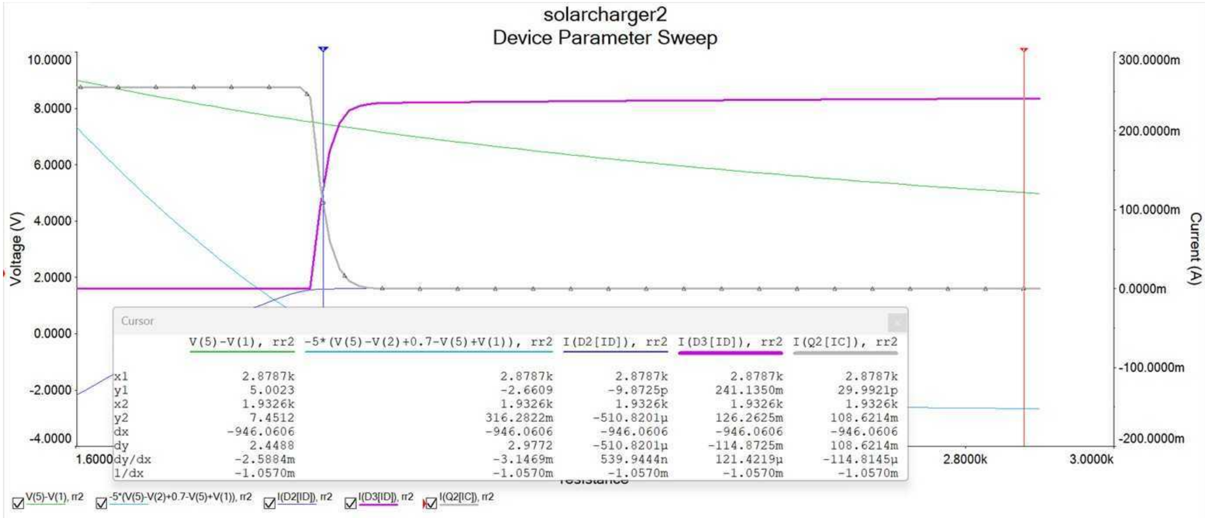
0.13 A going into the battery

0.12 A going into the protection circuit





The measurement might have been on the 2nd cursor on the figure below:



Note: 7.45 - 6.45 = ~ 1 V right shift (That could be the BE junction voltage of the protection transistor)

6.51 V

0.1 A going into the battery

0.16 A going into the protection circuit

3rd reading:

6.59 V

0.29 A going into the battery

0.0958 A going into the protection circuit

*This is weird. Now it shows there is no shift.

4th reading:

6.66 V

0.22 A going into the battery

0.0052 A going into the protection circuit

5th reading:

6.77 V

0.21 A going into the battery

0.0060 A going into the protection circuit

-Simulated 6.2 V Zener diode protection circuit:

6th reading:

6.83 V

0.21 A going into the battery

0.15 A going into the protection circuit

7th reading:

6.92 V

0.2 A going into the battery

0.012 A going into the protection circuit

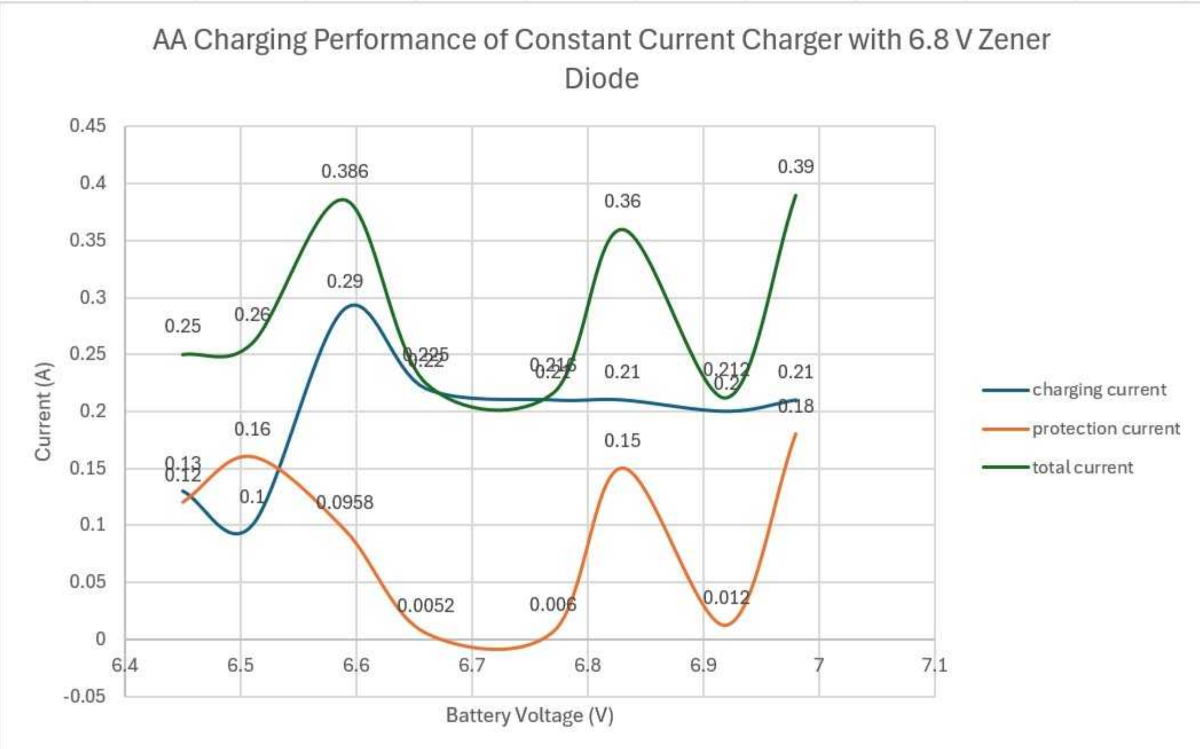
8th reading

6.98 V

0.21 A going into the battery

0.18 A going into the protection circuit

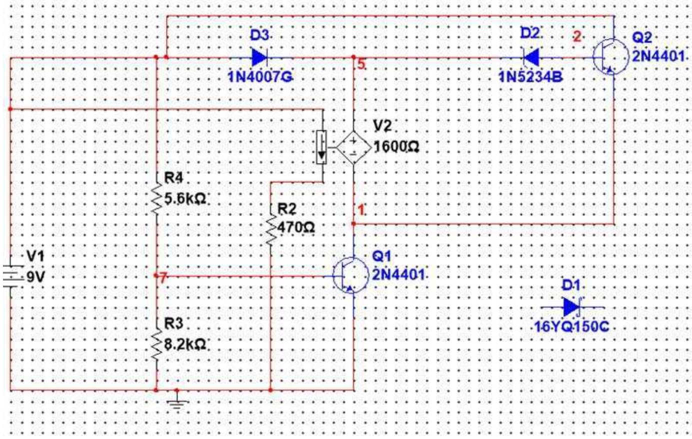
257	6.45	0.13	0.12	0.25
258	6.51	0.1	0.16	0.26
259	6.59	0.29	0.0958	0.386
260	6.66	0.22	0.0052	0.225
261	6.77	0.21	0.006	0.216
262	6.83	0.21	0.15	0.36
263	6.92	0.2	0.012	0.212
264	6.98	0.21	0.18	0.39

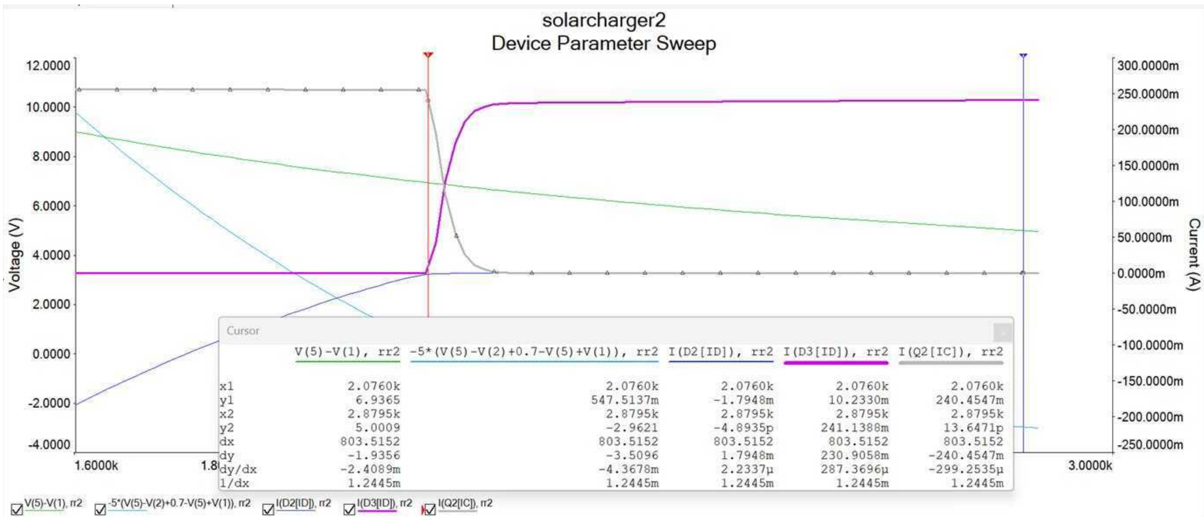


The experimental results graph agrees with the simulation except for the first readings.

It does not prevent overcharging because it only short when its 7.5 V.

Simulation results of 6.2 V Zener diode protection circuit:





26/08Aug/25 -

-Tested the protection circuit of 6.2 V Zener diode:

6.8 V

0 A going into the battery

0.2 A going into the protection circuit

2nd reading:

6.47 V

0.0839 A going into the battery

0.25 A going into the protection circuit

3rd reading:

6.48 V

0.24 A going into the battery

Oscillate between 0.33, 0.22, 0.1 and 0 going into the protection circuit

4th reading:

6.51 V

0.14 A going into the battery

Oscillate between 0.33, 0.22, 0.1 and 0 going into the protection circuit

-Replaced the transistors and zener diode:

1st reading:

6.50 V

0.055 A going into the battery

Oscillation going into the protection circuit

-Replaced 6.2 V back to 6.8 V Zener diode:

1st reading:

6.8V

0.28 A going into the battery

Oscillation in protection

2nd reading:

7.02 V

0.2 A going into the battery

Oscillation in protection

3rd reading:

7.04 V

0.18 A going into the battery

0.7 A going into the protection circuit

-Replaced 6.8 V into 6.2 V Zener diode again:

4th reading:

6.49 V

0.055 A going into the battery

Still oscillation in the protection circuit

5th reading:

6.51 V

0.062 A going into the battery

(7-0.7-6.2)/68 = 1/680 A

(1/680) * 200 = 5/17 = 0.294 A maximum protection current

-Added a 68-ohm resistor in series with the 6.2 V Zener diode:

1st reading:

6.55 V battery

0.06 A going into the battery

0.112 A going into the protection circuit (adding the resistor stopped the oscillation)

0.172 total current

2nd reading:

6.6 V battery

0.043 A going into the battery

0.09 A going into the protection circuit

0.133 A total current

3rd reading:

6.63 V

0.042 A going into the battery

0.115 A going into the protection circuit

0.157 A total current

No load current: 0.26 A

-Replaced 6.2 V Zener diode back into 6.8 V:

1st reading:

6.93 V

0.33 A batt

0 A prtc

0.33 A totl

2nd reading:

7.06 V

0.32 A batt

0 A prtc

0.32 A totl

3rd reading:

7.09 V

0.3 A batt

0.013 A prtc

0.313 A totl

This seems to be dangerously overcharging.

