

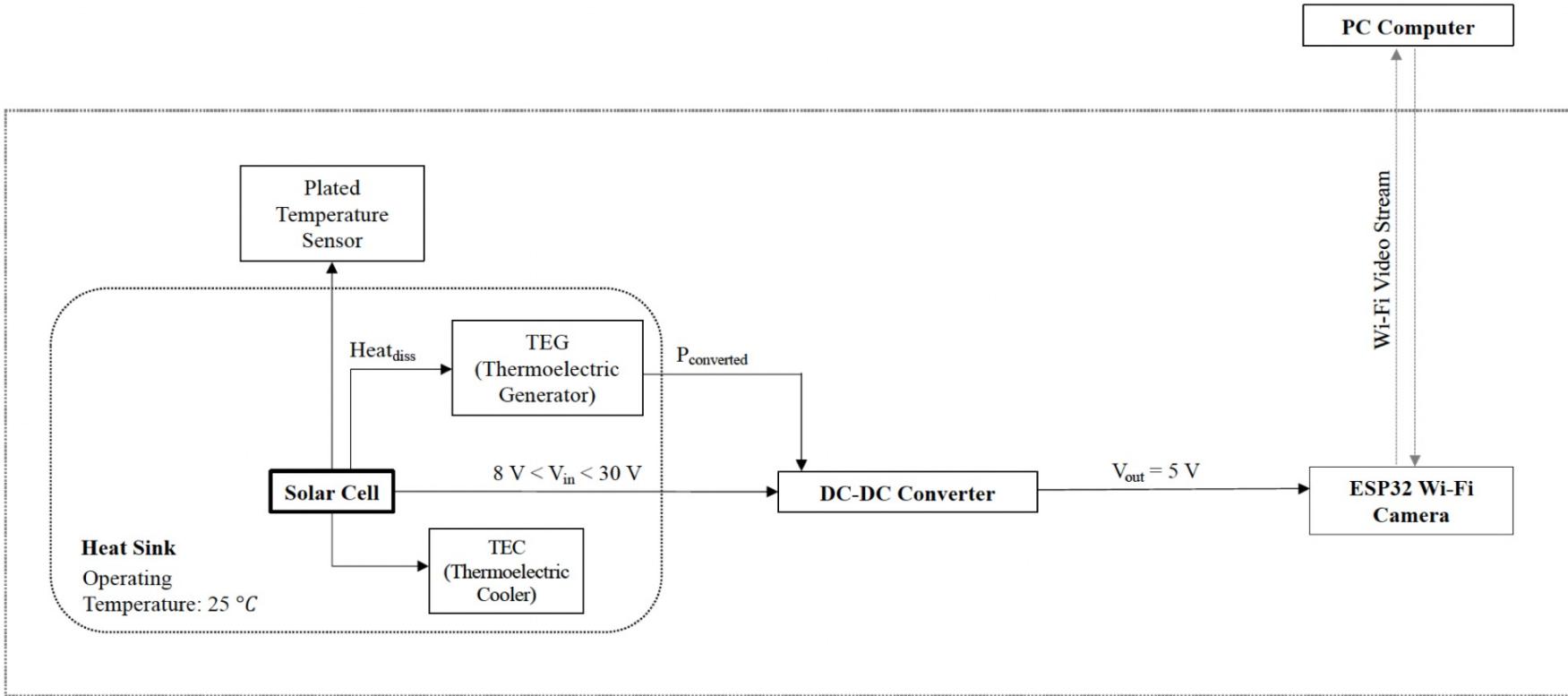
Laser-Based Wireless Power Transmission Receiver's Energy Harvester: Photovoltaic Power Converter Board

Haruka Kido

University of North Dakota

EE481. Senior Design II

Receiver Conceptual Block Diagram



Receiver Conceptual Block Diagram

Solar Cell: Si-based vertical multi-junction PV cell

Design Objective: Rapid Prototyping for Testing

- To replace the isolated LM2596 DC-DC Converter board with a compact Power Converter solution combined with a thermal regulation and energy harvesting system
- To provide a spatial layout for the PV cells with consideration to the TEC's placement beneath the board
- To implement either the Buck “step-down” or Boost “step-up” voltage converter mechanism from the quad-PV array to the camera load (*Note:* The selection between Buck or Boost DC-DC Converter depends on wattage output from the 4 PV cells)
- To implement a voltage-controlled power electronic system with ON-OFF switching and low-pass filter or to provide an extension board to do so
- To make a top-layer backplane system so the PV cells can be easily soldered to the PCB solder pads without electrode wiring or external cabling and so the load camera can also be soldered to the load output connector
- To minimize conduction losses and use power distribution techniques in a condensed form
- To verify the highest efficiency power converter board as part of the testing and performance evaluation
- To provide boards with test pads for fault detection during testing

Design Tools

- TI WEBENCH Power Designer
- Autodesk EAGLE
- Digi-Key's PCB Trace Width Calculator
- PCB fabrication machines
- Soldering equipment

39.37008 mils = 1 mm
1 mil = 0.0254 mm (millimeter)

