Supporting Information 1
Charge/Discharge Testing Device for:

Open-Source Equipment Design for Cost-Effective Redox Flow Battery Research

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Figure SI 1.1: The schematic of power modules

Experiment set up

All V redox flow battery was subjected to research and evaluation using power modules (Figure 4). The electrolyte used in the research and evaluation was a mixture of 1M $V^{3+/4+}$ and 2M H_2SO_4. This electrolyte was filled into two tanks, with each tank having a volume of 150mL. The electrolyte was then circulated within the flow cell by a pump operating at a flow rate of 20mL/min. The redox flow battery consisted of three mono cells. The mode used to charge was a constant current charge (CC-charge). The charging process aimed to reach a voltage of 5.4V while maintaining a current of 1.5A. The charging and discharging process of the redox flow battery system was closely monitored, and the results were recorded and depicted in Figure 5. The figure likely provides a graphical representation of the voltage and current profiles during the charging and discharging cycles of the flow battery system.

The charging and discharging system, utilizing power modules, operates in a stable manner with pre-set parameters. This stability ensures consistent and reliable performance of the system throughout its operation. By closely monitoring the system, operators can readily observe and assess the charging and discharging processes. This allows for a comprehensive evaluation of cell performance and the overall functioning of the battery system. Operators can easily identify any deviations or issues that may arise, enabling them to quickly address and resolve problems.

- Electrolyte : 1M V +2M H_2SO_4
- Volume: 150 mL
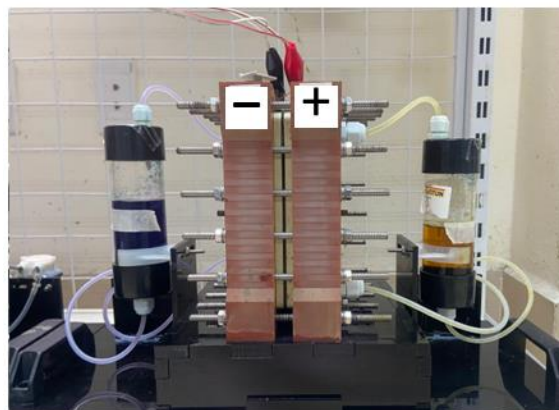- Constant current charge (CC charge): 5.4V-1.5A

Figure SI 1.2: The redox flow battery is used to charge and discharge through power modules.
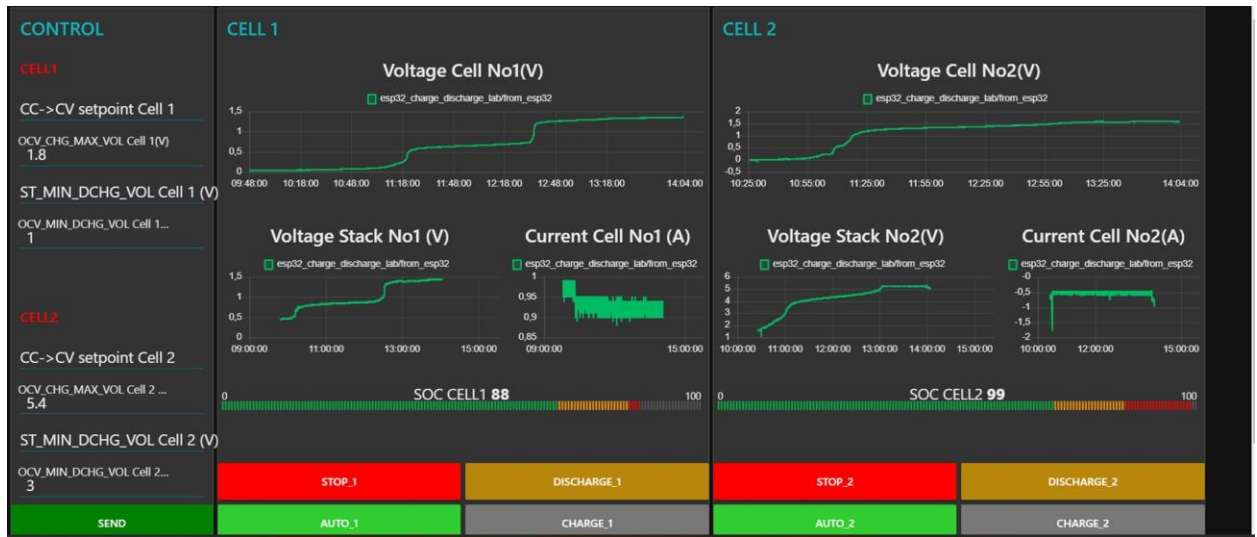
Figure SI 1. 3: The charging and discharging process of the battery through the power modules system is monitored in the app.
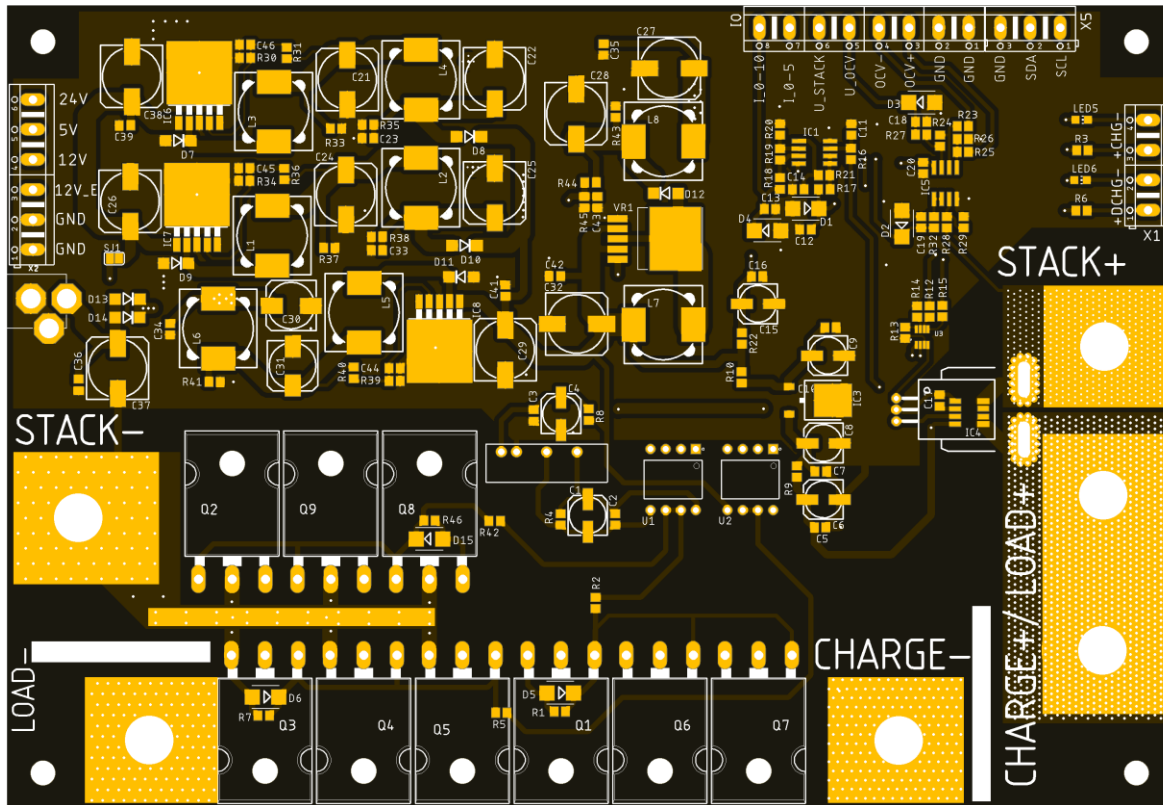
Table SI 1.1: Bill of materials

