Ultra Low-Cost High-Voltage Isolated Differential Probe for Teaching and Training

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॥ सा विद्या या विमुक्तये ॥

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Thiruvananthapuram

Outline:

- Introduction
- Probe features
- Proposed High Voltage Probe with Isolation
- Stages of Designed Probe
- Noise Blocking for isolation probe
- Power supply
- Hardware Results
- Layout and final product

Introduction:

- Need for High-voltage Isolated Measurement:
  - Education, training, Research (beyond just power engineering)
- Challenge:
  - Costly, Specialized Equipment for voltages >400V
  - Lack of galvanic isolation in oscilloscopes.

- **Existing solutions:**
  - Expensive differential probes, lacking galvanic isolated channels in oscilloscopes.

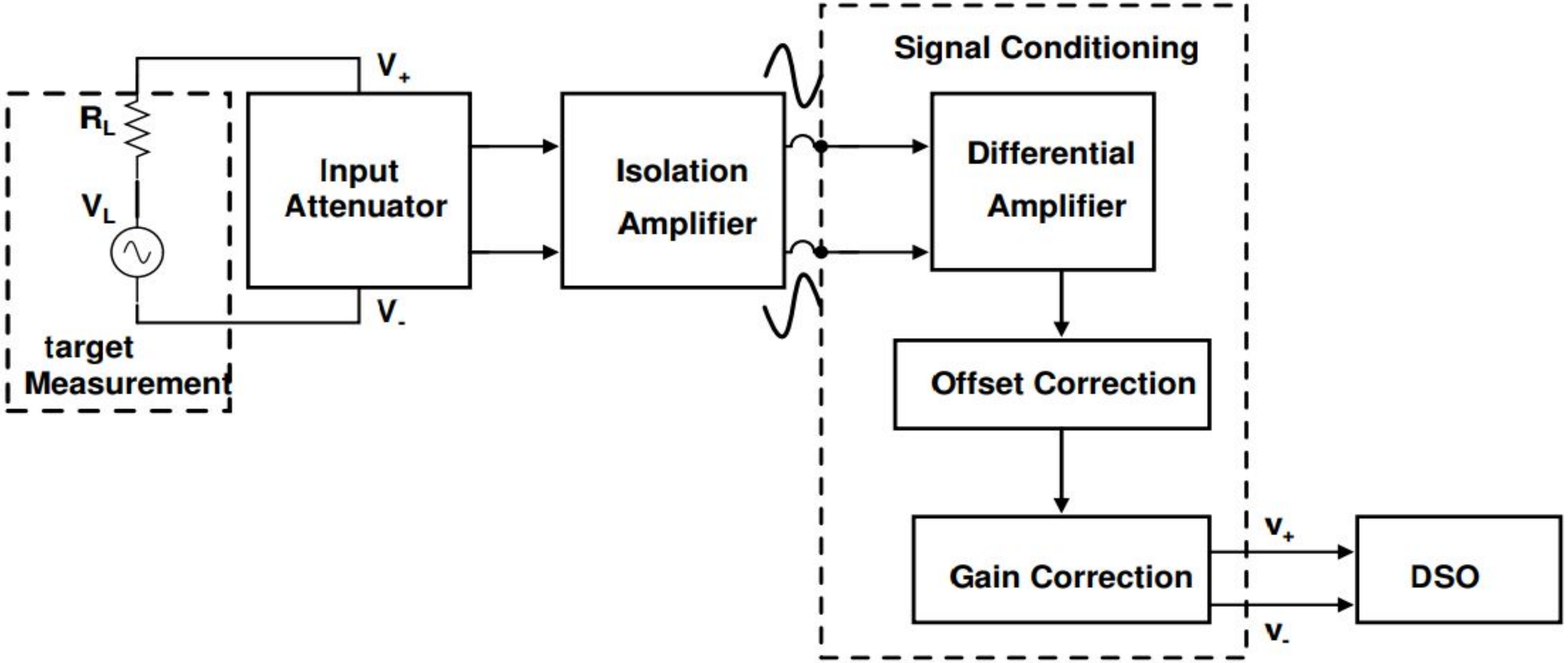
- **Target Spec: Affordable, portable, isolated high-voltage differential probe (up to 600V, 350 KHz bandwidth) designed for labs in Power Electronics, Electric Machines and Drives, Renewable Energy, etc.**

Desirable Features:

- **Removable lithium-ion battery, direct oscilloscope interface, gain/offset correction for periodic calibration**

- Target User: Cost-sensitive applications in universities, makerspaces, startups, and industries requiring effective yet affordable high-voltage measurement solutions.

Proposed High Voltage Probe with Isolation:

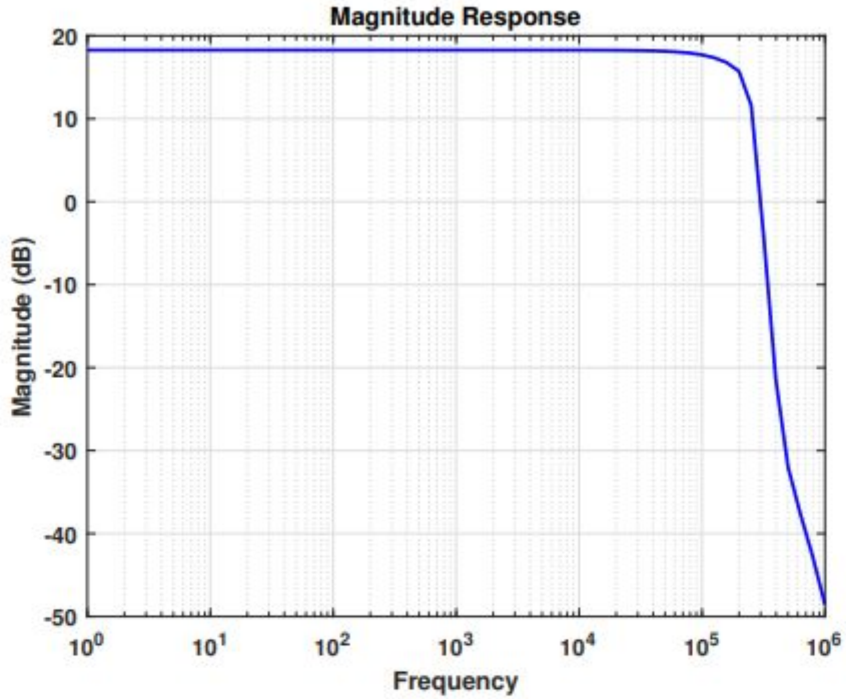


Attenuator:

- Isolation Amplifier Limitation: Input range constrained between +300mV and -300mV, necessitating attenuation of high input voltages.
- Attenuator Circuit: Comprises eight 250kΩ resistors in series and one 1kΩ resistor to reduce the high input voltage to the isolation amplifier's acceptable range.
- **Input range of HV Probe =** $\mathbf{2000 \times (-300\mathit{mV}, +300\mathit{mV})}$**,**
- **where (-300mV, +300mV) represents the isolation amplifier input voltage range.**
- Resulting Measurement Range: The proposed HV probe can measure input voltage signals ranging from -600V to +600V.