-Replaced 6.8 V to 6.2 V Zener diode:

-Tested 7.09 V to test overcharge protection:

0 A batt

0.26 A prtc

4th reading:

6.6 V

0.025 A batt

0.10 A prtc

0.125 total current

-Brought back 6.8 V and continue testing the 7.09 V battery:

Convinced by ChatGPT that 1.32 V is 50 - 60% capacity and is way undercharged for maximum voltage.

4th reading:

7.10 V

0.28 A batt

0.0017 A prtc

0.282 A totl

5th reading:

7.13 V

0.29 A batt

0.030 A prtc

0.32 A totl

6th reading:

7.19 V

0.25 A batt

0.0218 A prtc

0.272 A totl

8th reading:

7.23 V

0.23 A batt

0.035 A prtc

0.265 A totl

7th reading:

7.21

0.21 A batt

0.1 A prtc

0.31 totl

9th reading:

7.24 V

0.18 A batt

0.031 A prtc

0.211 A totl

10th reading:

7.23 V

0.28 A batt

0.005 A prtc

-Replaced the protection transistor with a new one:

11th reading:

7.24 V

0.22 A batt

0.044 A prtc

12th reading:

7.22 V

0.26 A batt

0.035 A prtc

13th reading:

7.22 V

0.17 A batt

0.082 A prtc

0.252 A totl

14th reading:

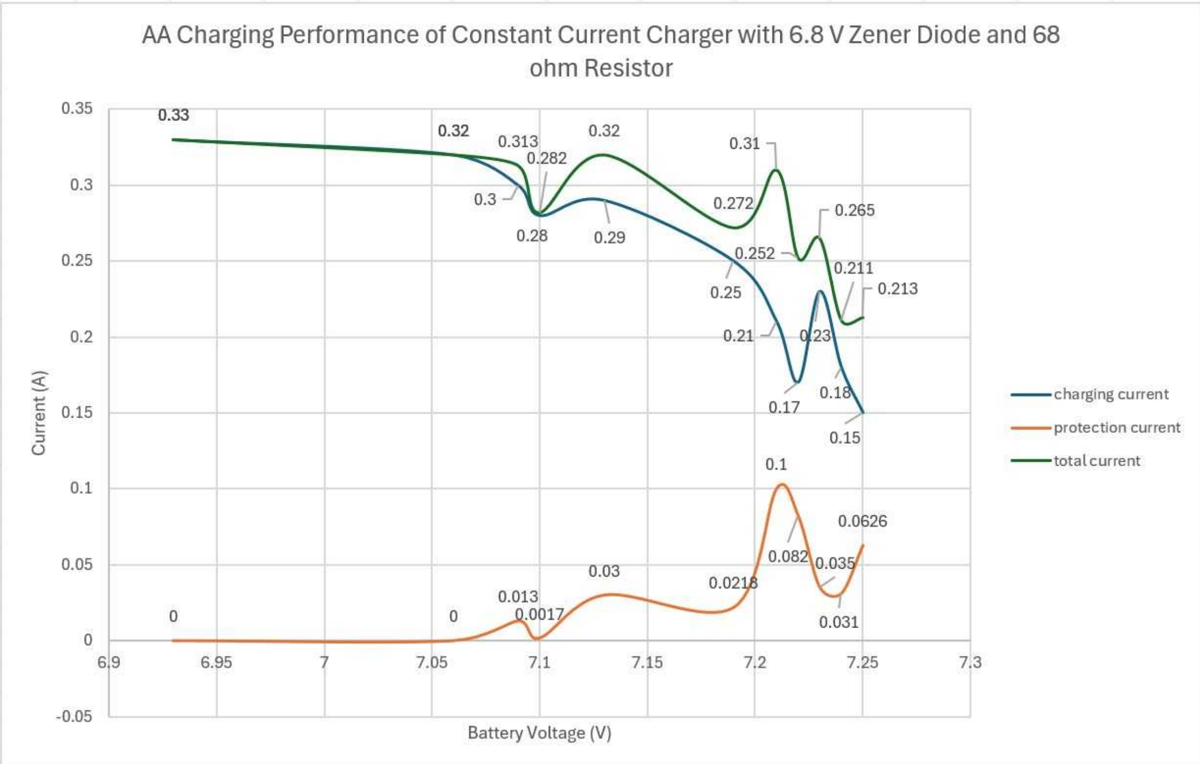
7.25 V

0.15 A batt

0.0626 A prtc

0.213 A totl

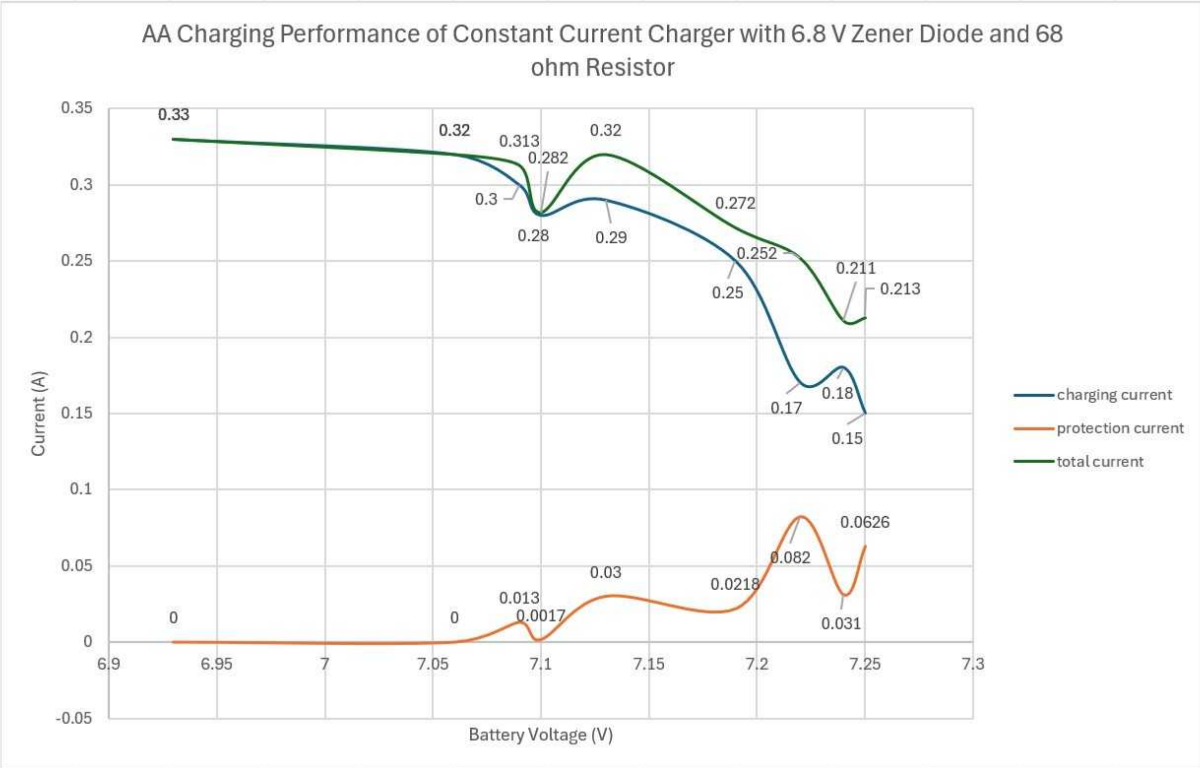
257	6.93	0.33	0	0.33
258	7.06	0.32	0	0.32
259	7.09	0.3	0.013	0.313
260	7.1	0.28	0.0017	0.282
261	7.13	0.29	0.03	0.32
262	7.19	0.25	0.0218	0.272
263	7.21	0.21	0.1	0.31
264	7.22	0.17	0.082	0.252
265	7.23	0.23	0.035	0.265
266	7.24	0.18	0.031	0.211
267	7.25	0.15	0.0626	0.213



This confirmed that the overcharge protection circuit works with a cutoff of 7.25/5 = 1.45 V per battery, reducing the charging current of 0.33 A to 0.15 A.

There are some outliers in the data such as line 263 and 265. These could be due to human errors in measurement.

If these are removed, the graph would be as follows:

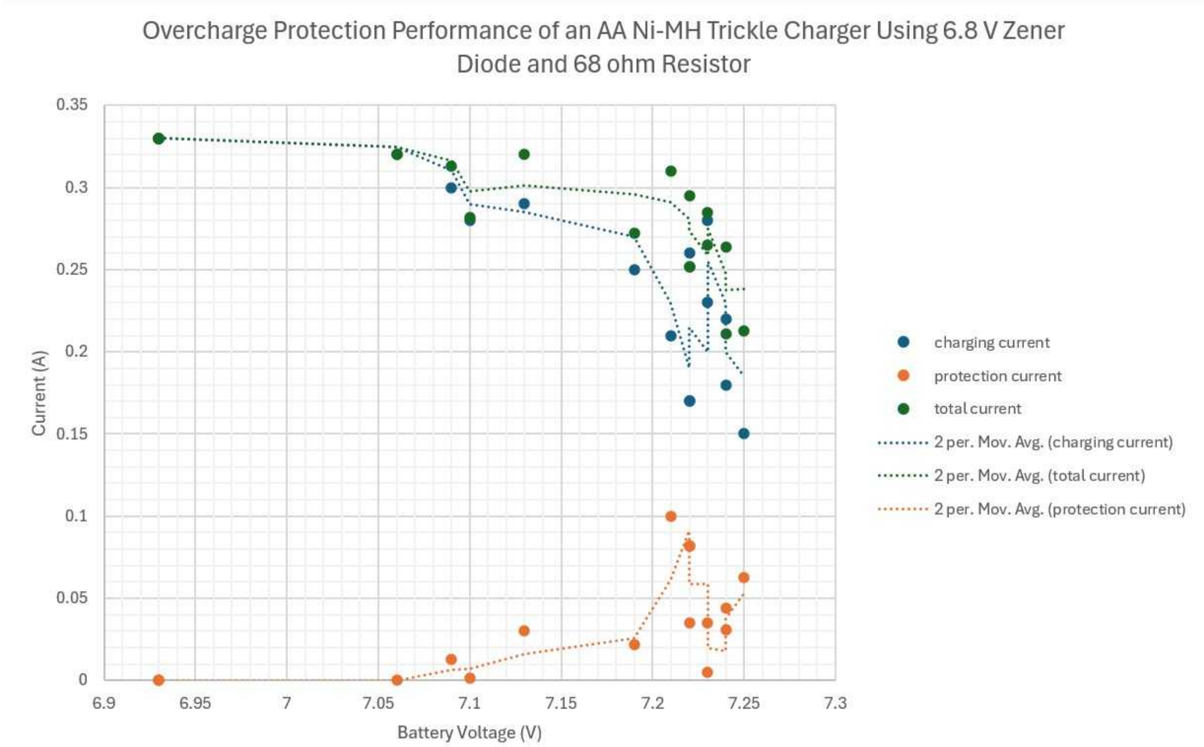


28/08Aug/25-

-Remade the graph with all the data including outliers:

-Doubled the first measurement to extend the moving average to the first point.