Value	Device	Package	Parts	Qty	Unit Price (USD)	Ext. Price (USD)	Mouser #	Description
Header 3P	AK500/3	AK500/3	X5	01	00.92	00.92	179-TB0010-500-03GR	CONNECTOR
Header 4P	AK500/4	AK500/4	X1	01	01.23	01.23	179-TB0010-500-04GR	CONNECTOR
Header 6P	AK500/6	AK500/6	X3	01	01.40	01.40	179-TB0010-500-06GR	CONNECTOR
Header 8P	AK500/8	AK500/8	IO	01	01.87	01.87	179-TB0010-500-08GR	CONNECTOR
DC Female	DC-2.1MM-5MM	DC-21MM	X2	01	01.00	01.00	992-CON-SOCJ-2155	5mm x 2.1mm jack
ORANGE	LEDCHIP-LED0805	CHIP-LED0805	LED5, LED6	02	00.39	00.78	630-HSMD-C170	LED
GREEN	LEDCHIP-LED0805	CHIP-LED0805	LED5, LED6	02	00.37	00.74	630-HSMG-C170	LED
0.1R	R-EU_R2512	R2512	R11	01	00.54	00.54	71-WSL2512R1000FEA	RESISTOR, European symbol
1.2K	R-EU_R0805	R0805	R30, R34	02	00.11	00.22	71-CRCW08051K20FKEC	RESISTOR, European symbol
100nF	C-EUC0805	C0805	C2, C3, C5, C7, C10-13, C14, C16, C17, C18-20, C23, C33, C34-36, C39, C41, C42	22	00.10	02.20	581-08055C104K	CAPACITOR, European symbol
100uH	DR127	DR127	L6	01	01.10	01.10	603-BPSC131380101M00	High Power Density, High Efficiency, Shielded Inductors
10K	R-EU_R0805	R0805	R1, R3, R6, R7, R13, R14, R19, R20, R23, R25, R46	11	00.29	03.19	755-SDR10EZPF1002	RESISTOR, European symbol
10R	R-EU_R0805	R0805	R2, R5, R12, R15, R42	05	00.18	00.90	71-CRCW080510R0FKEAH	RESISTOR, European symbol
10nF	C-EUC0805	C0805	C43, C44, C45, C46	04	00.10	00.40	581-08055C103KAT4A	CAPACITOR, European symbol
11K	R-EU_R0805	R0805	R31, R36, R45	03	00.10	00.30	71-CRCW0805-11K-E3	RESISTOR, European symbol