Isolation Amplifier:

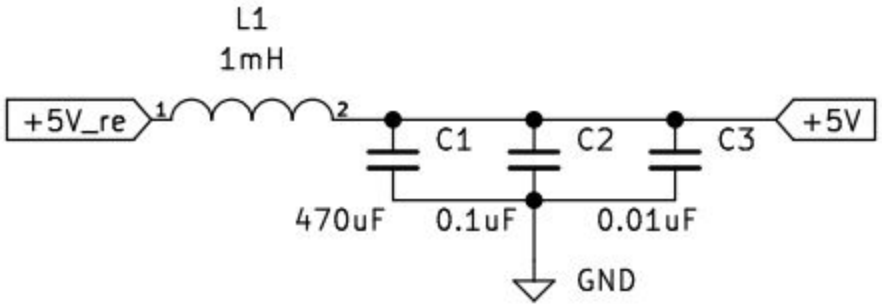
- **Isolation Amplifier:** Utilizes the Texas Instruments AMC1301, requiring a +5V power supply generated through the LM7805 regulator.
- **Amplifier Gain:** LTspice simulation indicates an amplifier gain of 18.6 dB, translating to a voltage gain of 8 up to 100 KHz.
- LC Low-Pass Filter Employed in the power supply to eliminate unwanted noise signals before reaching the isolation amplifier.



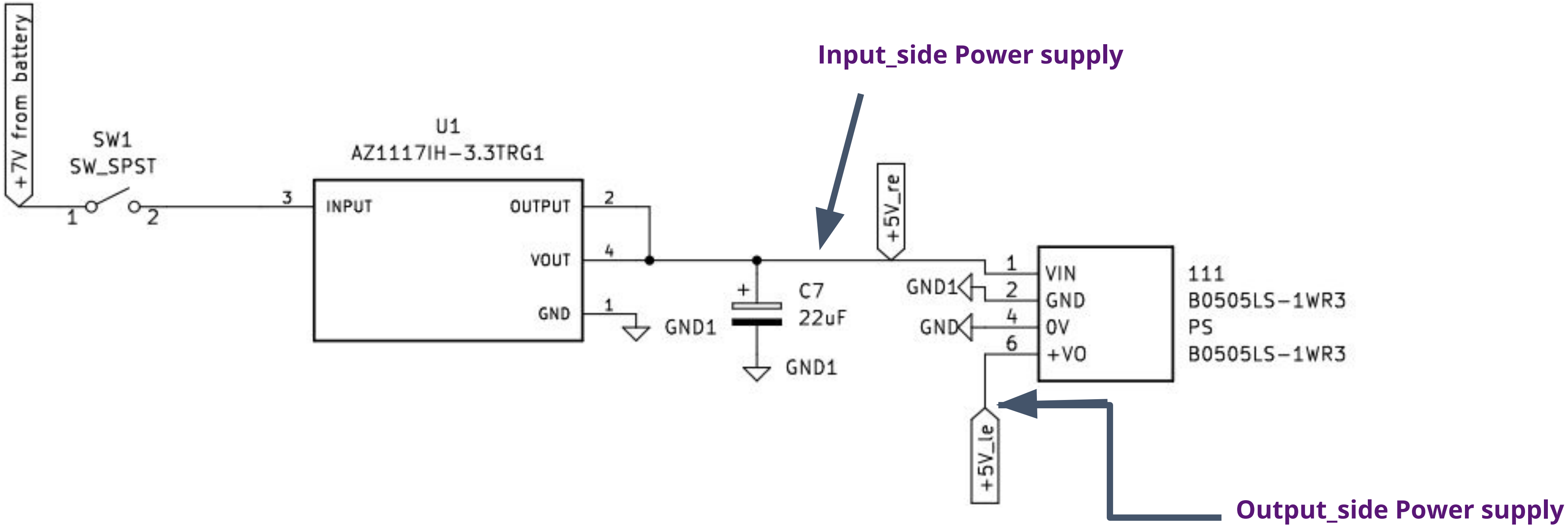
Power Supply Decoupling For Isolation Amplifier:

- Filter Configuration: Designed for DC signal passage by setting a low cutoff frequency.
- Cutoff Frequency Calculation: Cutoff frequency derived from combined capacitance (C = 470.1μF) and inductor value (L = 1mH) using the formula:

This LC low-pass filter setup aims to allow only DC signals by ensuring a very low cutoff frequency.



POWER SUPPLY:

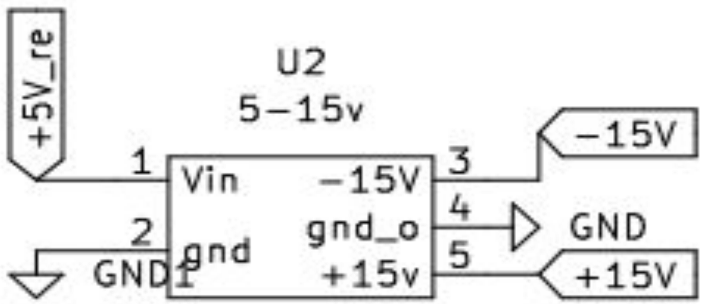


- Batteries 7V input is regulated by an LDO to yield 5V for the isolation amplifier's input, while the LDO output feeds a 5V-to-5V DC-DC converter, providing isolated 5V for the amplifier's output

Differential Amplifier:

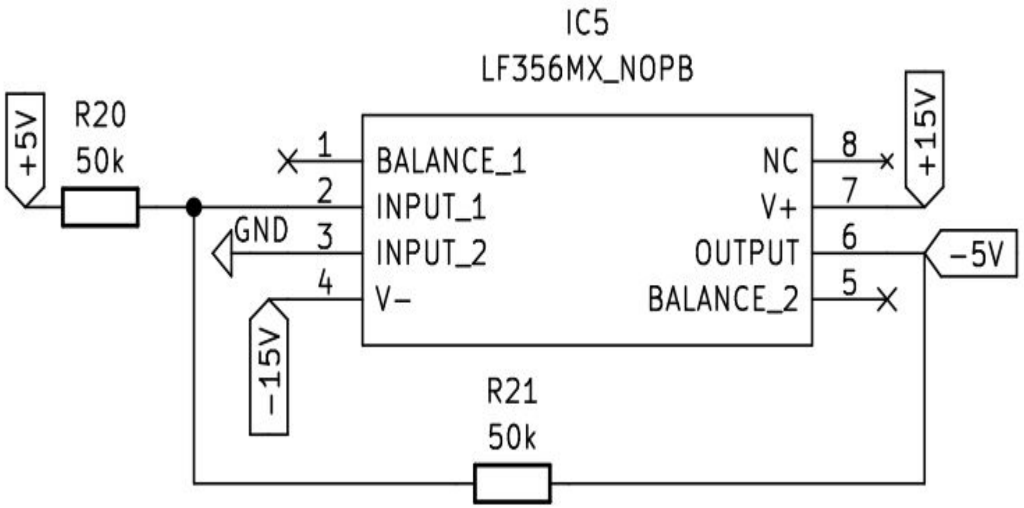
- Converts the differential input into a ground-referenced signal, enabling analysis via an oscilloscope.
- LF356 Op-Amp Implementation: Utilizes the LF356 integrated circuit operational amplifier (op-amp) within the differential circuit for this transformation.

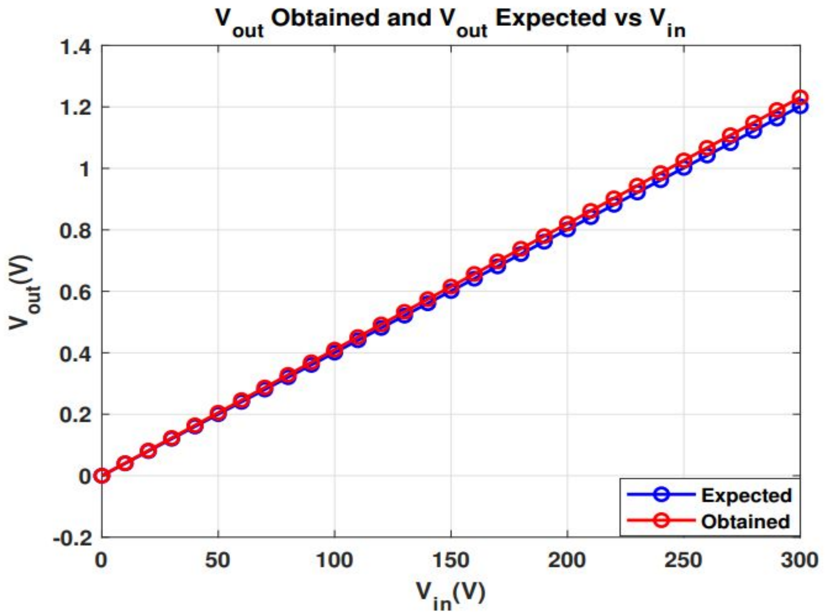
Power Supply:



Offset Error:

- DC Offset Issue: Expected output shows a DC offset at higher input voltage levels , requiring correction.
- Correction Method was Employed by a summing amplifier for fine-tuning the DC level, utilizing a trimmer for adjustment.
- +5V and -5V DC Generation Illustrated below, which is crucial for achieving the required DC level adjustment in the signal conditioning circuit.

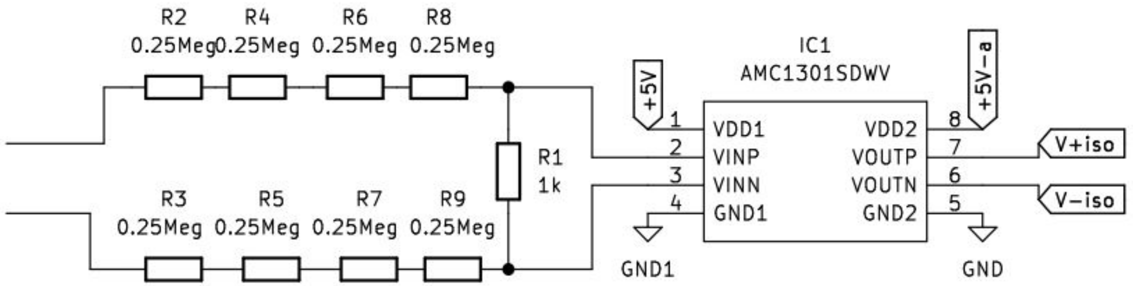




Offset Error:

- Observes decreased isolation amplifier gain above 100 kHz, impacting high-frequency applications.
- **Need for Gain Correction:** Above 100 kHz, requires a gain correction circuit for proper signal amplification.
- Incorporated Solution was Integration of an inverting amplifier within the signal conditioning circuit. Features a trimmer for manual gain adjustment, crucial for compensating attenuations and ensuring accurate signal amplification at higher frequencies.