257	6.93	0.33	0	0.33
258	6.93	0.33	0	0.33
259	7.06	0.32	0	0.32
260	7.09	0.3	0.013	0.313
261	7.1	0.28	0.0017	0.282
262	7.13	0.29	0.03	0.32
263	7.19	0.25	0.0218	0.272
264	7.21	0.21	0.1	0.31
265	7.22	0.17	0.082	0.252
266	7.22	0.26	0.035	0.295
267	7.22	0.17	0.082	0.252
268	7.23	0.23	0.035	0.265
269	7.23	0.28	0.005	0.285
270	7.24	0.18	0.031	0.211
271	7.24	0.22	0.044	0.264
272	7.25	0.15	0.0626	0.213

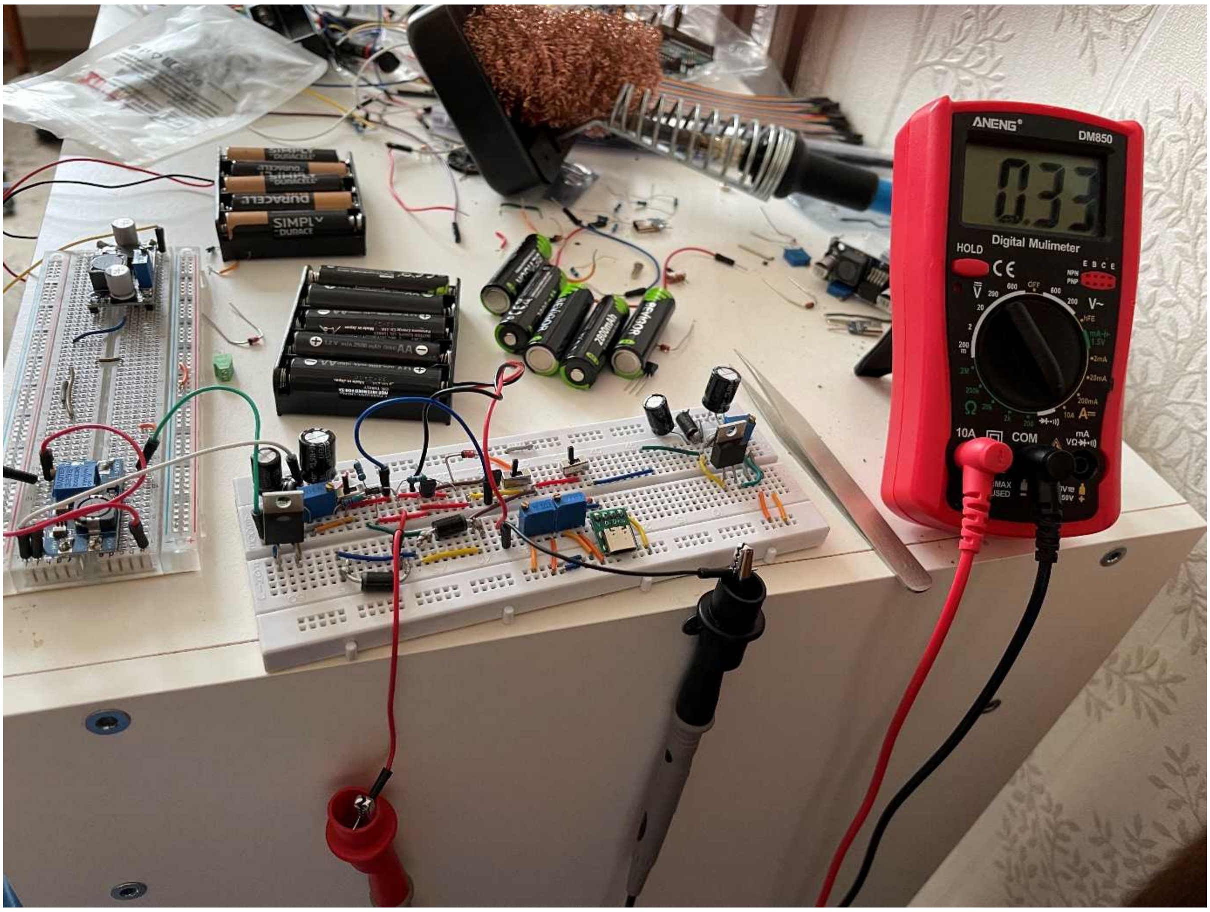


-Tested 6.6 V battery:

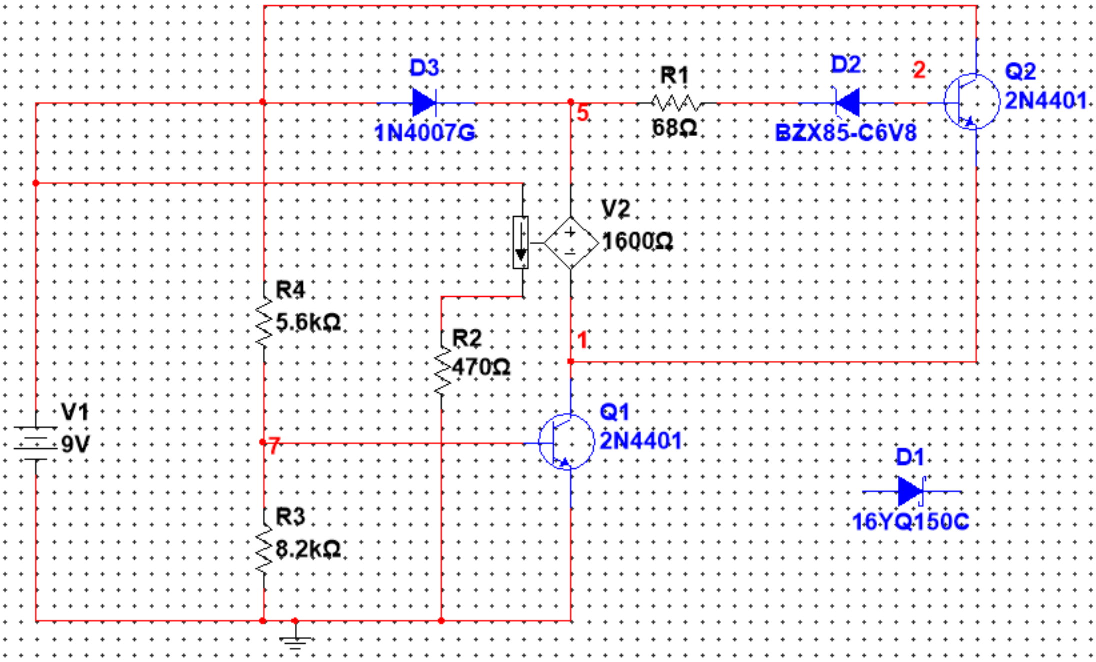
0.33 A batt

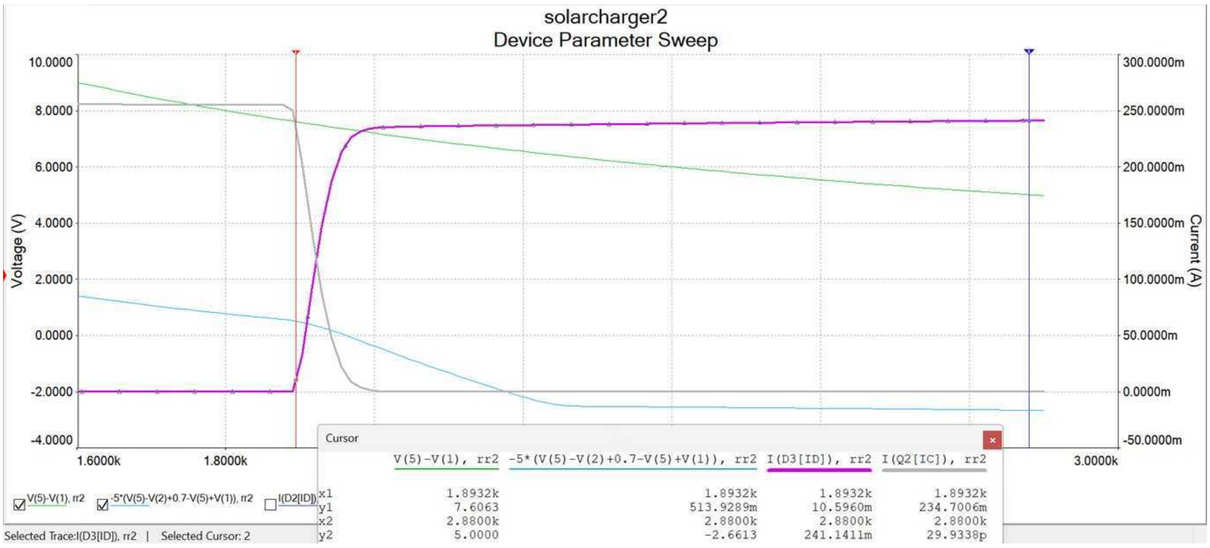
0.0013 A prtc

0.331 A totl


ANENG
DM850
0.33
Digital Mulimeter
HOLD
COM
10A

Simulation:


D3
1N4007G
5
R1
68Ω
D2
BZX85-C6V8
2
Q2
2N4401
V2
1600Ω
R4
5.6kΩ
R2
470Ω
1
V1
9V
7
Q1
2N4401
D1
16YQ150C
R3
8.2kΩ



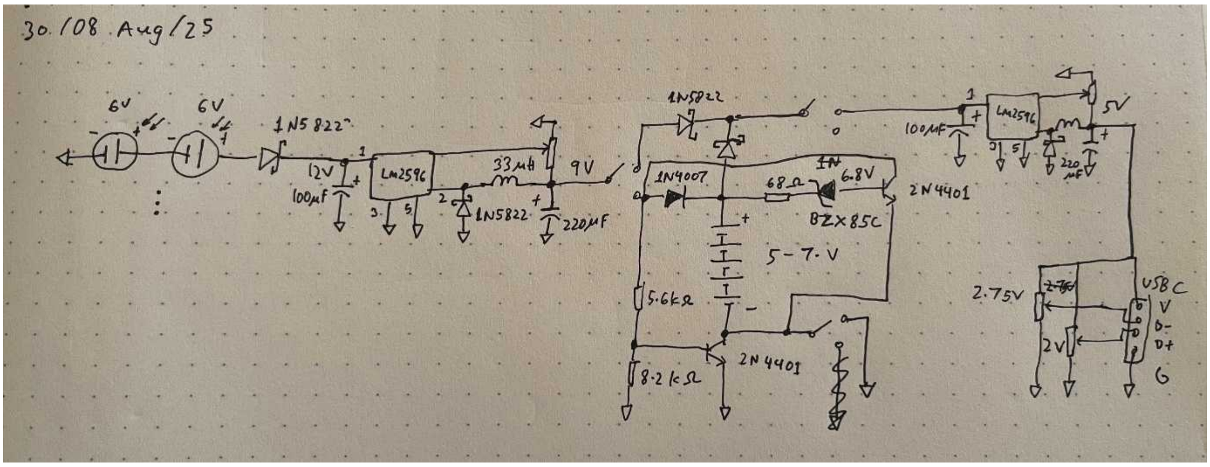
-Tested 7.98 V to show charging current going to zero:

-0.004 A batt

0.27 A prtc

0.27 A totl

30/08Aug/25-



-Started making the PCB schematic in KiCad.