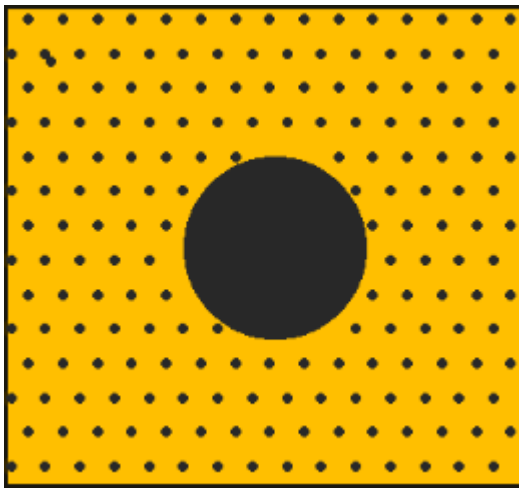| Value	Device	Package	Parts	Qty	Price	Total	Mouser	Description
16K	R-EU_R0805	R0805	R40	01	00.10	00.10	71-CRCW080516K0FKEA	RESISTOR, European symbol
16V-680uF	CPOL-EU153CLV-1012	153CLV-1012	C21, C22, C24, C25	04	00.84	03.36	80-EXV687M016S9PAA	POLARIZED CAPACITOR, European symbol
16V_100uF	CPOL-EU153CLV-0605	153CLV-0605	C1, C4, C6, C8, C9, C15	06	00.65	03.90	667-EEE-FPC101XAP	POLARIZED CAPACITOR, European symbol
1K	R-EU_R0805	R0805	R16, R17, R18, R21, R27, R32, R35, R38, R41, R43	10	00.10	01.00	71-RCA08051K00FKEA	RESISTOR, European symbol
2.2K	R-EU_R0805	R0805	R33, R37	02	00.10	00.20	71-CRCW08052K20FKEB	RESISTOR, European symbol
200K	R-EU_R0805	R0805	R44	01	00.11	00.11	71-CRCW0805200KFKEB	RESISTOR, European symbol
20K	R-EU_R0805	R0805	R24, R26	02	00.10	00.20	71-CRCW0805-20K-E3	RESISTOR, European symbol
24K	R-EU_R0805	R0805	R29	01	00.10	00.10	71-CRCW0805-24K-E3	RESISTOR, European symbol
25V-470uF	CPOL-EU153CLV-1012	153CLV-1012	C26, C29, C32, C37	04	01.23	04.92	80-A784MS477M1ELAS18	POLARIZED CAPACITOR, European symbol
IRFZ44N			Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9	09	00.88	07.92	942-IRFZ44NPBF	Mosfet
290N08	IRFP240-H	TO247BH	Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9	09	02.84	25.56	844-IRFP240PBF	HEXFET Power MosFet
33uH	DR127	DR127	L7	01	01.28	01.28	704-DR127-330-R	High Power Density, High Efficiency, Shielded Inductors
35V_470uF	CPOL-EU153CLV-1012	153CLV-1012	C27, C28	02	01.46	02.92	667-EEE-FN1V471UV	POLARIZED CAPACITOR, European symbol

4.7K	R-EU_R0805	R0805	R4	01	00.10	00.10	71-CRCW0805-4.7K-E3	RESISTOR, European symbol
47uH	DR127	DR127	L1, L2, L3, L4, L5, L8	06	01.28	07.68	704-DR127-470-R	High Power Density, High Efficiency, Shielded Inductors
5.1K	R-EU_R0805	R0805	R39	01	00.10	00.10	71-CRCW08055K10JNEA	RESISTOR, European symbol
56K	R-EU_R0805	R0805	R28	01	00.11	00.11	71-CRCW080556K0FKEAC	RESISTOR, European symbol
6.3V_1000uF	CPOL-EU153CLV-0810	153CLV-0810	C30, C31	02	00.78	01.56	667-EEE-FP0J102AL	POLARIZED CAPACITOR, European symbol
63V_100uF	CPOL-EU153CLV-1012	153CLV-1012	C38	01	01.79	01.79	80-A784MS107M1JLAV28	POLARIZED CAPACITOR, European symbol
7805DT	7806DT	TO252	IC3	01	01.02	01.02	511-L7805CD2T-TR	Positive VOLTAGE REGULATOR
ACS712	ACS712	SO08	IC4	01	03.79	03.79	250-712ELCTR20AT	
ACS750LCA-200	ACS750LCA-200	ACS75050	IC2	01	10.20	10.20	250-759ECB200BPFFT	Current Sensor
B1212S-2W	B1212S-2W	B1212S-2W	B1212S_2W	01	04.91	04.91	490-PEME2-S12-S12-S	
DZ12V	ZENER-DIODESMB	SMB	D4, D5, D6, D15	04	00.39	01.56	625-ZM4742A	Z-Diode
DZ5.1V	ZENER-DIODESMB	SMB	D1, D2, D3	03	00.22	00.66	78-TZMC5.1	Z-Diode
FB_100R	R-EU_R0805	R0805	R9, R22	02	00.11	00.22	810-MPZ2012S101AT000	RESISTOR, European symbol
FB_1R	R-EU_R0805	R0805	R8, R10	02	00.21	00.42	710-742792091	RESISTOR, European symbol
LM2596-5.0	LM2596S	TO263-5	IC8	01	06.70	06.70	926-LM2596S-12/NOPB	STEP-DOWN VOLTAGE REGULATOR
LM2596HVS	LM2596S	TO263-5	IC6, IC7	02	06.95	13.90	926-LM2596S-ADJ/NOPB	STEP-DOWN VOLTAGE REGULATOR