PV Cell Form Factors

- *1 cm x 1 cm (10 mm x 10 mm) MIH® VMJ PV Cell Form Factor (Part #: 5S1010.4)*
- *2.5 cm x 2.5 cm (25 mm x 25 mm) PV Cell Form Factor*
- *5 cm x 5 cm (50 mm x 50 mm) PV Cell Form Factor*

Total number of form factors: 3

PV Cell Electrical Arrangement Types

- *Isolated: Configurable Externally for Adaptive Methods*
- *Series*
- *Parallel*

Total number of arrangements: 3

Total number of possible board prototypes: 9

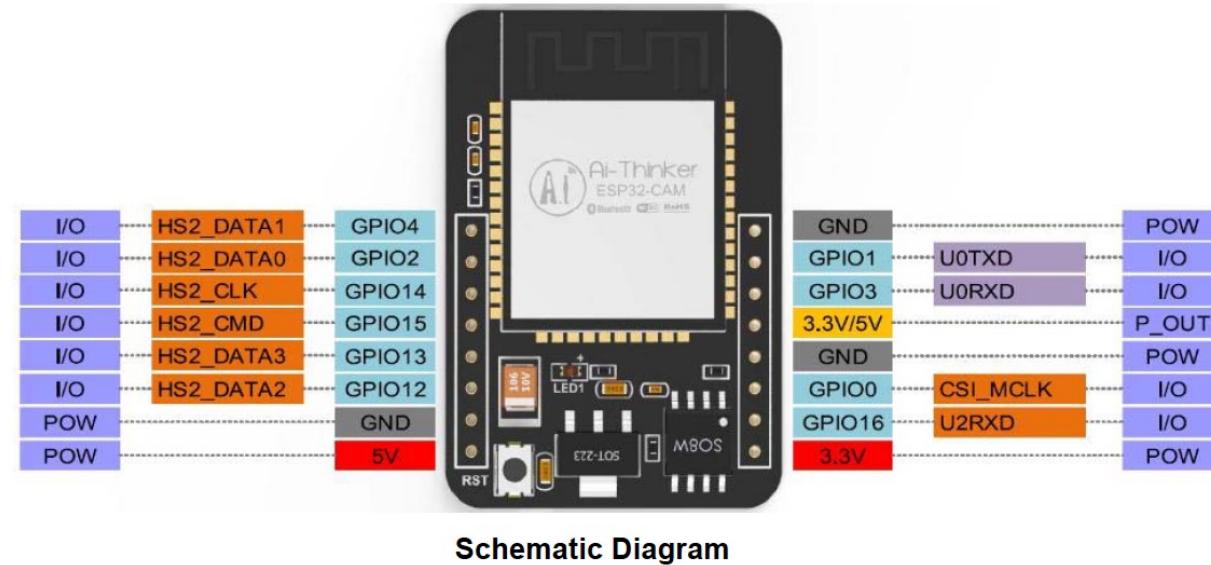
Total number of design files for board prototypes: 7 (due to adjustable dimensions and tolerances from same circuitry)

ESP-32 Wi-Fi Load Input Requirements

Power consumption is

$$(180 \text{ mA} \times 5\text{V}) = 900\text{mW} = 0.9 \text{ W}$$

(Flash OFF)



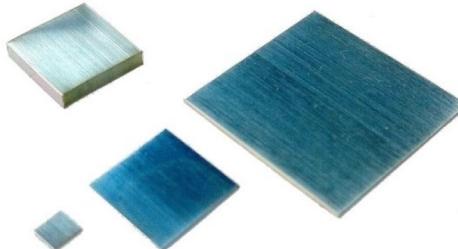
1. Design Specifications

1 cm x 1 cm MIH® VMJ PV Cell Form Factor,

4-PV, Series; Extension Board: Configurable for Externally Adaptive Load Circuitry

Peripherals:

- **Inputs:**
 - PV Array: 2 leads (+ and -) x 4 PV cells = 8 leads
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- **Outputs:**
 - ESP-32 Wi-Fi camera



Internals:

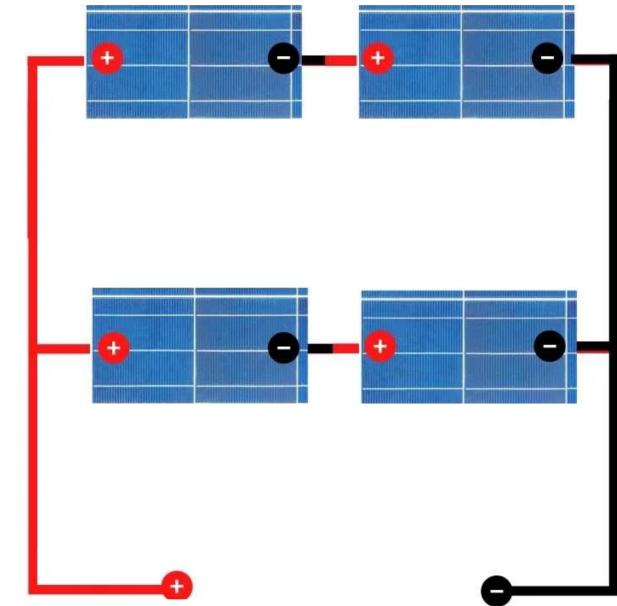
- Pads for soldered PV cells
- I/O Ports as Female Connectors