01/09Sept/25 -

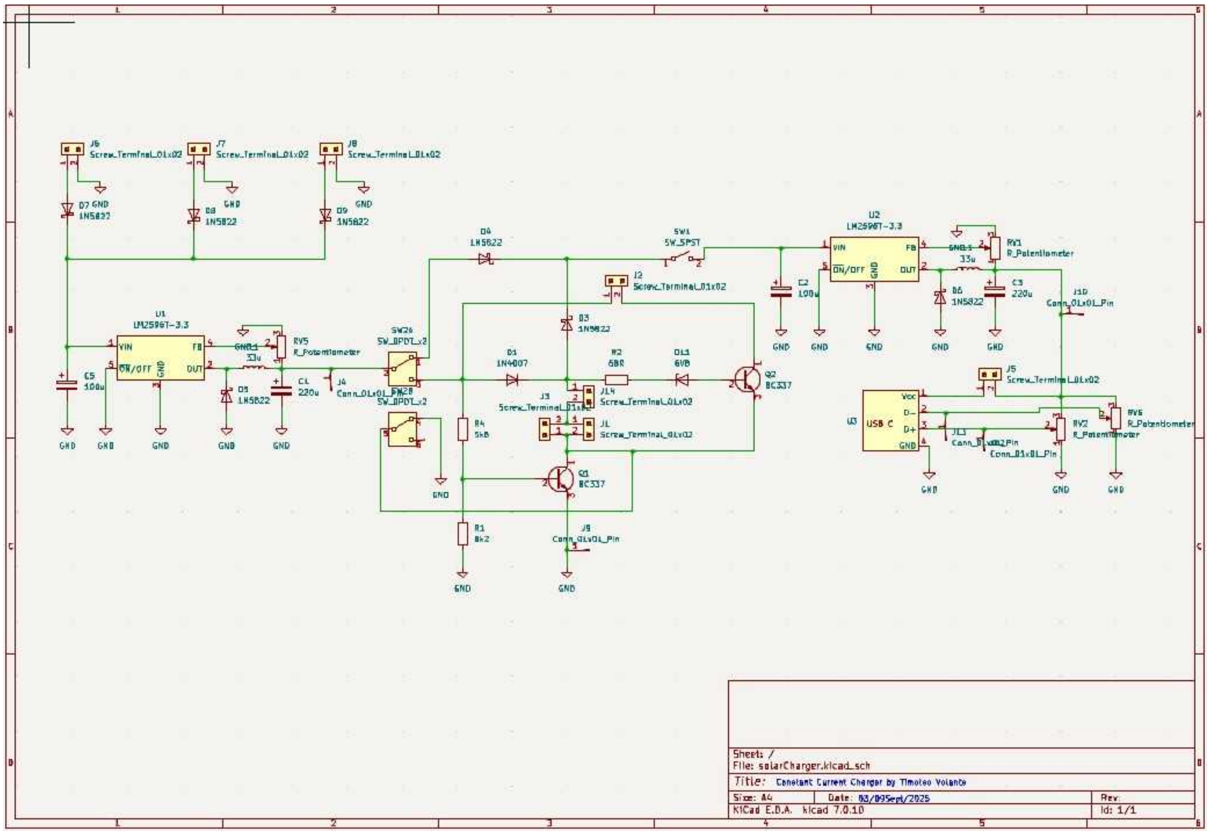
-Started making the footprints of each symbol.

PCB manufacturer:

https://jlcpcb.com/?from=VGPCBA&utm_source=google&utm_source=google&utm_medium=cpc&utm_medium=cpc&utm_campaign=20338495875&utm_campaign=20338495875&utm_content&utm_term=_&adgroupid&utm_network=x_&gad_source=1&gad_campaignid=21402499807&gbraid=0AAAAABS1QqkbQyjXOoGetbR1y_B9xaDQa&gclid=CjwKCAjwiNXFBhBKEiwAPSaPCcsrEqtacvUIJH4TN7RDWIOc-k3Jv_bpZNcc25zTgCnmJxYQv6zO5xoC7PQQAvD_BwE

03/09Sept/25 -

-Finished making the schematic, symbols, and footprints:



04/09Sept/25-

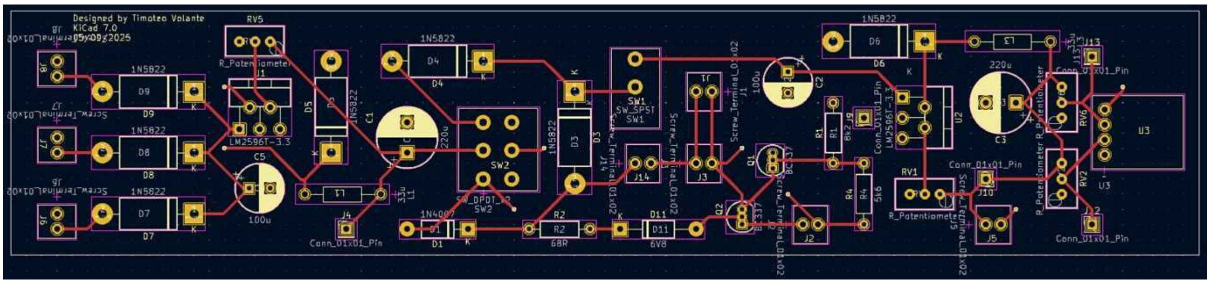
-Use this website to calculate trade width and clearance:

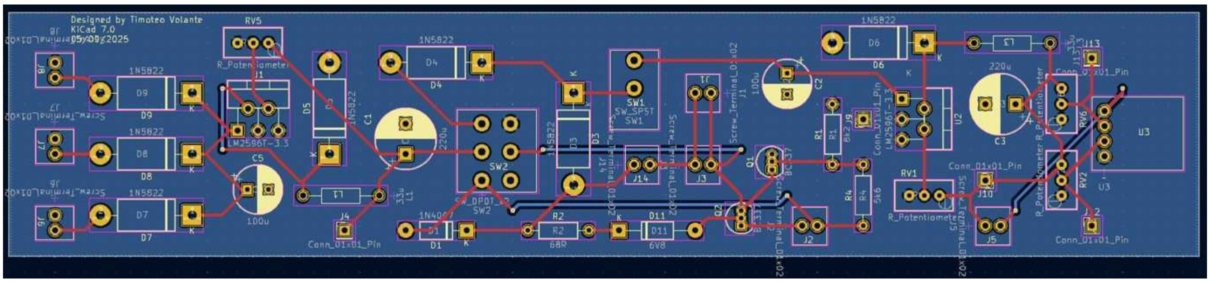
https://nick.desmith.net/Electronics/TraceWidth.html

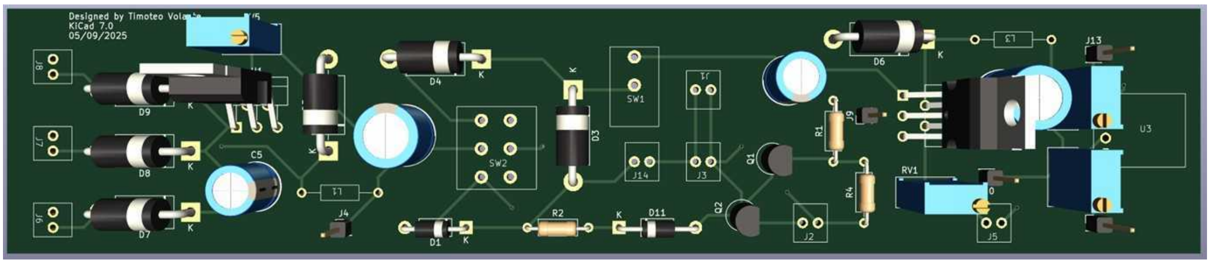
-Started routing the PCB.

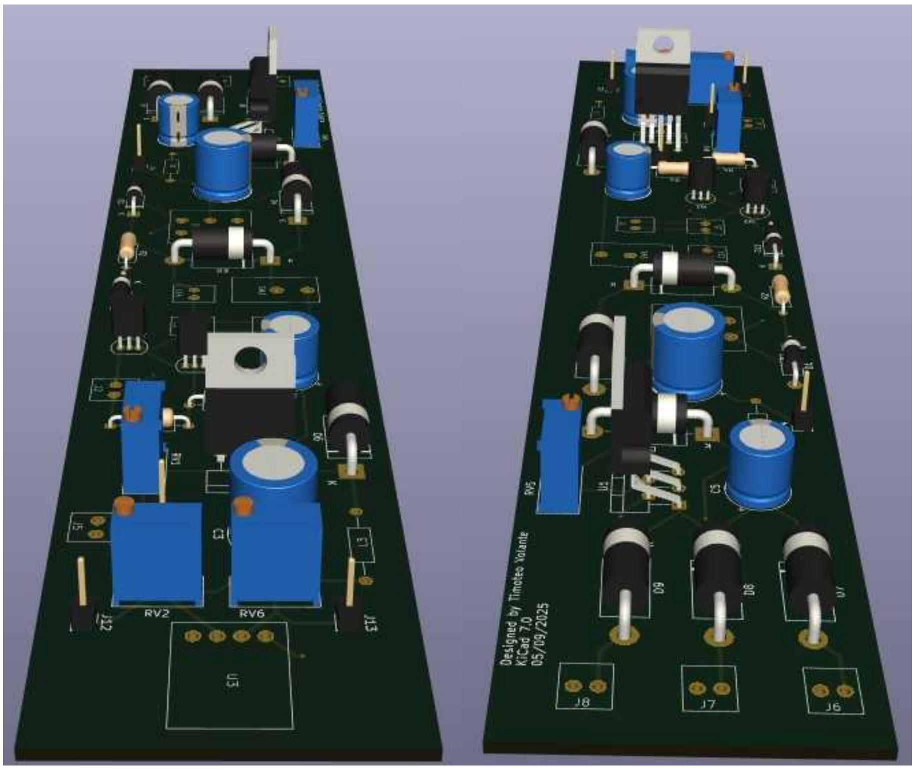
05/09Sept/25-

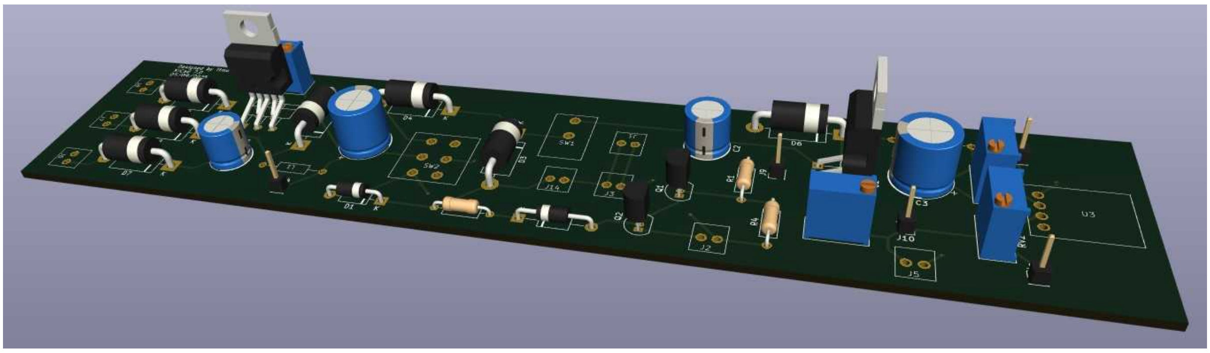
-Finished routing the PCB:



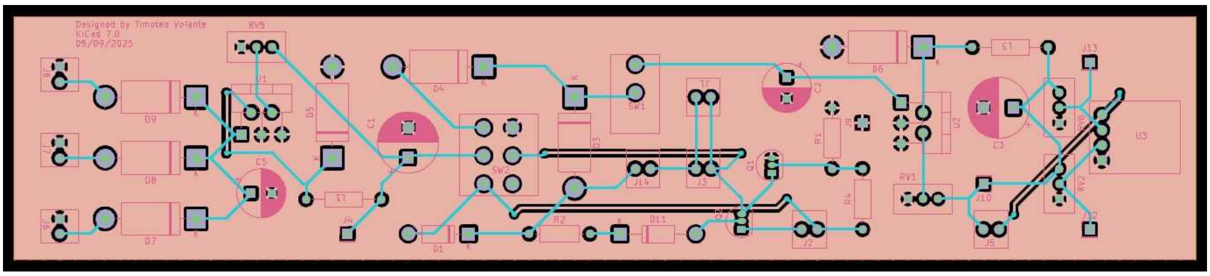








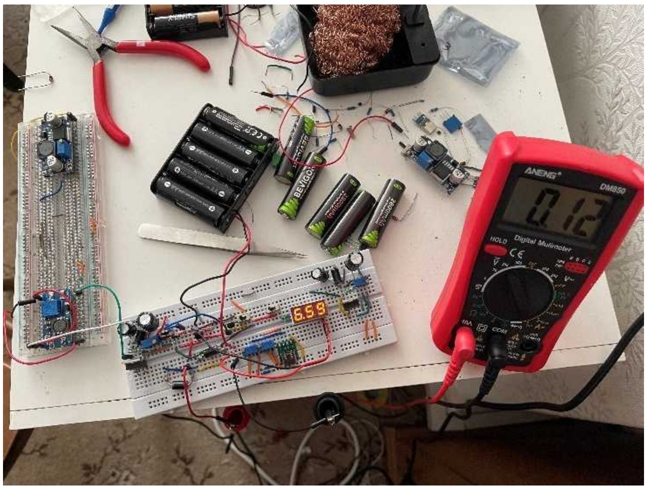
-Made the Gerber files:

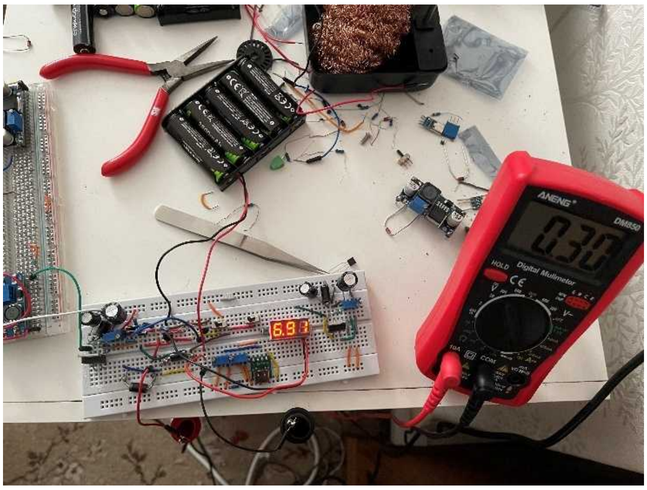


-Ordered the PCB from JLCPCB.

08/09Sept/25-

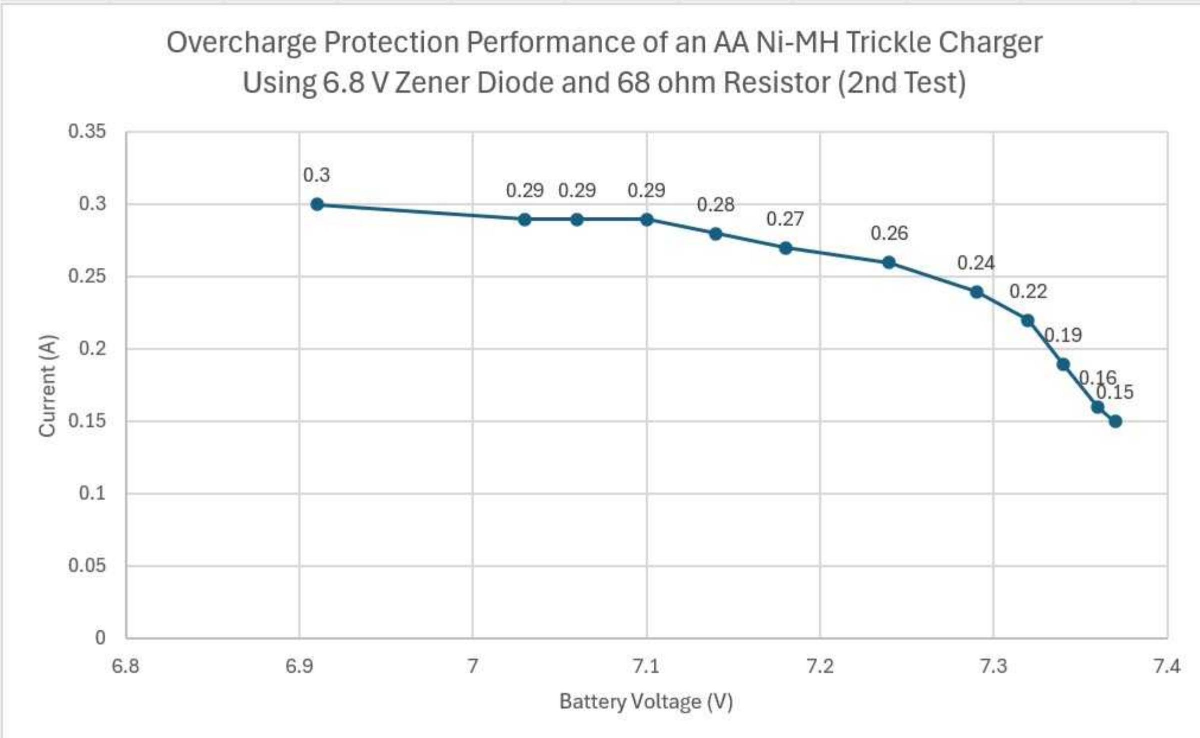
-Tested the new voltmeter with the charging circuit:



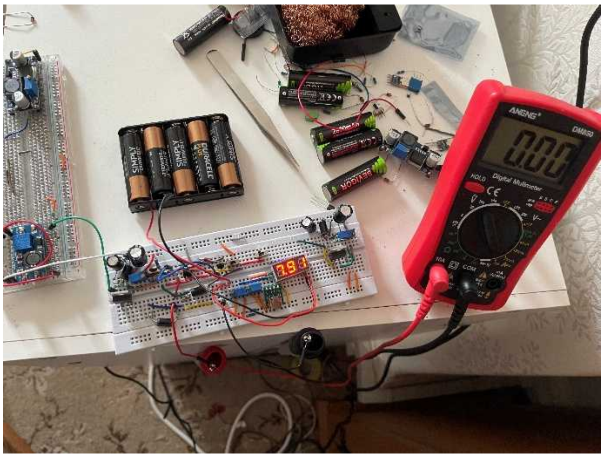


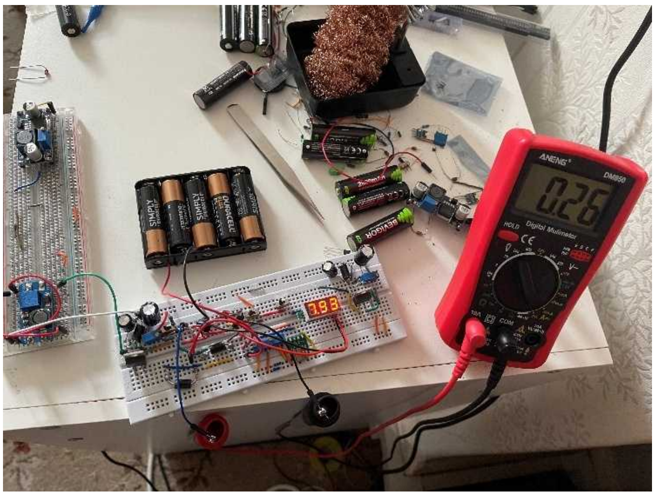
-Redid the test with the charging current against voltage in excel.

283	6.91	0.3
284	7.03	0.29
285	7.06	0.29
286	7.1	0.29
287	7.14	0.28
288	7.18	0.27
289	7.24	0.26
290	7.29	0.24
291	7.32	0.22
292	7.34	0.19
293	7.36	0.16
294	7.37	0.15

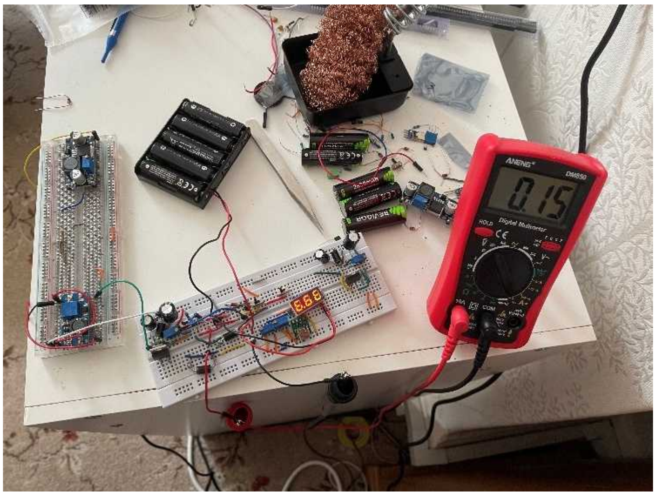


-Tested the overcharge protection current going to maximum and charging current going to zero with the voltmeter:





-Tested with another battery set (4 eneloops and 1 bevigor):



The lower charging current might be because of the inconsistent battery brands in series.

-Tested charging iPhone from 21 %:

21 % 0.35 A

22 % 0.35 A 1 min

-Removed the voltmeter to increase charging current:

Voltmeter roughly uses 60 mA cause charging current increased to 0.41 A from 0.35 A.