LM358D	LM358D	SO08	IC1, IC5	02	03.57	07.14	[511-LM358D](#)	OP AMP also LM158; LM258; LM2904
SS34-AB	DIODE-DO214BA	DO214BA	D7, D8, D9, D10, D11, D12, D13, D14	08	00.72	05.76	[512-SS34](#)	DIODE
TLP250(F)	TLP250(F)	DIP1016W50P254 L966H380Q8P	U1, U2	02	01.70	03.40	[757-TLP250HTP1F](#)	
XL6009	XL6009	DPAK170P1435X 465-6N	VR1	01	00.66	00.66	[C73018 (*)](#)	LCSC
INA219	INA219	SOT23-8	U3	01	02.20	02.20	[595-INA219BIDR](#)	INA219 - I2C Current/Power Monitor

THE POWER MODULE BOARD

I. Stack I/O:

- Hole diameter: 8mm
- Pad MIN Size: 20x20mm
- Connection
  - STACK-/STACK+ : to negative and positive current collector of the Stack
  - CHARGE-/CHARGE+ : to the negative/positive of the Programable Power source (PPS

- LOAD-/LOAD+ : to the negative/positive of the load
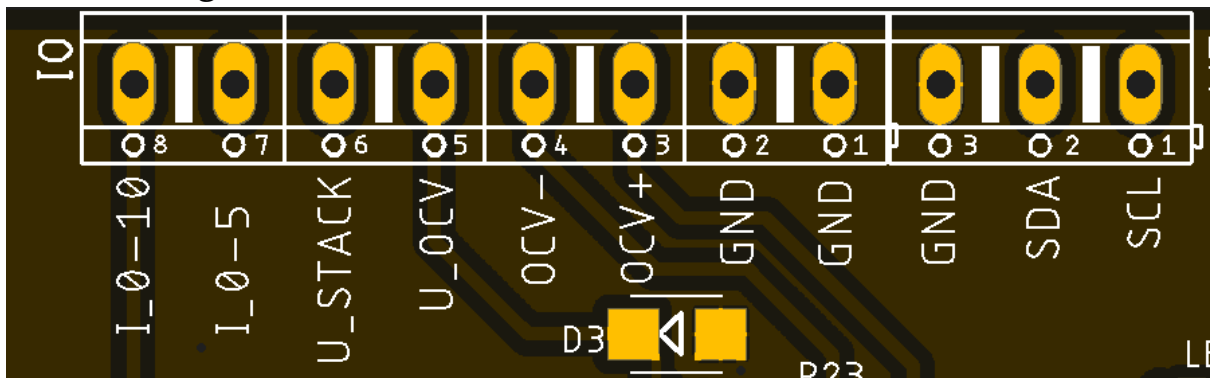
**Notice*: Do not connect PPS gate to load gate and vice versa*

II. **PPS gate:**
- **03 gates into DC connector**
  - 24V – 2A
  - 5V – 3A
  - 12V – 4A
- **01 gate into DC connector**
  - 12V – 2A (Disconnect SJ1)
- **SJ1:**
  - **Short**: Power from stack
  - **Open**: Power from external

III. **Mornitoring connector**

- I_0-10: Current monitoring out (0 -> 10V ~ -200 -> 200A)
- I_0-5: Current monitoring out (0 -> 5V ~ -200 -> 200A)

- U_STACK: Stack potential monitoring out, $U_{STACK} = \dfrac{V_{U\_STACK}}{\frac{R_{29}}{R_{28}+R_{29}}}$

- U_OCV: OCV monitoring out : $V_{U\_STACK} = U_{OCV} = V_{OCV+} - V_{OCV-}$
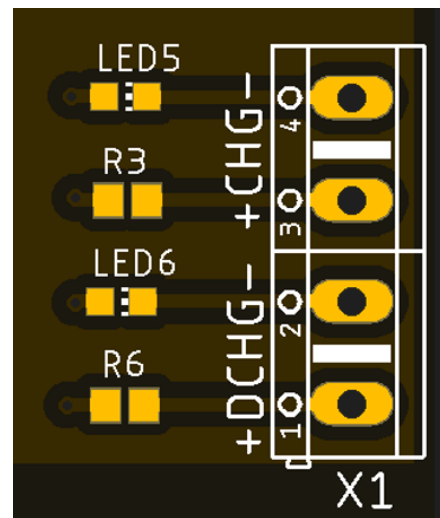- SDA, SCL: Bus I2C for INA219