Circuit Diagram :



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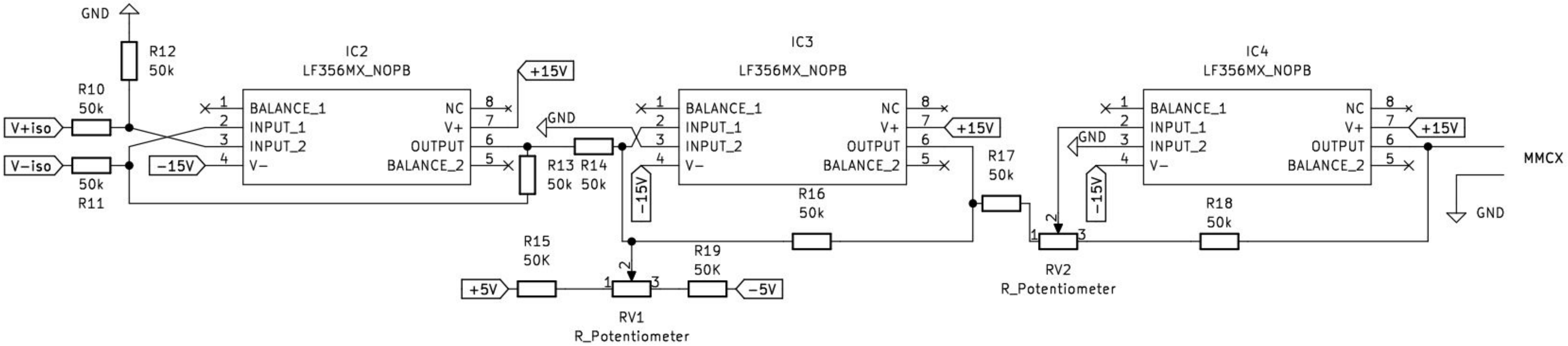
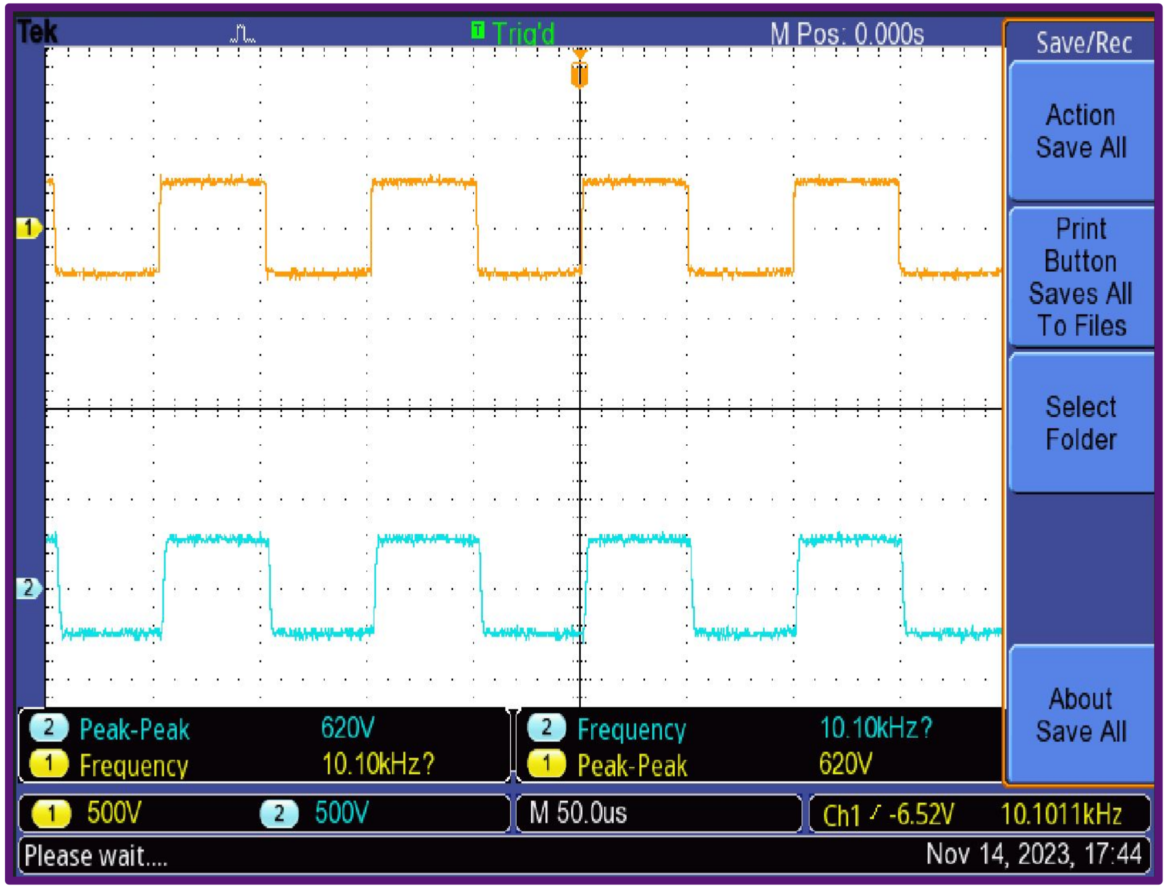
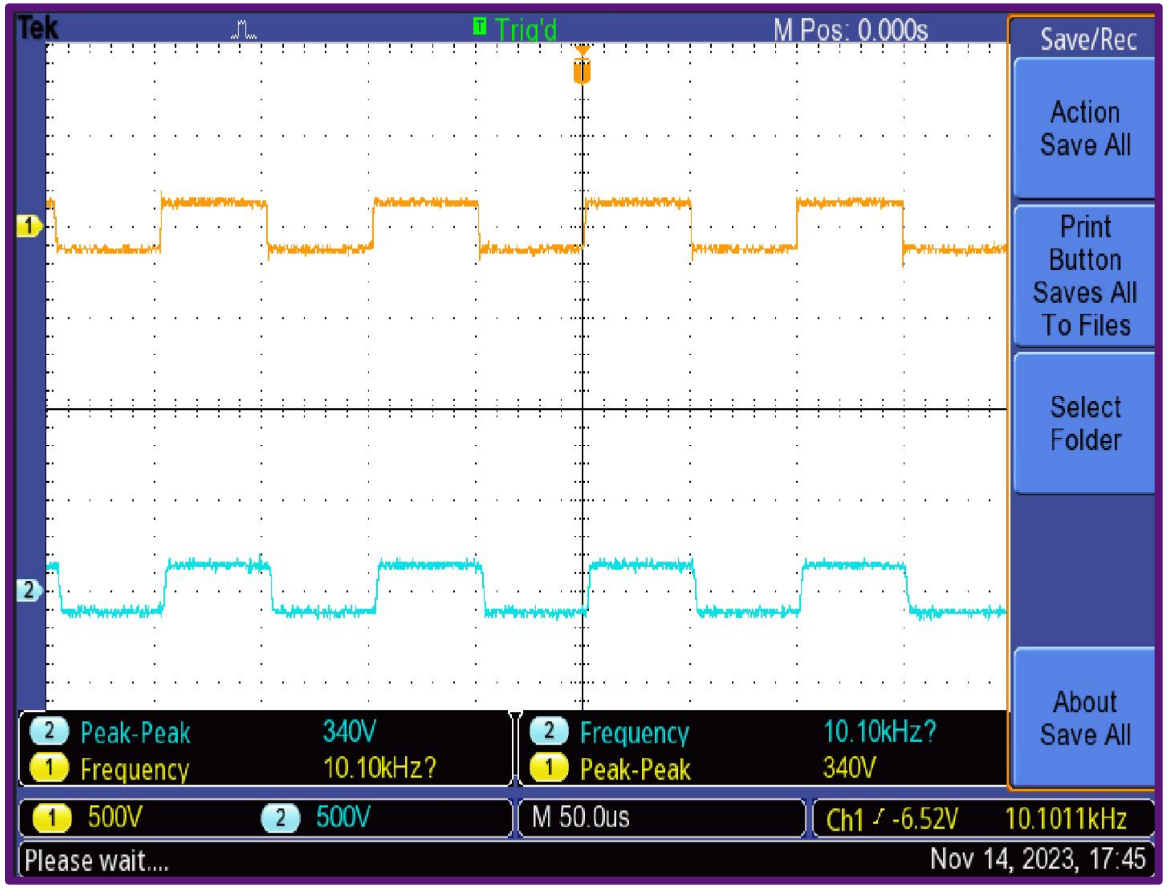