22 % 0.41 A

23 % 0.42 A 10 mins

24 % 0.40 A 9 mins

25 % 0.40 A 13 mins

26 % 0.40 A 9 min

27 % 0.38 A 15 min

28 % 0.30 A 7 min

29 % 0.39 A 5 min

30 %   0.40 A 16 min

32 %   0.40 A 16 min

33 %   0.40 A 9 min

34 %   0.4 A   14 min

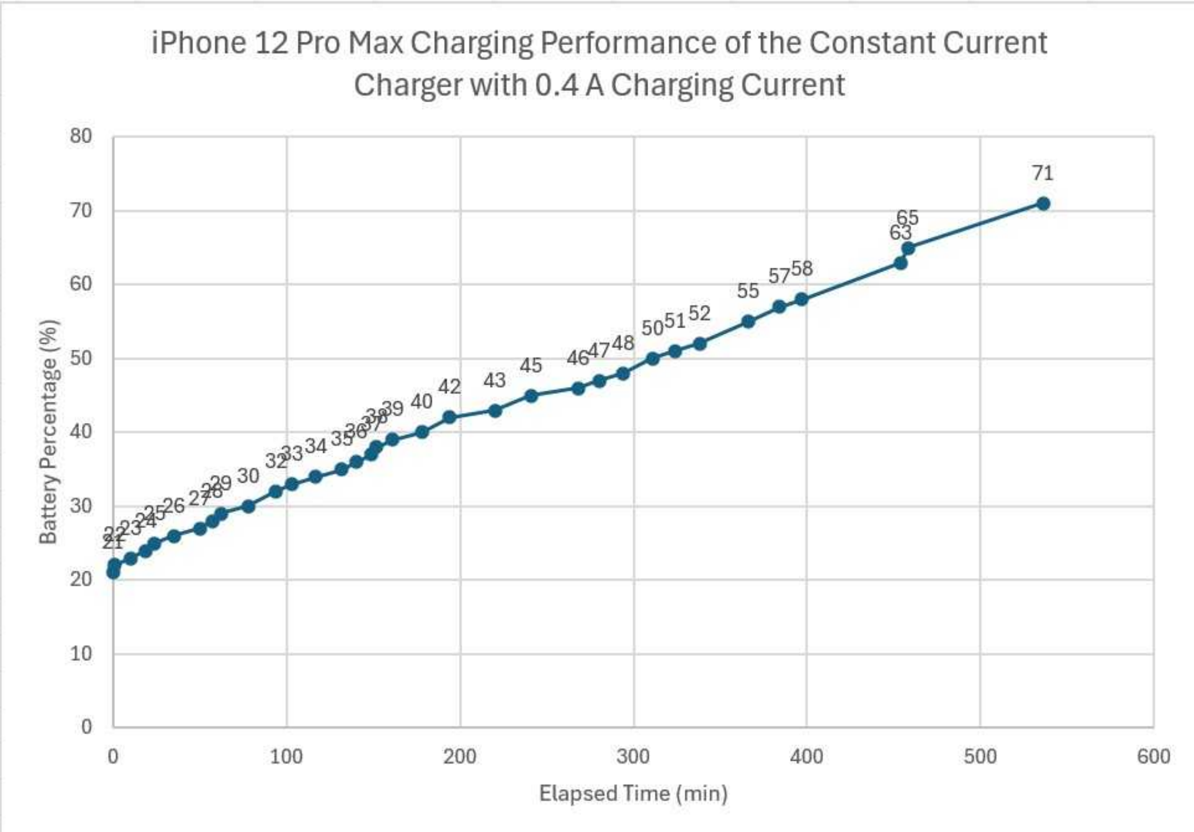
35 %   0.39 A 15 mins

36 %   0.39 A 8 mins

37 %   0.36 A 9 mins

38 %   0.36 A 3 mins

-Continued the data in the excel document.



18/09Sept/25 -

-PCB arrived.

-Started soldering the first half of the PCB:

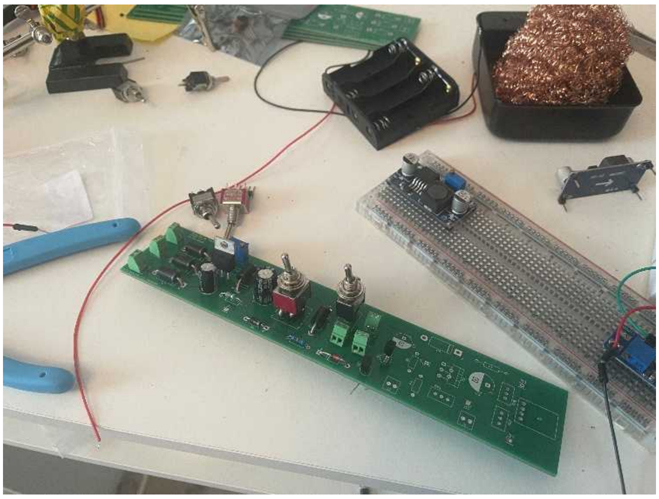
1) Encountered a problem with the switches component's pins not fitting into the holes.

Fixed this by cutting the pins short and soldering them to connectors.

2) Another problem is that the transistor holes are too close together, and as a result, I accidentally created a short circuit.

Will try and fix this by using a solder flux and removing the short with a solder wick.

Will also replace the ¼ W inductor with a 1 W. (This might be the reason for the reduction of current in previous tests)



20/09Sept/25 -

-Finished soldering the PCB. (Used solder flux for the closely spaced holes)

-Used the soldering pump to removed solder from holes with the help of books to hold the PCB in place.

Note: I must point the soldering pump directly on the hole to remove the solder.

21/09Sept/25 -

-Adjusted the buck converter voltages into 9.09 V and 5.06 V respectively, and D+ = 2.02 V, D- = 2.77 V.

-Replaced the broken potentiometer associated with D- with a new one.

-There is no current, so I replaced one of the transistors.

-There is still no current. Will replace the other transistor tomorrow.

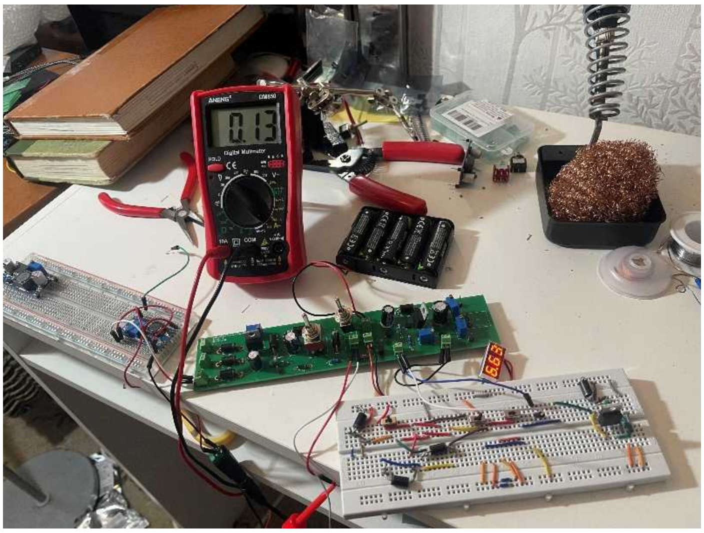
-Realised the transistor might have been connected the other way around.

22/09Sept/25 -

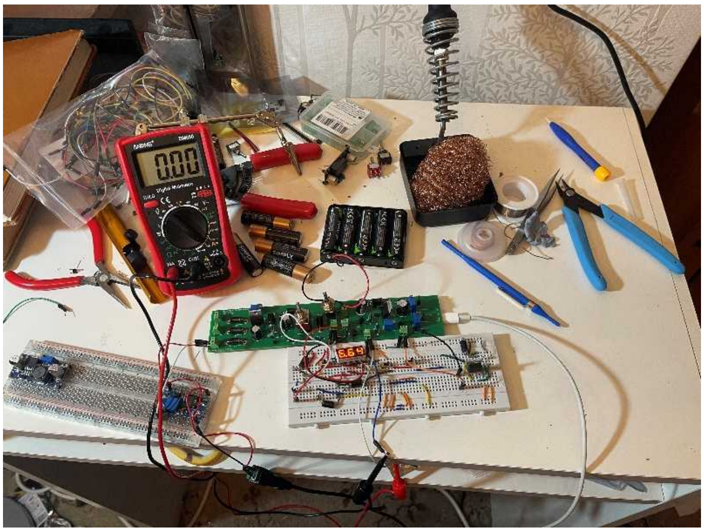
-Replaced and oriented the transistors the opposite way.

-Tested the AA battery charger:

AA battery holder voltage = 6.63 V

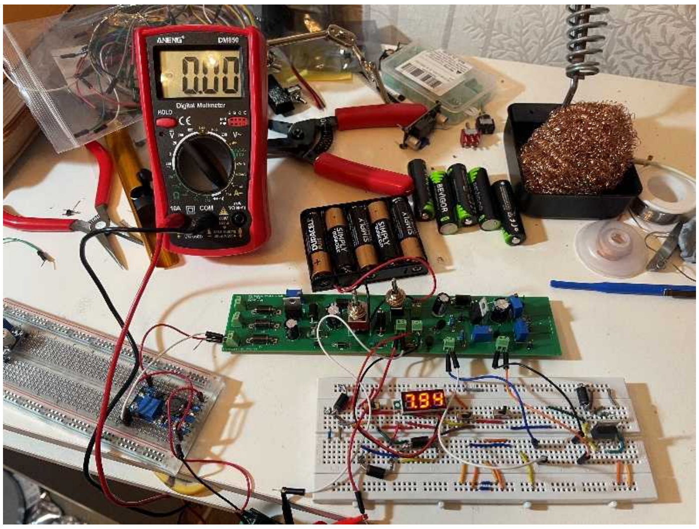


AA battery charging current = 0.13 A

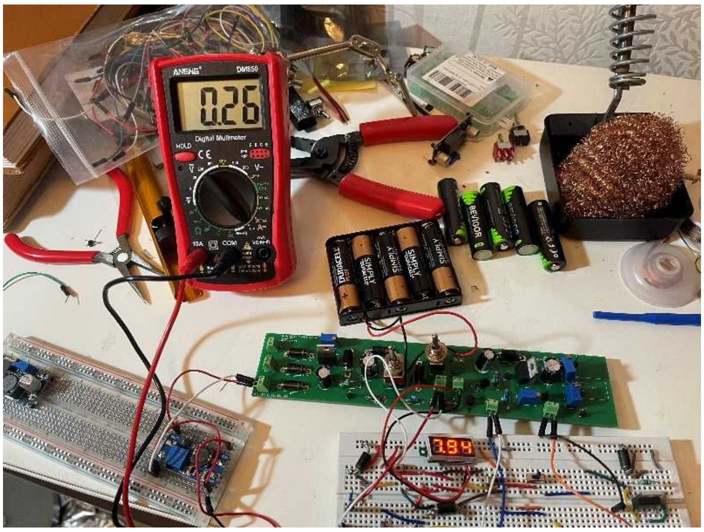


Overcharge protection current = 0 A

AA battery holder voltage = 7.94 V



AA battery charging current = 0 A



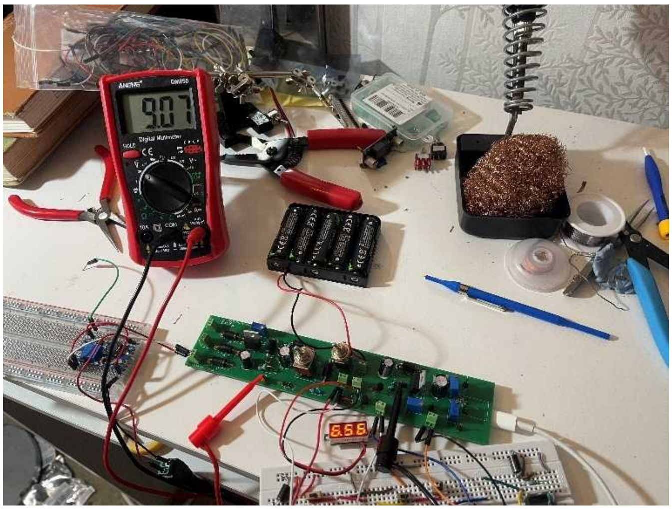
Overcharge protection current = 0.26 A

*The AA battery charger works.