Default value:
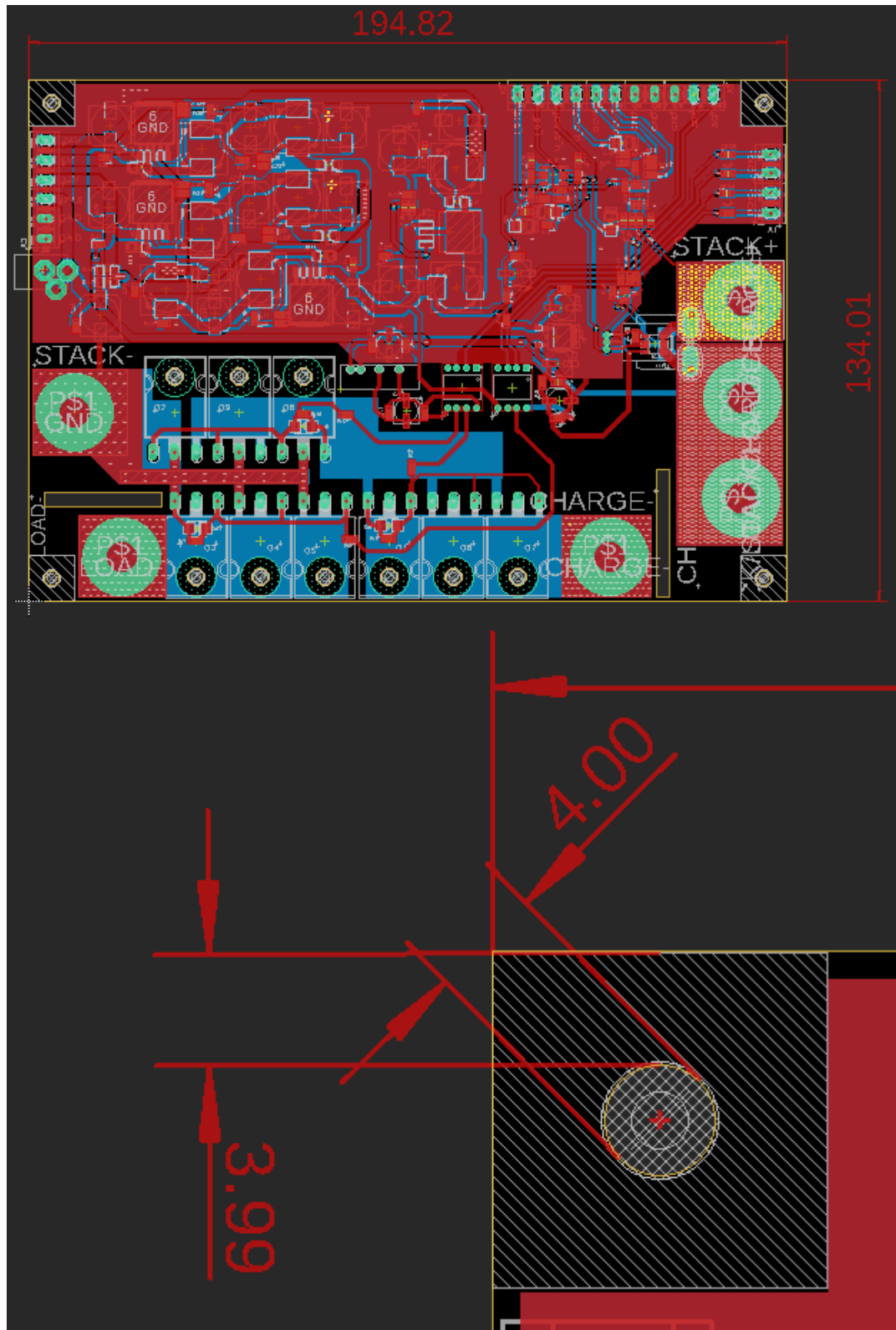- *R28 = 56K*
- *R29 = 24K*
- *Current range: -200 -> 200A*

IV. Charge/discharge controller I/O:
- OPTO in, 12V – 24V
- CHG: Charge control gate
- DCHG: Discharge control gate
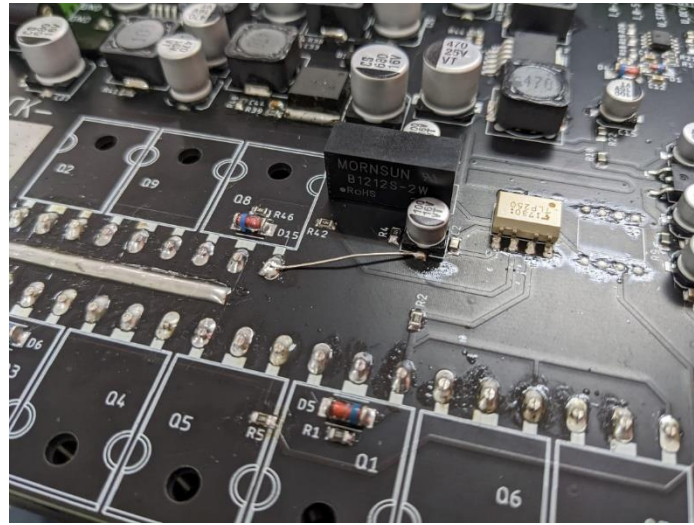- Allowing pulse input, max frequency 800kHz