Hardware Results:





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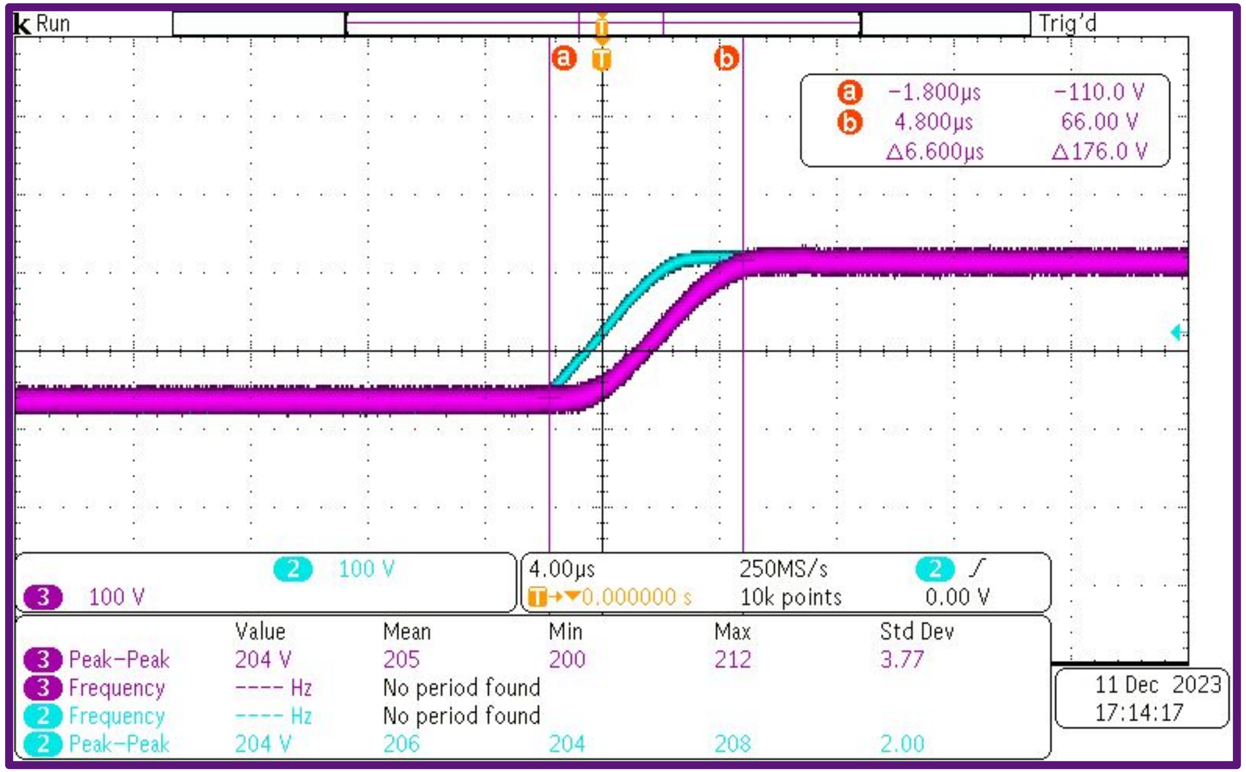