Voltage Requirements:

- **Input:**
 - Each PV cell has a 0.02029 A maximum current output
 - Each PV cell has a 29.21 V maximum voltage output
 - Each PV cell has a 0.59267 W maximum power output
 - Total max $V_{out} = 29.21 \text{ V} \times 4 \text{ PV cells}$; Voltage output = 116.84 V for a series connection
 - Total max current = 0.02029 A for a series connection
- **Output:** 5 V at 180 mA *or .18 A = 0.9 W

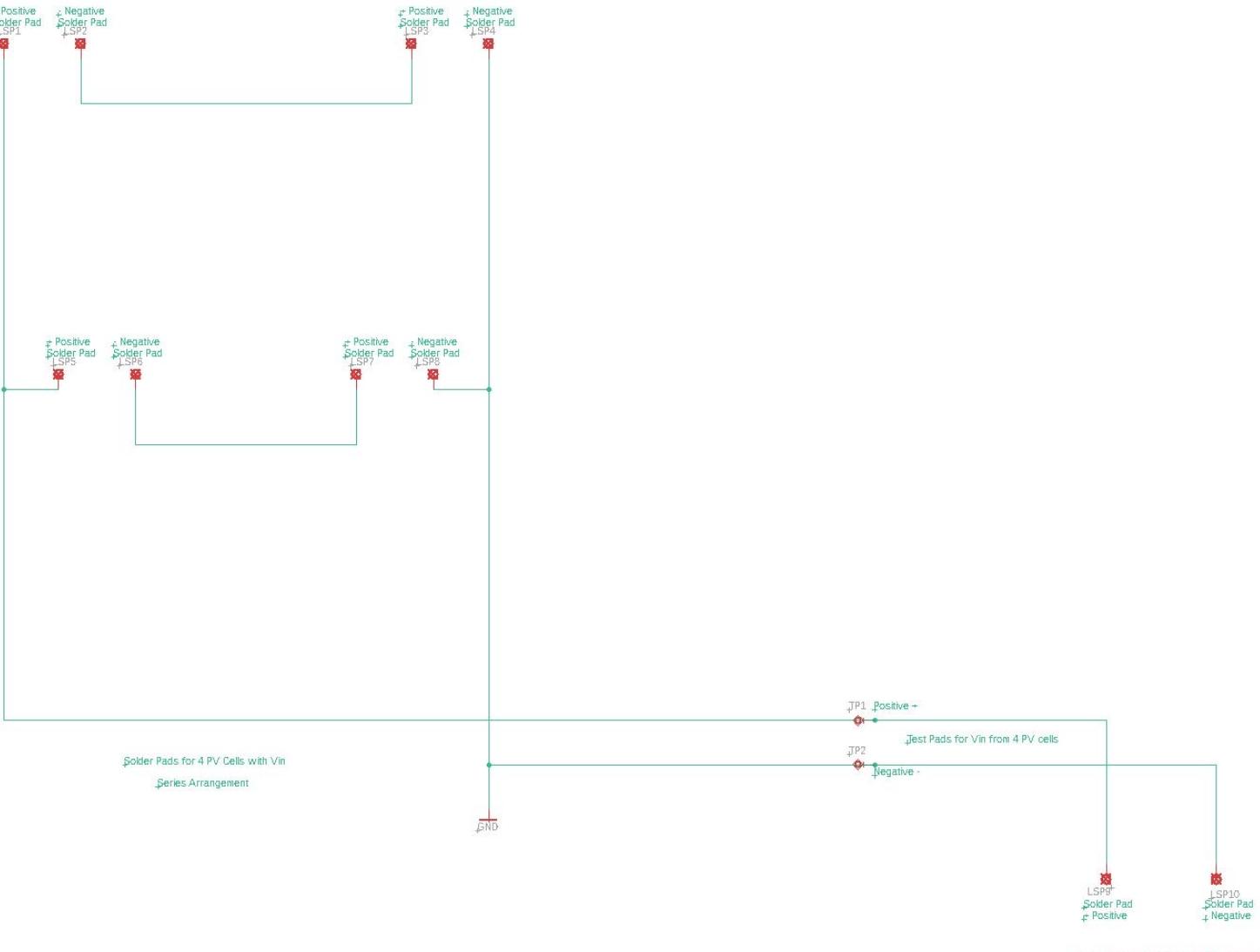
Miscellaneous:

- Heat Sink

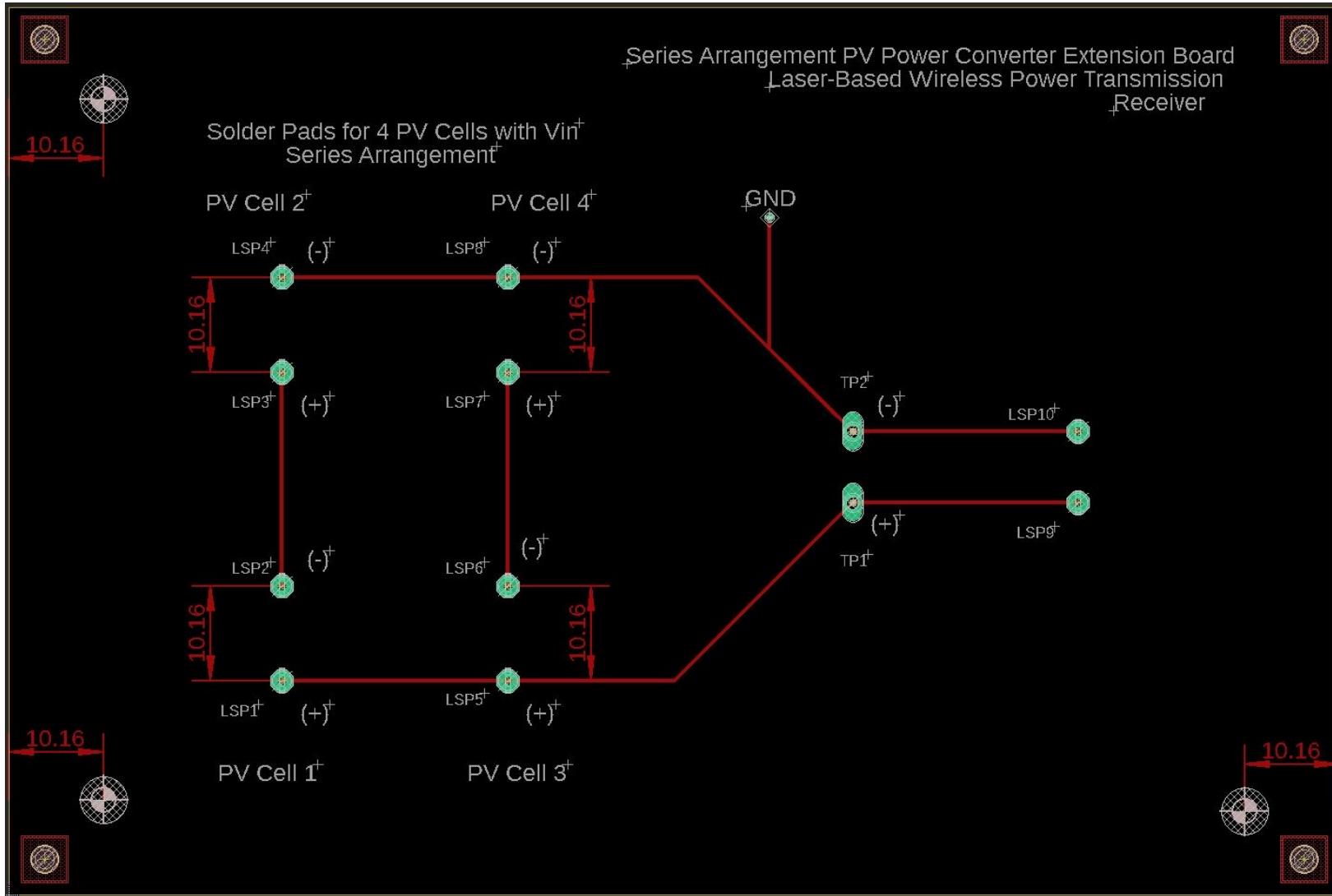


*Required Separately: **Buck DC-DC Converter circuit: 116.84 V to 5 V**

1.



1.

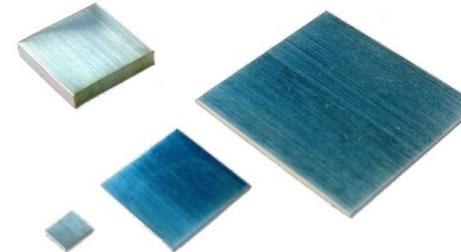


2. Design Specifications

1 cm x 1 cm MIH® VMJ PV Cell Form Factor, 1-PV; Full Backplane Board

Peripherals:

- **Inputs:**
 - PV Array: 2 leads (+ and -)
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- **Outputs:**
 - ESP-32 Wi-Fi camera



Internals:

- Pads for soldered PV cells
- PWM Control DSP, MCU, or FPGA for Switch Control
- **Buck DC-DC Converter** circuit with Low-Pass Filter: **29.21 V to 5 V**
 - R, L, C, MOSFET Switch (Voltage-Controlled)
- I/O Ports as Female Connectors

Voltage Requirements:

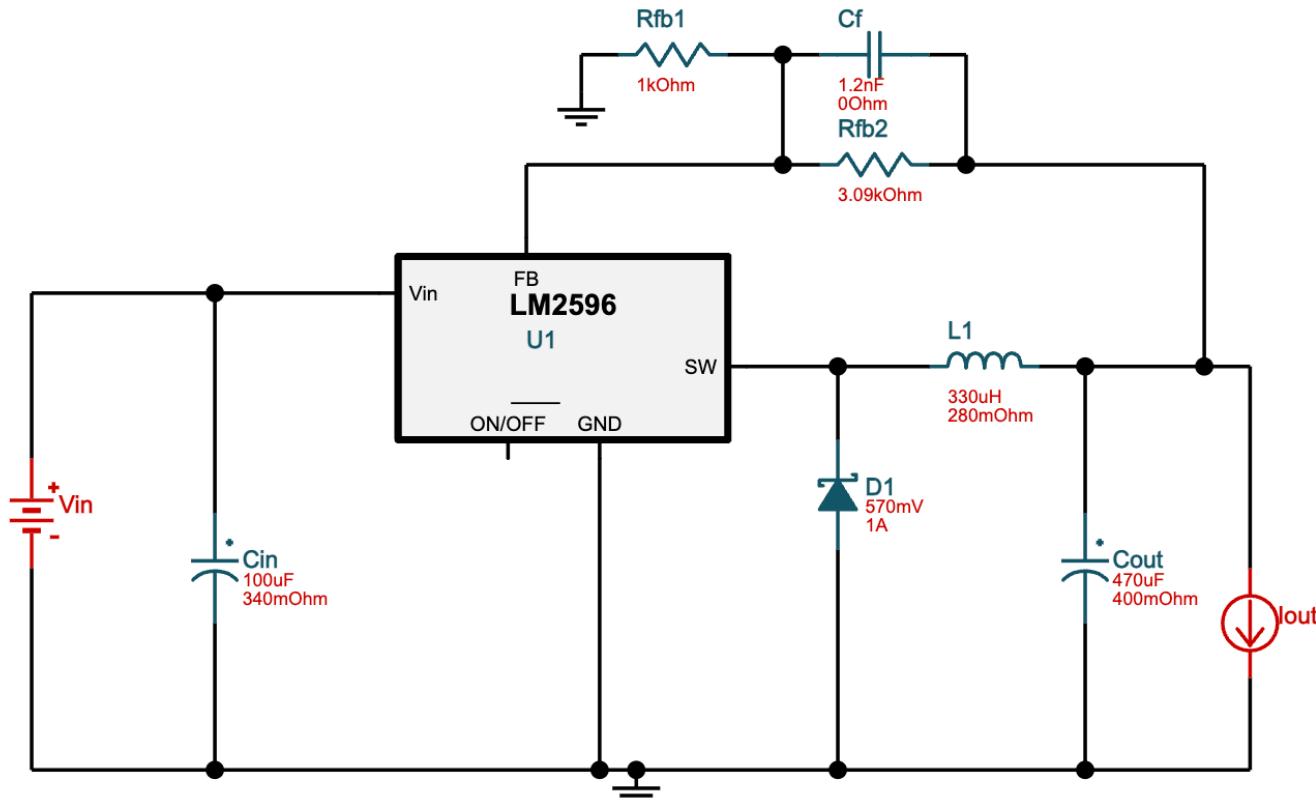
- **Input:** 8 - 30 V:
 - Each PV cell has a 0.59267 W maximum power output
 - Each PV cell has a 29.21 V maximum voltage output
 - Total max $V_{out} = 29.21 \text{ V} \times 1 \text{ PV cell}$; Voltage output = 29.21 V for a single PV solution
 - Total max current = 0.02029 A for a single PV solution
- **Output:** 5 V at 180 mA *or .18 A = 0.9 W

Miscellaneous:

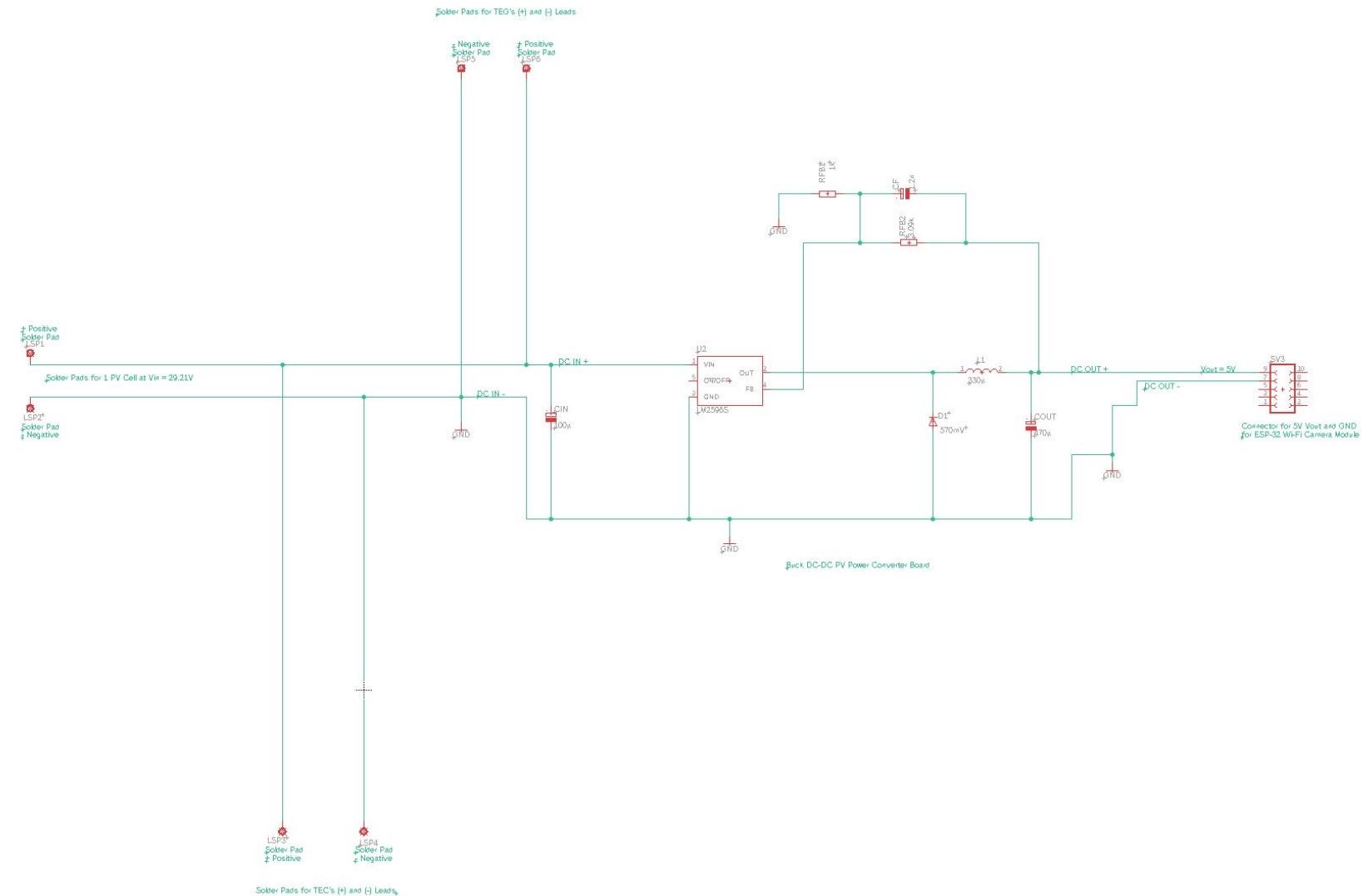
- Heat Sink

2. Buck DC-DC Converter

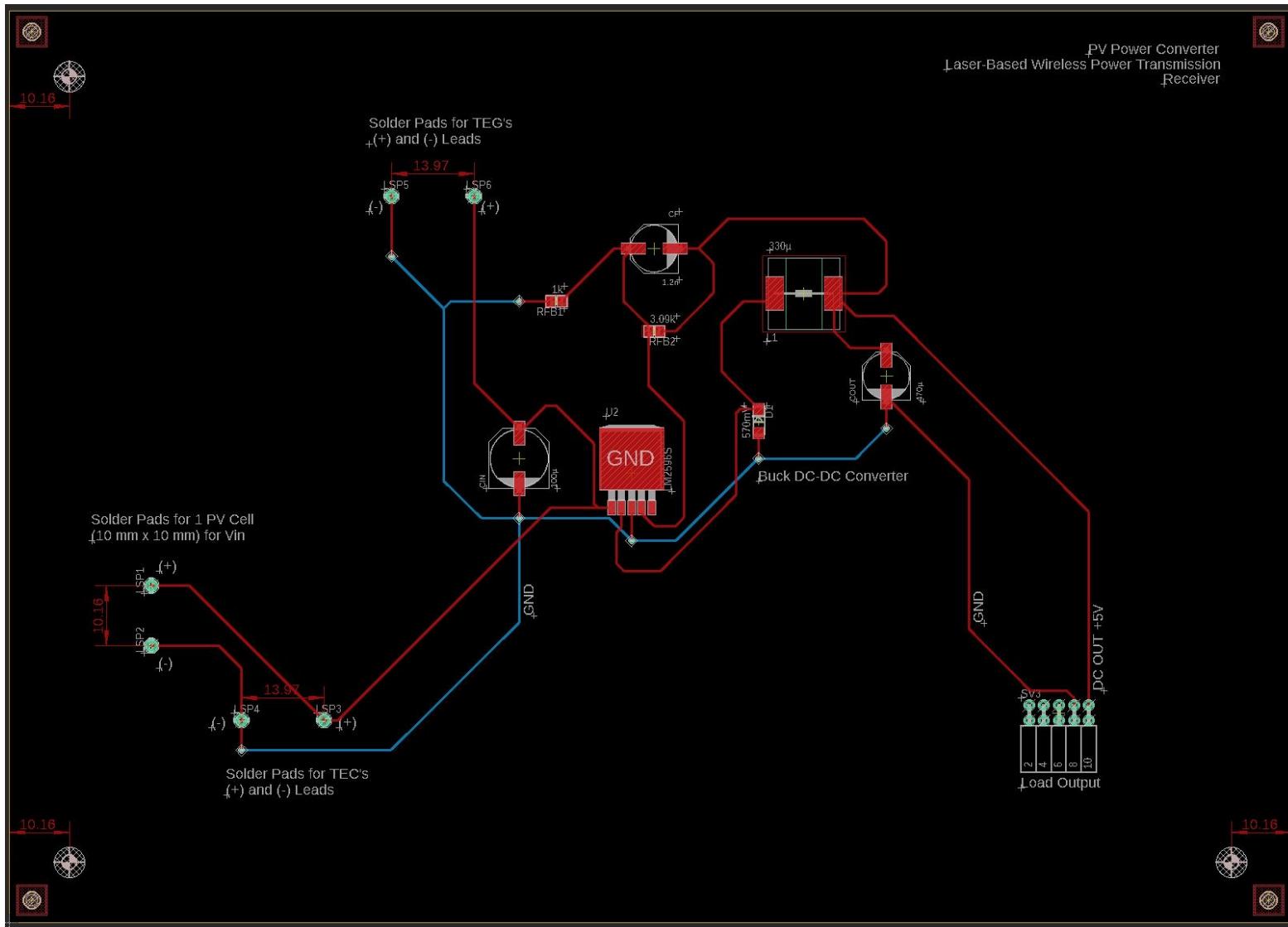
LM2596T-ADJ/NOPB - 25V-30V to 5.00V @ 0.18A. 69.4% Efficiency