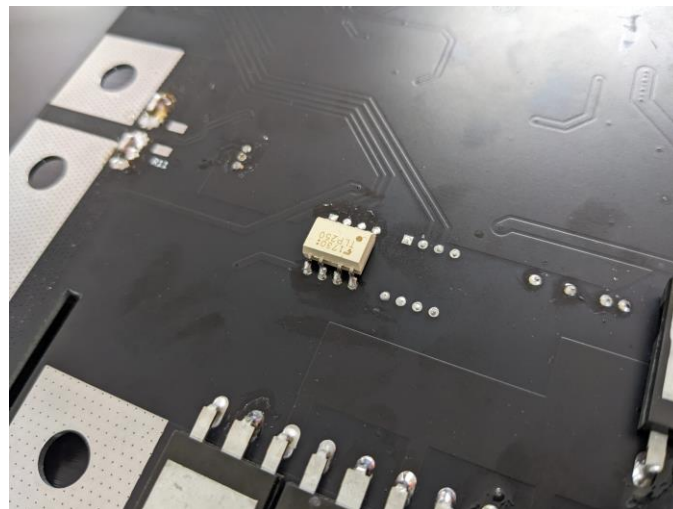*** Notice: V1 design flaw: opposite site of negative and positive of DCHG (+- DCHG)*
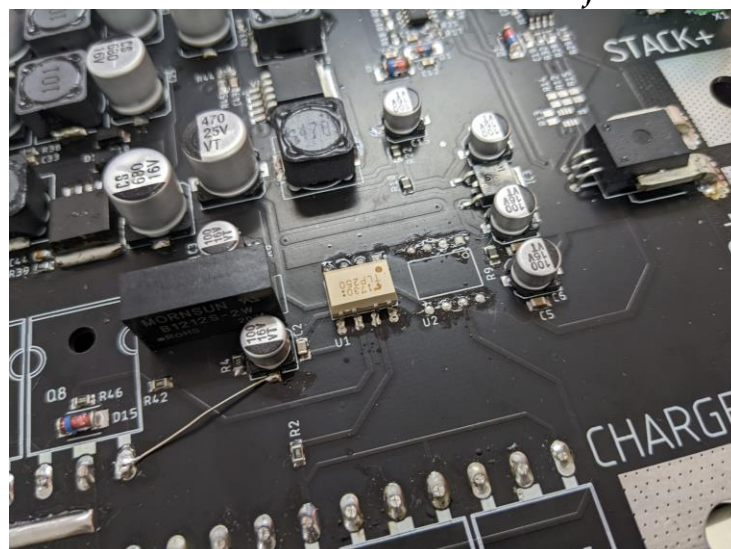
V. Dimension:

VI.   MANUFACTURE NOTE:

1. V1 fix driver flaw as below

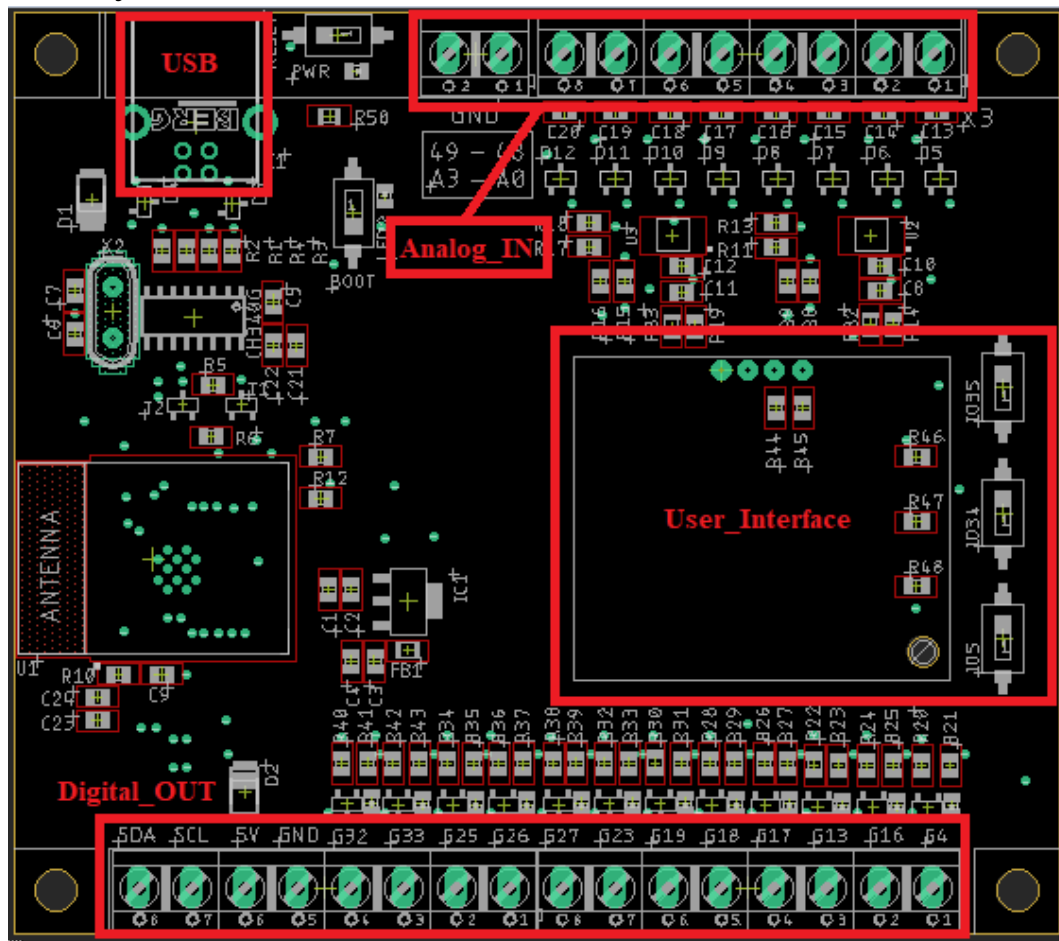**Connect S of Q8 to DRIVER- (negative capacitor C1)**