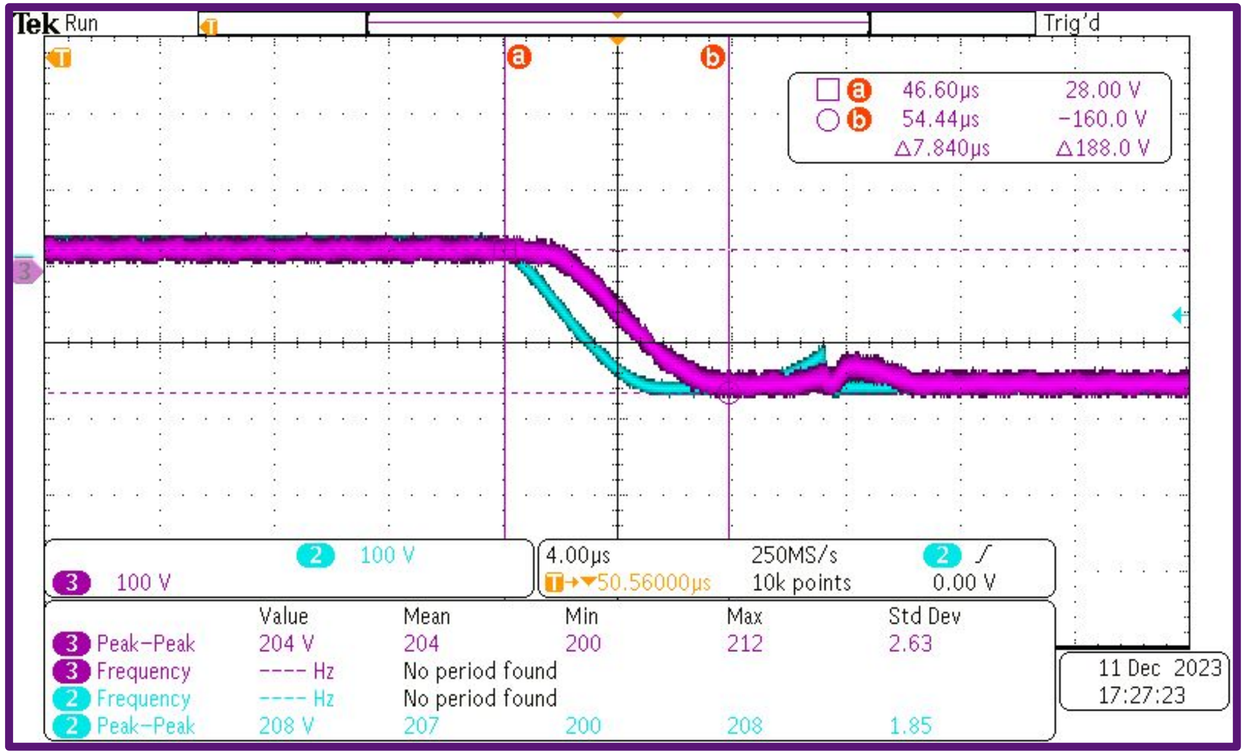

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