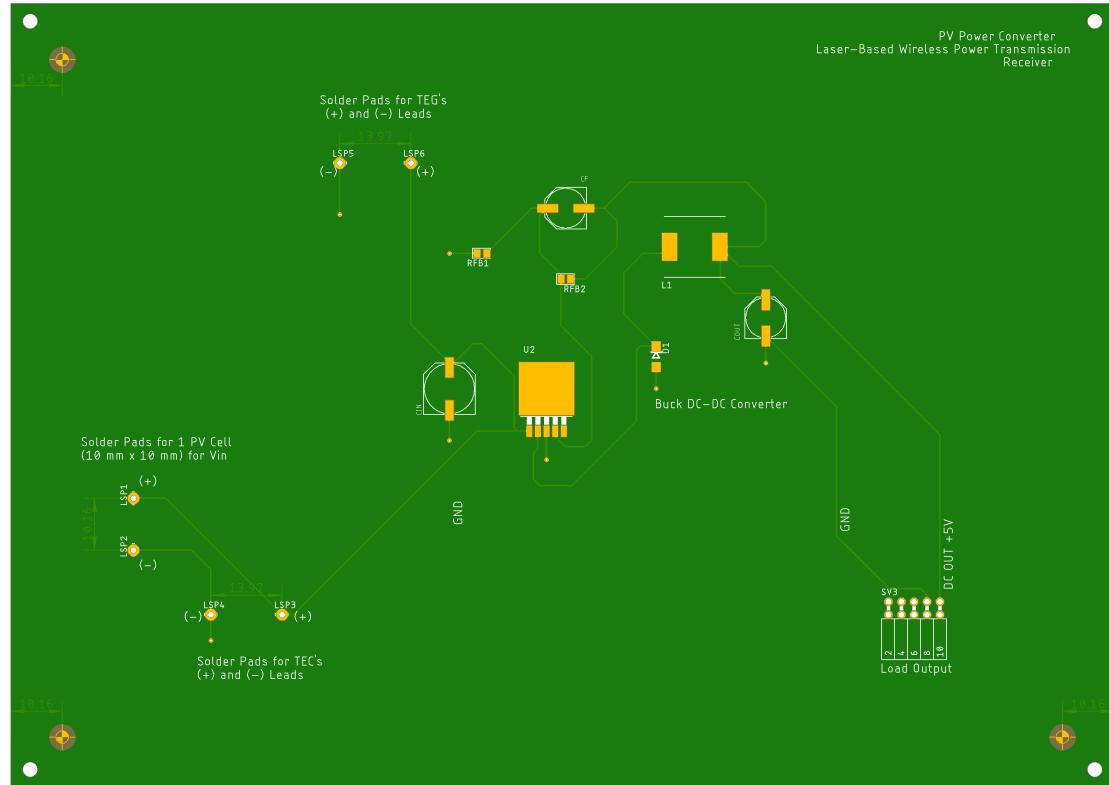
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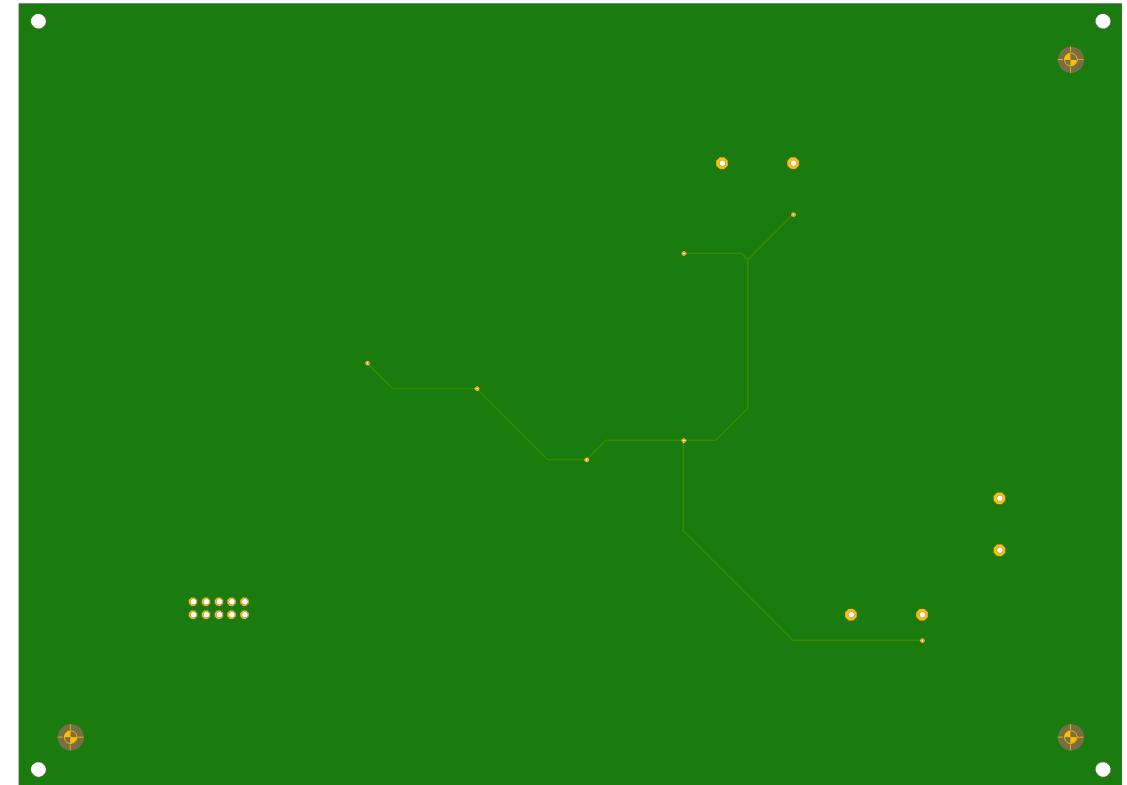
2.