Weld inverse U2 onto otherside of PCB

ESP32-IO BOARD DOCUMENT
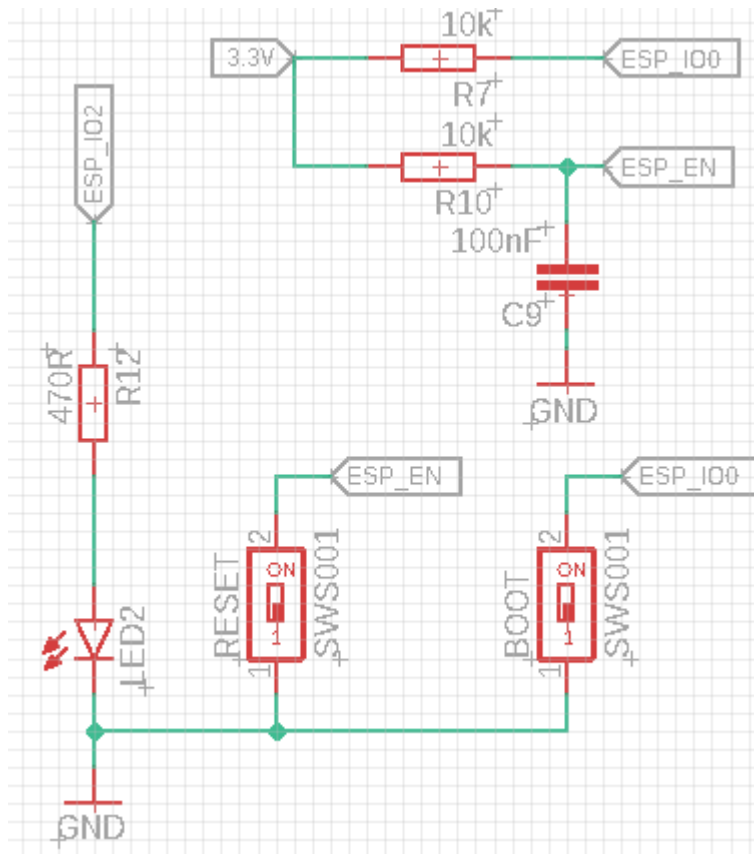
1. PCB layout:

2. Boot-mode config:

- ESP32-Bootmode table:
  - GPIO0 has an internal pullup resistor, so if it is left unconnected then it will pull high.
  - The ESP32 will enter the serial bootloader when GPIO0 is held low on reset. Otherwise it will run the program in flash.

GPIO0 Input	Mode
Low/GND	ROM serial bootloader for esptool
High/VCC	Normal execution mode

- Boot mode shematic:

- Both EN and GPIO0 pull-up by default, press button make Active_LOW

3. **Analog_INPUT:**
   - ESP32-IO Board has 08 analog input, 0-5V input, Rail-to-Rail TVS diode protected
   - ADC chip: ADS1115
   - Communitication: I2C, 0x49, 0x48
   - Pcb layout:

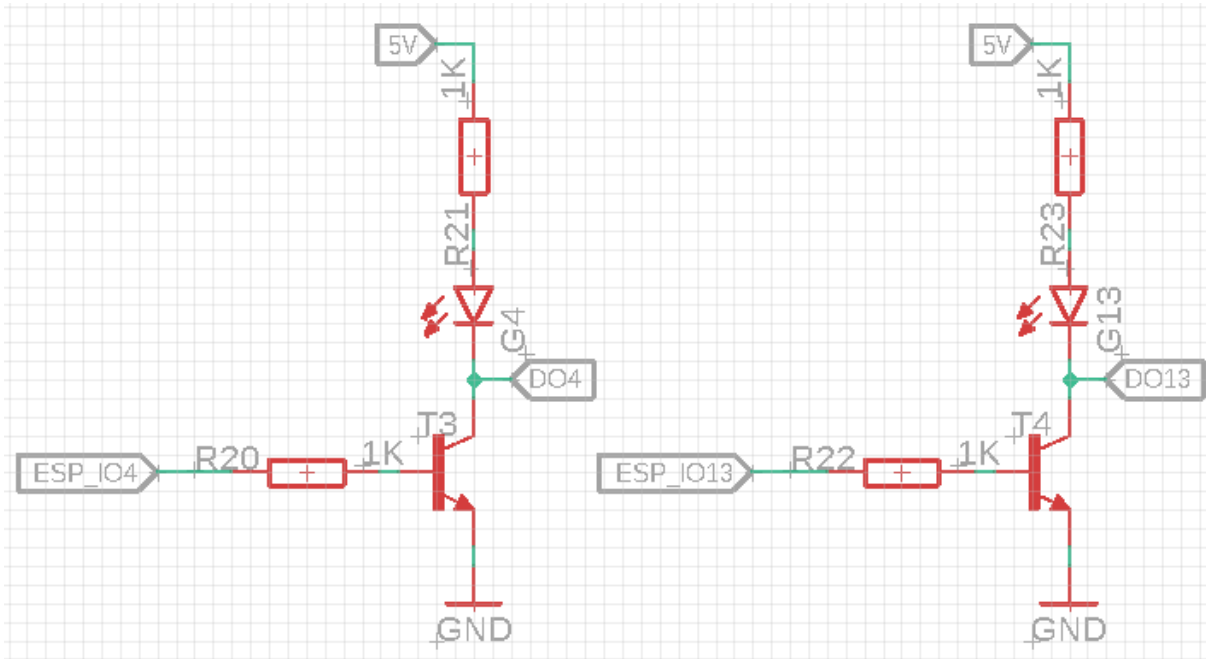*Blue: GND, Yellow: 0x49 IC, Red: 0x48 IC*

4. **Digital_OUTPUT, Power, Other:**
   - Pcb layout:

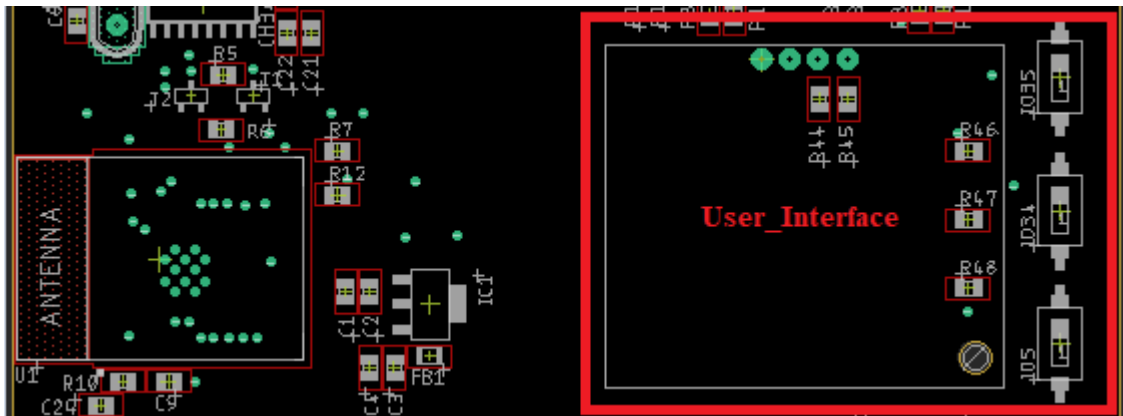*G=GPIO, I2C TTL: 3.3-5V, OUTPUT NPN, Active LOW*

- Output shematic:

- Output current must not exceed 100mA

- Power in put: 4.5 – 7.5V, min 1A

- **FACTORY NOTE:** *To convert Digital Output to Digital Input or Direct Digital Output(TTL 3.3V), bypass Base Current limit resistor (R20, R22…) and B-E pins of driver transistor (T1, T3…)*

5. **User interface:**

- UI use 1.3" Oled display and 03 buttons (Connected to GPIO35, 34, 05, Pull-Up, active Low)

Safety Protocols for Charge/Discharge Testing Module

To ensure the safe and reliable operation of the charge/discharge testing module, especially considering its high-voltage connections and the potential for chemical leaks, adherence to essential safety precautions and best practices is crucial.

1. High-Voltage Safety: Given the high-voltage nature of the module, ensure all connections are secure and insulated. Regularly inspect cables and connectors for wear or damage. Maintain a safe distance from live circuits and use insulated tools where necessary.

2. Chemical Handling: When dealing with chemicals, particularly those that are wet or prone to leakage, use appropriate personal protective equipment (PPE) such as gloves, goggles, and lab coats. Ensure chemicals are handled in well-ventilated areas and stored in leak-proof containers.

3. Emergency Response: Be prepared for emergencies by having a clear understanding of emergency shut-off procedures for the module. Keep a spill kit and fire extinguisher readily accessible, and ensure all personnel are trained in their use.

4. Routine Inspections: Conduct routine inspections to identify and rectify any potential hazards like loose connections, frayed wires, or chemical leaks. Such preemptive checks are vital for preventing accidents.

5. Training and Documentation: Ensure all users are properly trained in operating the module and are familiar with its safety protocols. Maintain detailed documentation of operational procedures, safety guidelines, and emergency response plans.