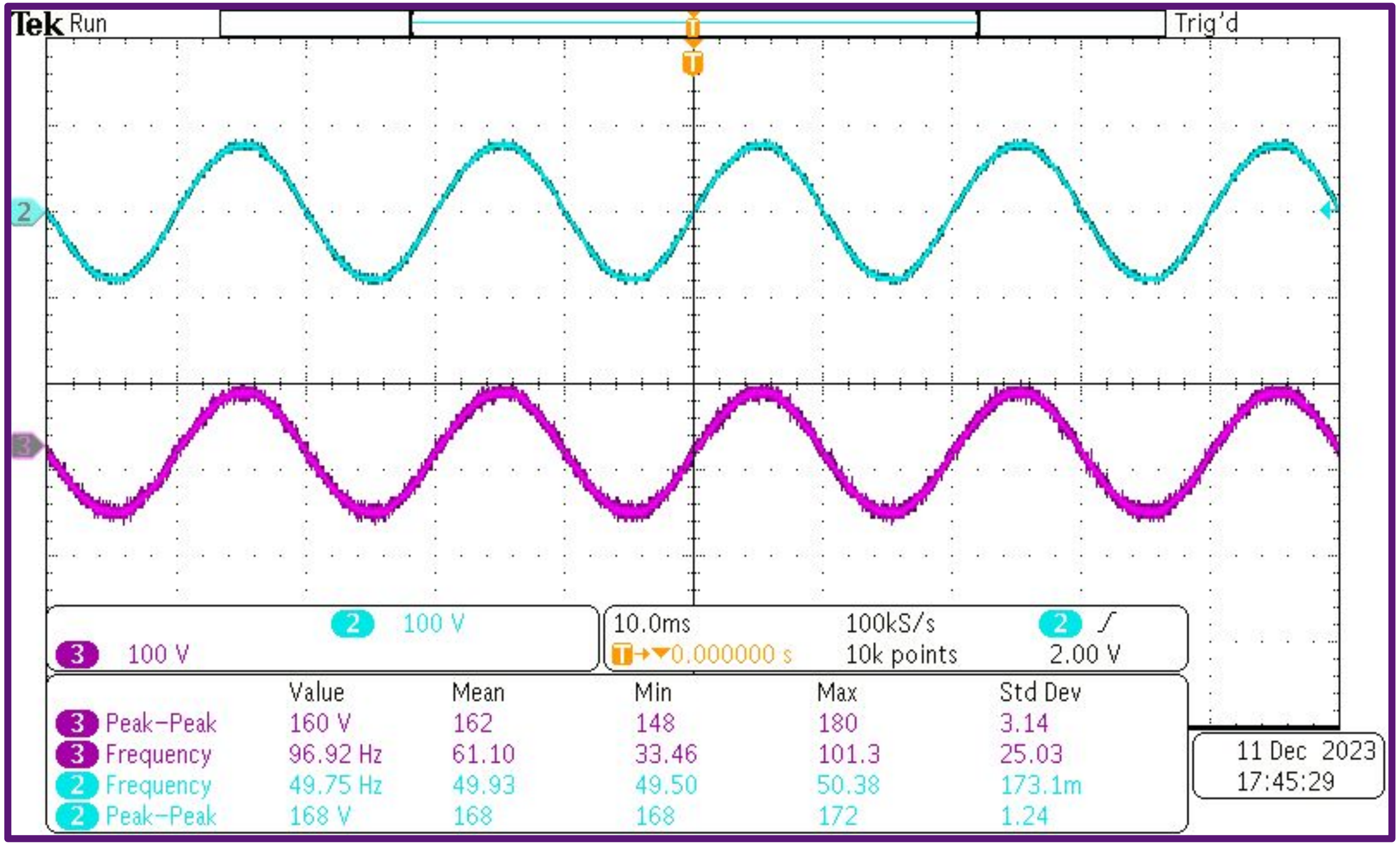
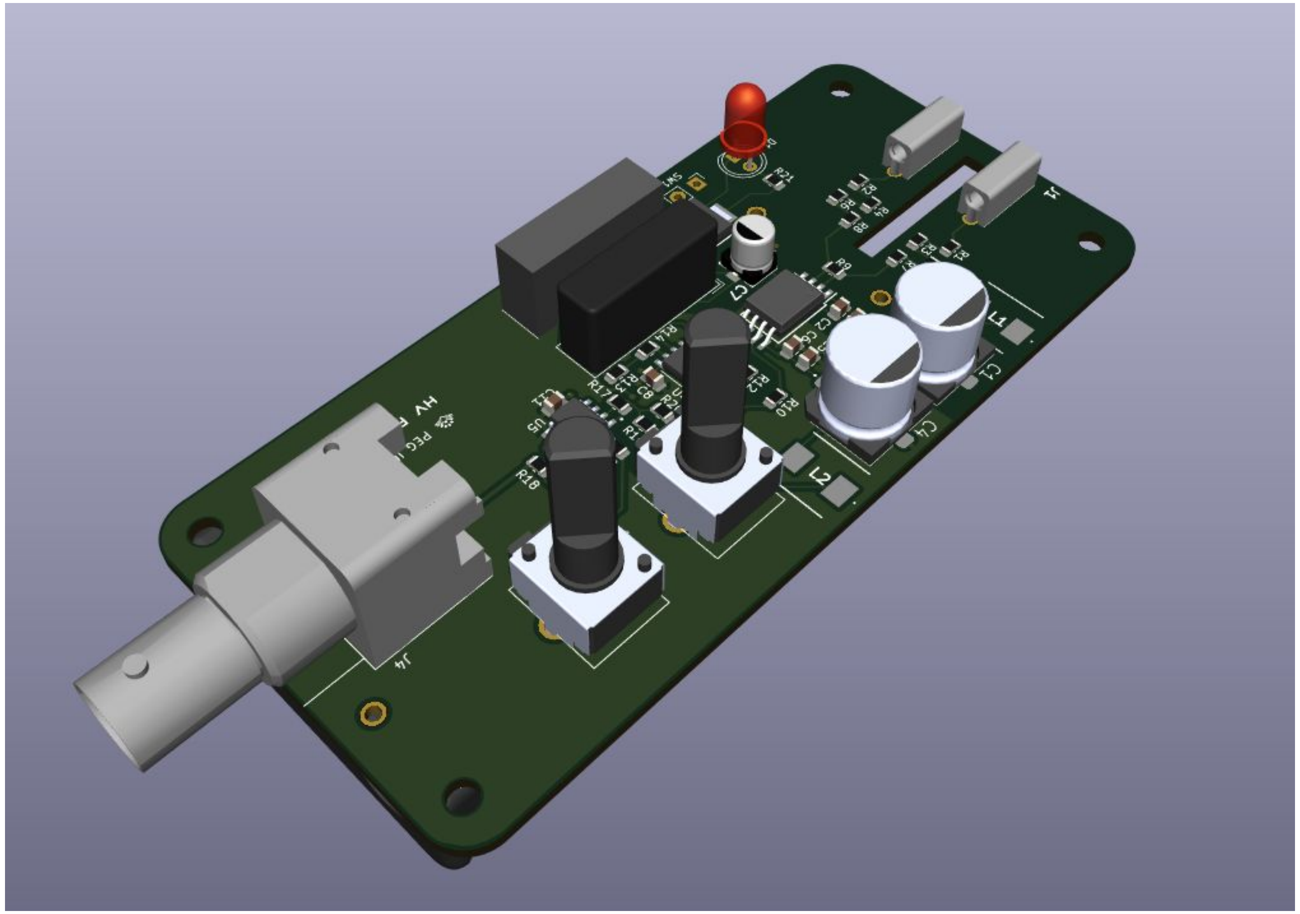
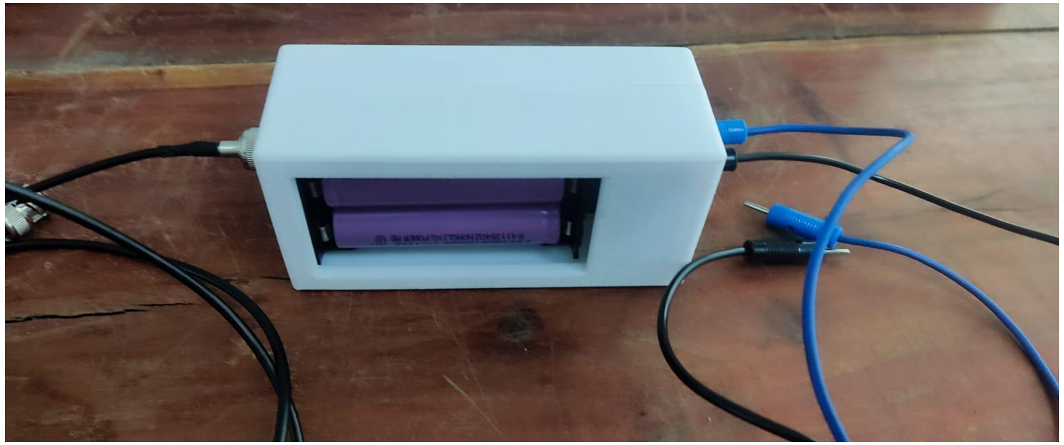