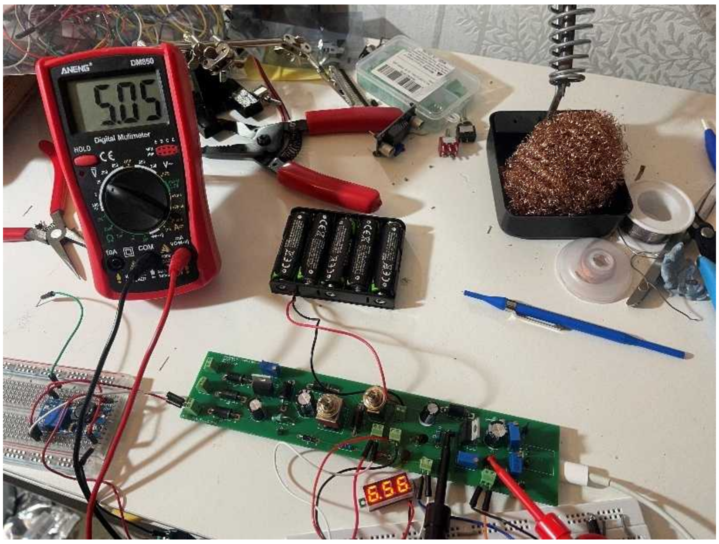
-Tested the iPhone charger:

Did not work.

*Is it possible the usb wire is oriented the wrong way when connecting?



9 V buck converter



5 V buck converter

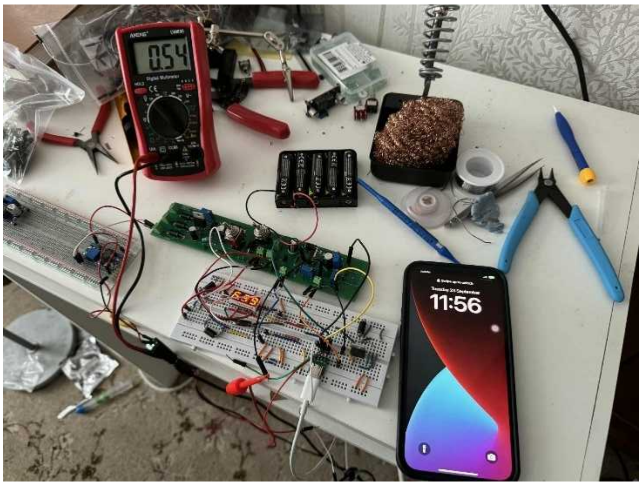
-Will try setting the D- = 2.75 V exactly or if that did not work, 2.7 V tomorrow.

*A reason could also be that D+ and D- are swapped in the module.

Or the module is broken.

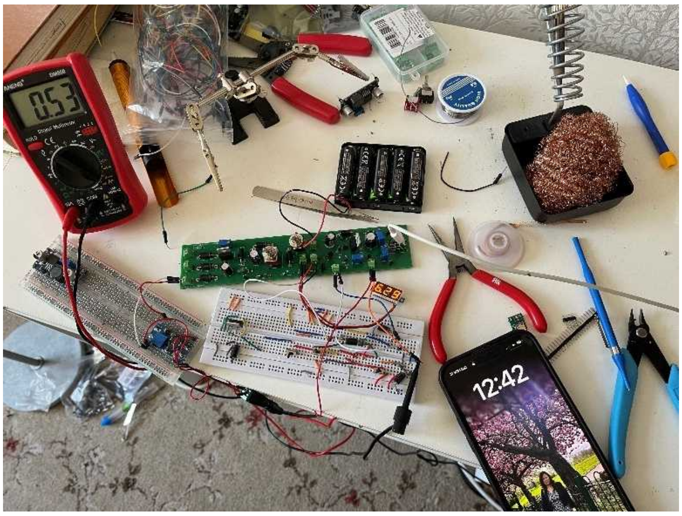
23/09Sept/25-

-Redirected the wires to the previous usb c module that were working in the breadboard and tested charging iPhone:



It worked and it has a 0.54 A charging current.

-Replaced the broken USB C module with the working one and tested the iPhone charger:



iPhone charging current = 0.53 A

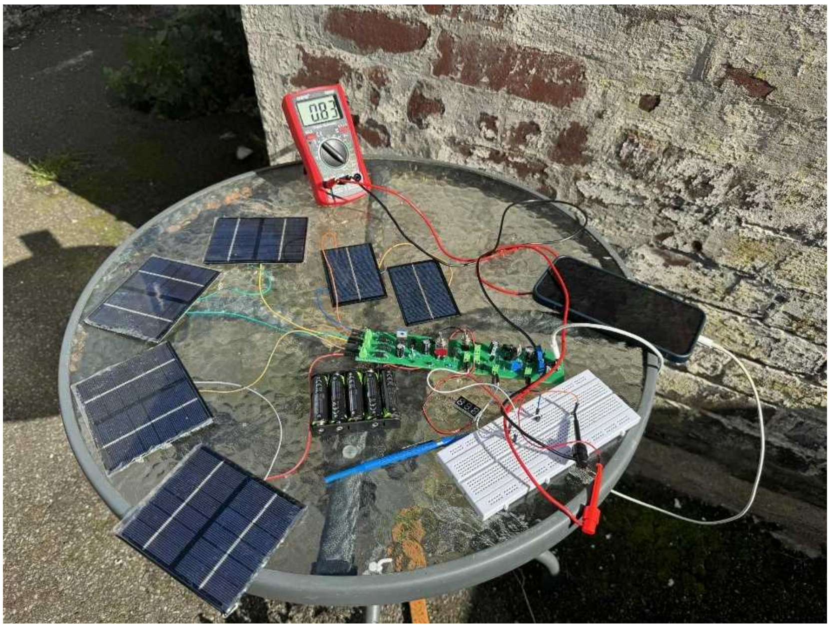
It works!

-Soldered the solar panels and attached them to the charger.

-Tested the charger:

AA battery holder voltage: 6.55 V

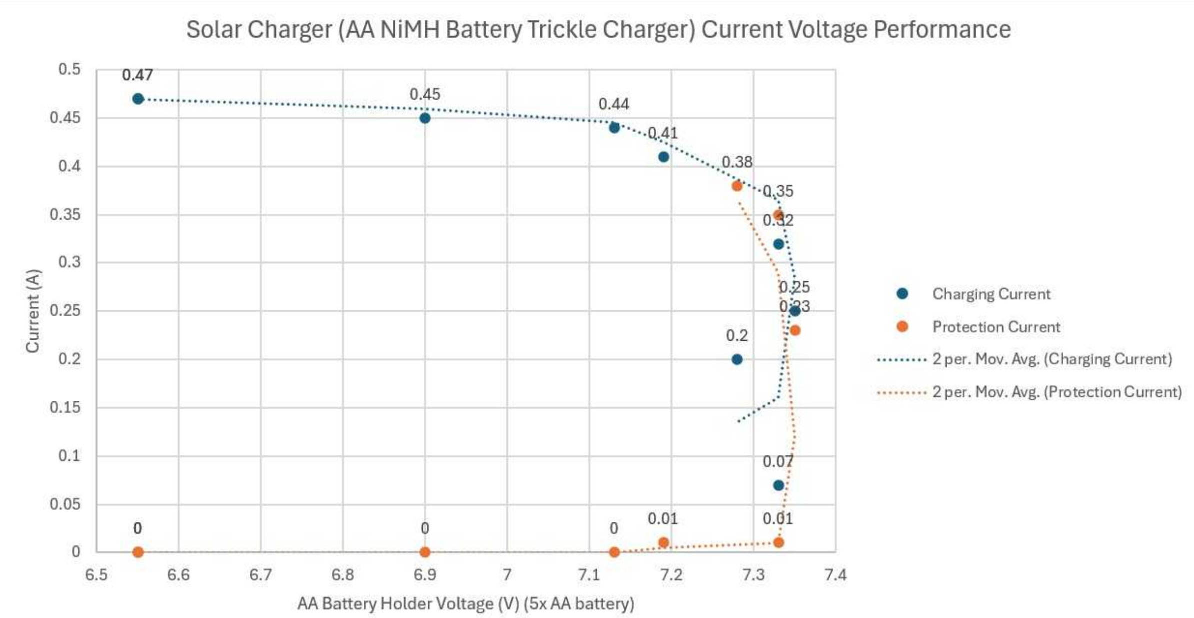
AA battery charging current = 0.48 A



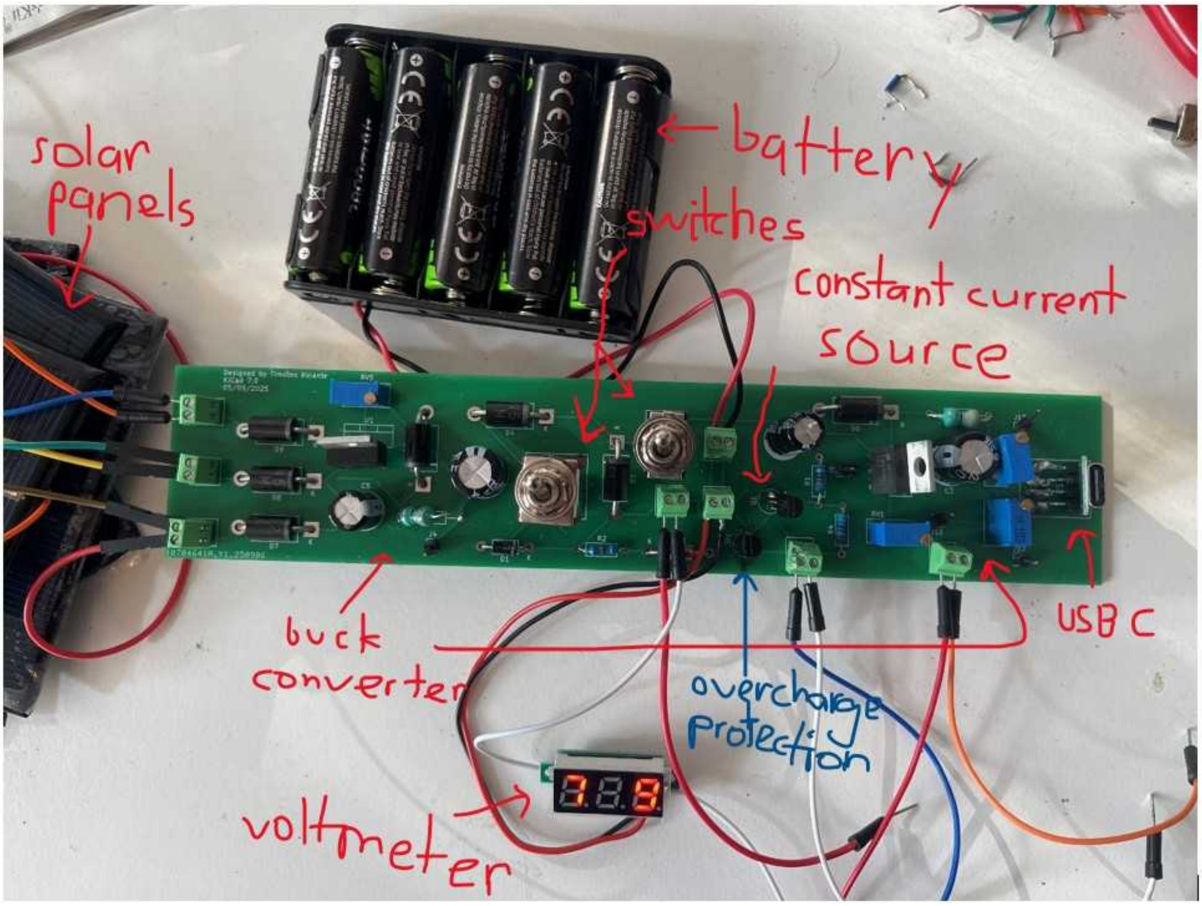
iPhone charging current = 0.83 A

-Gathered data for charging AA batteries:

6.55	0.47	0	0	13:35
6.55	0.47	0	0	13:35
6.9	0.45	0	21	13:56
7.13	0.44	0	35	14:10
7.19	0.41	0.01	50	14:25
7.33	0.32	0.01	83	15:08
7.35	0.25	0.23	119	15:44
7.33	0.07	0.35	127	15:52
7.28	0.2	0.38	133	15:58



Overview of the PCB:



Main inspirations/ references:

https://www.eleccircuit.com/simple-1-2v-aa-battery-solar-charger-circuit/ for the constant current source

https://www.edn.com/solar-charger-circuit/ for the overcharge protection

Own design ideas:

- Using the collector side for the battery as current source.
- Using a buck converter instead of a linear regulator for efficiency (though I might have seen a comment from online suggesting changing to a buck from linear for an article of a different circuit)
- Integrating both an iPhone and AA battery charging in the same PCB by using switches.

Estimated Cost of the charger:

2x 2n4401 transistors £0.0939

2x LM2596T buck converter £1.42

7x 1n5822 Schottky diode £2.338

1x BZX85C 6v8 zener diode £0.27

1x spst switch £0.898

1x dpdt switch £1.15

4x 10k variable resistors £1.712 → £0.0764

2x 100uF capacitors £1.356

2x 220uF capacitors £1.196

1x 33uH inductor £0.06

1x voltmeter £2.99

1x USB C connector board £0.649

8x Terminal block connectors £2.798→ £0

3x resistors £0.01

1x PCB £0.48

5x connector £0.01

4x solar panels £19.992

2x solar panels £4.495

Total £41.92

Total without detachable components

£14.44

Total without detachable components and test hardware

£10

Solar panels could be replaced by this

https://www.amazon.co.uk/Monocrystalline-Lighting-Scientific-Research-Projects/dp/B0B5GZCJYY/ref=sr_1_26_sspa?crid=12NC77EX67F84&dib=eyJ2IjoiMSJ9.vHyQspLQgRLNSmuwA2_mwyk3xDwesV64670wcMXZi3NV3ZqNaWmrXl6u43K8ILLv9ymoZHvp2X_QuKgHI-DHT511DiTAFlBjo_4yGW2QzvG95KYnuxNjD5N2MZ7-DprB8ylhNRjL-Fzd5sb_DUryvgW5lK3WyvHJddSxLX43a_YQoocCmdHUHv83p_ZhhA1GDL94pvpRaBmrM4lJeJKyfZPn2iGoBR9vS7gc7umvePk4vtUcLVrCoSw6HXJmIpkhh6xm2zuidEMOr_LDn7y-BsQdIuv3Q02U_HA7vTNXwZc.SvCiSj8kPJ4Q3ws7yaHBObaaRDRrZeL92a6yNQP80co&dib_tag=se&keywords=solar+panel&qid=1758662525&s=electronics&sprefix=solar+panel%2Celectronics%2C105&sr=1-26-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9tdGY&psc=1

18 V 4.2 W can charge iPhone with the AA batteries with only £10.69

With this solar panel:

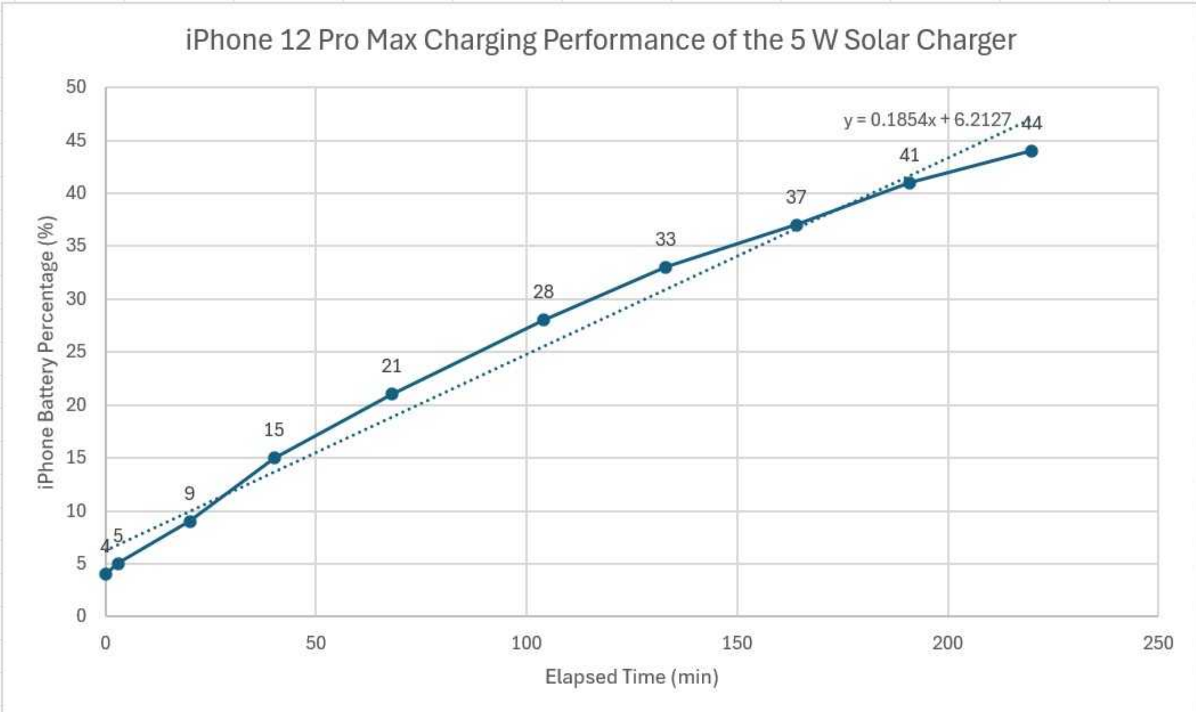
Total without test hardware: (alternative cheaper solar panels)

£20.99

24/09Sept/25-

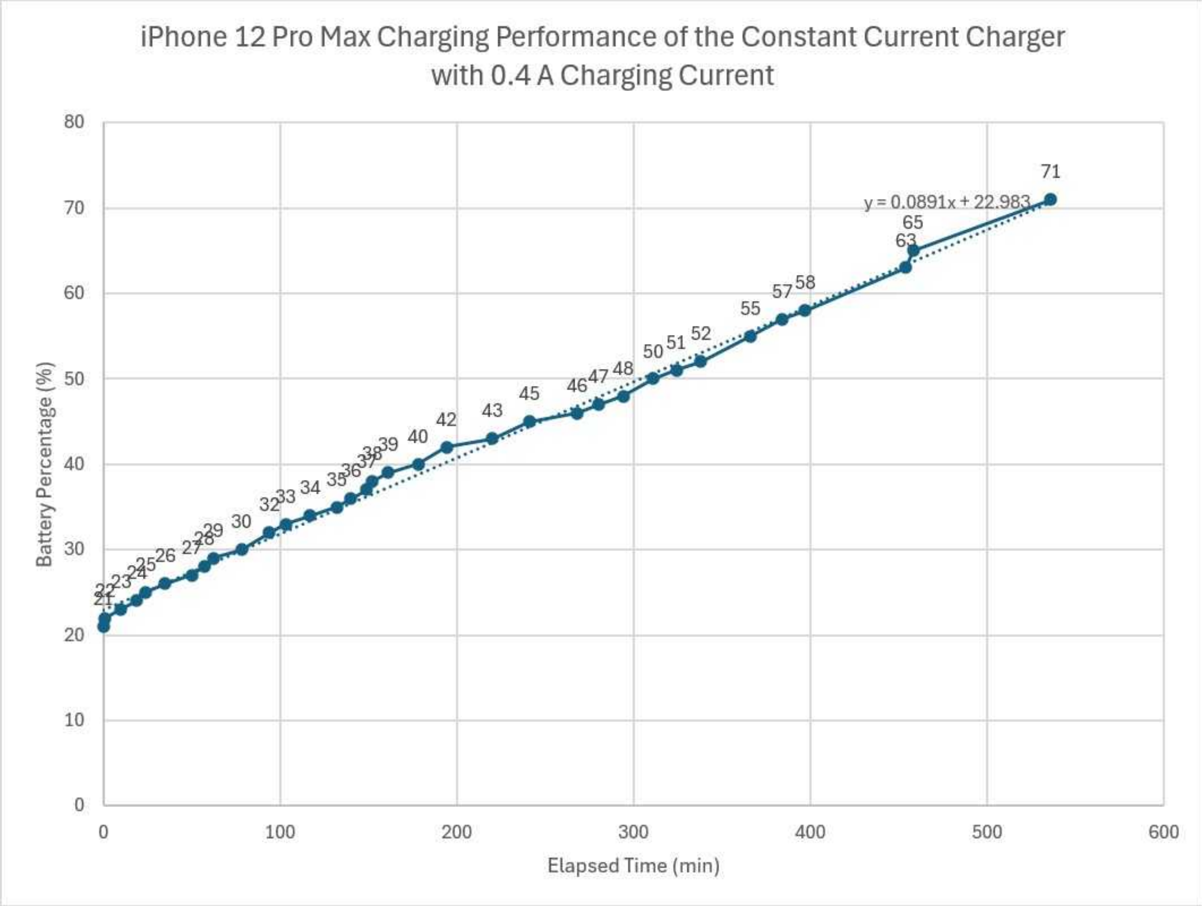
-Gathered data about charging iPhone:

366	Minutes	Batt %
367	0	4
368	3	5
369	20	9
370	40	15
371	68	21
372	104	28
373	133	33
374	164	37
375	191	41
376	220	44



0.1854 % / min → 1 % / 5.39 min   for 1 A charging current (5 W)

0.0891 %/ min → 1 % / 11.22 min   for 0.4 A charging current that was recorded in the breadboard prototype



Calculation of how many iPhone 12 Pro Max (3,687 mAh) full charges can the solar charger do with 5x Bevigor batteries (2800 mAh each):

2.8 x 5 = 14 000 mAh

14 000 / 3687 = ~ 3.797 full charges → 3 full charges

The solar charger battery bank can charge an iPhone 12 Pro Max three times.