Symbol : Footprint Assignments

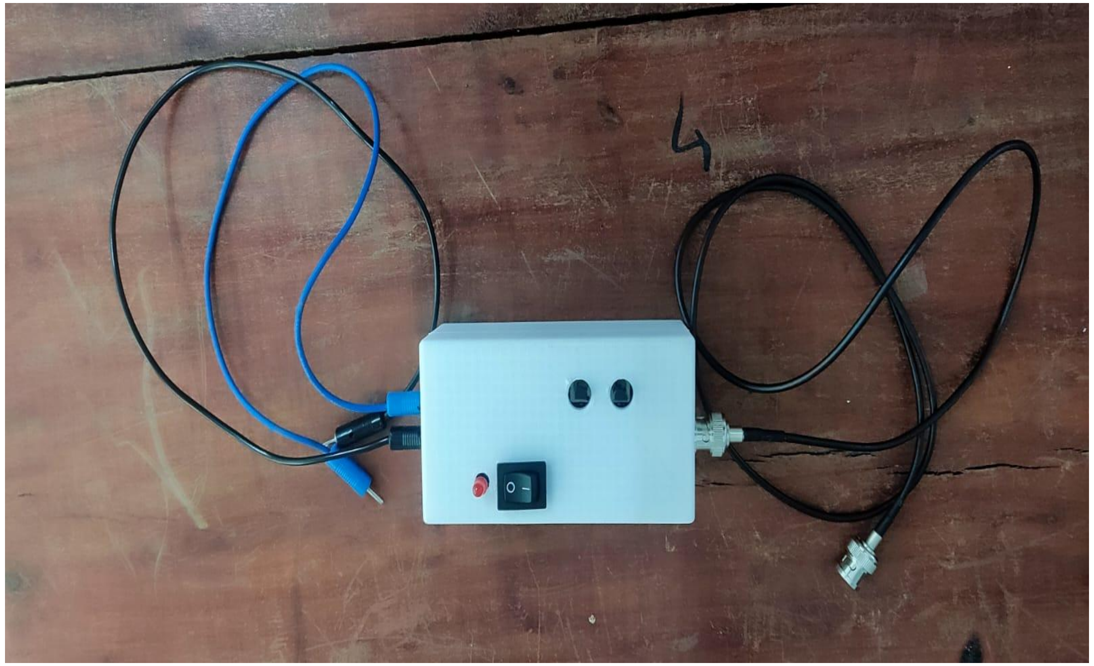
1	111	-	B0505LS-1WR3	:	5v-5v:B0505LS1WR3
2	C1	-	470uF	:	470uf:CAPAE1030X1050N
3	C2	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
4	C3	-	0.01uF	:	Capacitor_SMD:C_0805_2012Metric
5	C4	-	470uF	:	470uf:CAPAE1030X1050N
6	C5	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
7	C6	-	0.01uF	:	Capacitor_SMD:C_0805_2012Metric
8	C7	-	22uF	:	22uf:EEE0GA101SR
9	C8	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
10	C9	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
11	C10	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
12	C11	-	0.1uF	:	Capacitor_SMD:C_0805_2012Metric
13	D1	-	LED	:	LED_THT:LED_D5.0mm
14	H1	-	MountingHole	:	MountingHole:MountingHole_3.2mm_M3
15	H2	-	MountingHole	:	MountingHole:MountingHole_3.2mm_M3
16	H3	-	MountingHole	:	MountingHole:MountingHole_3.2mm_M3
17	H4	-	MountingHole	:	MountingHole:MountingHole_3.2mm_M3
18	IC1	-	AMC1301SDWV	:	AMC1301:SOIC127P1150X280-8N
19	J1	-	Conn_01x01_Male	:	banana jack:1050752001
20	J2	-	Conn_01x01_Male	:	banana jack:1050752001
21	J3	-	Conn_01x02_Male	:	2S-18650-Holder:BAT_BK-18650-PC4
22	J4	-	Conn_Coaxial	:	coaxial:TE_227161-1
23	L1	-	1mH	:	inductor:DR74
24	L2	-	1mH	:	inductor:DR74
25	R1	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
26	R2	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
27	R3	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
28	R4	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
29	R5	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
30	R6	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
31	R7	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
32	R8	-	0.25Meg	:	Resistor_SMD:R_0805_2012Metric
33	R9	-	1k	:	Resistor_SMD:R_0805_2012Metric
34	R10	-	50k	:	Resistor_SMD:R_0805_2012Metric
35	R11	-	50k	:	Resistor_SMD:R_0805_2012Metric
36	R12	-	50k	:	Resistor_SMD:R_0805_2012Metric
37	R13	-	50k	:	Resistor_SMD:R_0805_2012Metric
38	R14	-	50k	:	Resistor_SMD:R_0805_2012Metric
39	R15	-	50k	:	Resistor_SMD:R_0805_2012Metric
40	R16	-	50k	:	Resistor_SMD:R_0805_2012Metric
41	R17	-	50k	:	Resistor_SMD:R_0805_2012Metric
42	R18	-	50k	:	Resistor_SMD:R_0805_2012Metric
43	R19	-	50k	:	Resistor_SMD:R_0805_2012Metric
44	R20	-	50k	:	Resistor_SMD:R_0805_2012Metric
45	R21	-	4.7k	:	Resistor_SMD:R_0805_2012Metric
46	SW1	-	SW_SPST	:	Connector_PinHeader_2.54mm:PinHeader_1x02_P2.54mm_Vertical
47	U1	-	AZ1117IH-3.3TRG1	:	LDO:SOT230P700X185-4N
48	U2	-	5-15v	:	Converter_DCDC:Converter_DCDC_Murata_NMAxxxxSC_THT
49	U4	-	LF353M	:	LF353:SOIC127P599X175-8N
50	U5	-	LF353M	:	LF353:SOIC127P599X175-8N
51	VR1	-	PTV09A-4225F-B104	:	trim:PTV09
52	VR2	-	PTV09A-4225F-B104	:	trim:PTV09

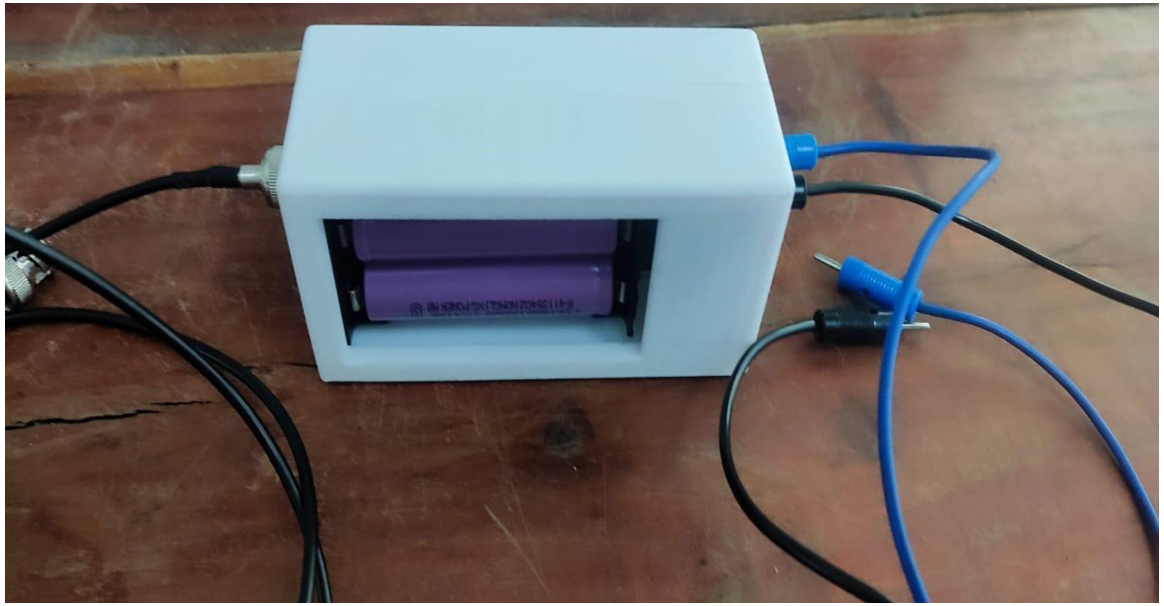
Optimized layout with all-SMD components, clearance distances and compact design:





FINAL PRODUCT:





THANK YOU

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