2.



Top



Bottom

3. Design Specifications

1 cm x 1 cm MIH® VMJ PV Cell Form Factor, 4-PV, Parallel; Full Backplane Board

Peripherals:

- **Inputs:**
 - PV Array: 2 leads (+ and -)
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- **Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

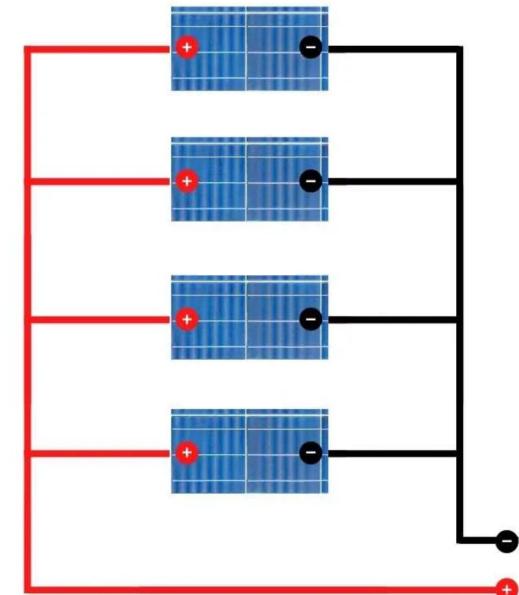
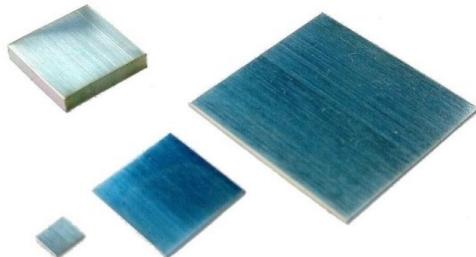
- Pads for soldered PV cells
- PWM Control DSP, MCU, or FPGA for Switch Control
- **Buck DC-DC Converter** circuit with Low-Pass Filter: **29.21 V to 5 V**
 - R, L, C, MOSFET Switch (Voltage-Controlled)
- I/O Ports as Female Connectors

Voltage Requirements:

- **Input:** 8 - 30 V:
 - Each PV cell has a 0.59267 W maximum power output
 - Each PV cell has a 29.21 V maximum voltage output
 - Total $V_{out} = 29.21 \text{ V}$ for a parallel connection
 - Total current = $0.02029 \text{ A} \times 4 \text{ PV cells} = 0.08116 \text{ A}$ for a parallel connection
 - Total power = $29.21 \text{ V} \times 0.08116 \text{ A} = 2.3706836 \text{ W}$
- **Output:** 5 V at 180 mA *or .18 A = 0.9 W

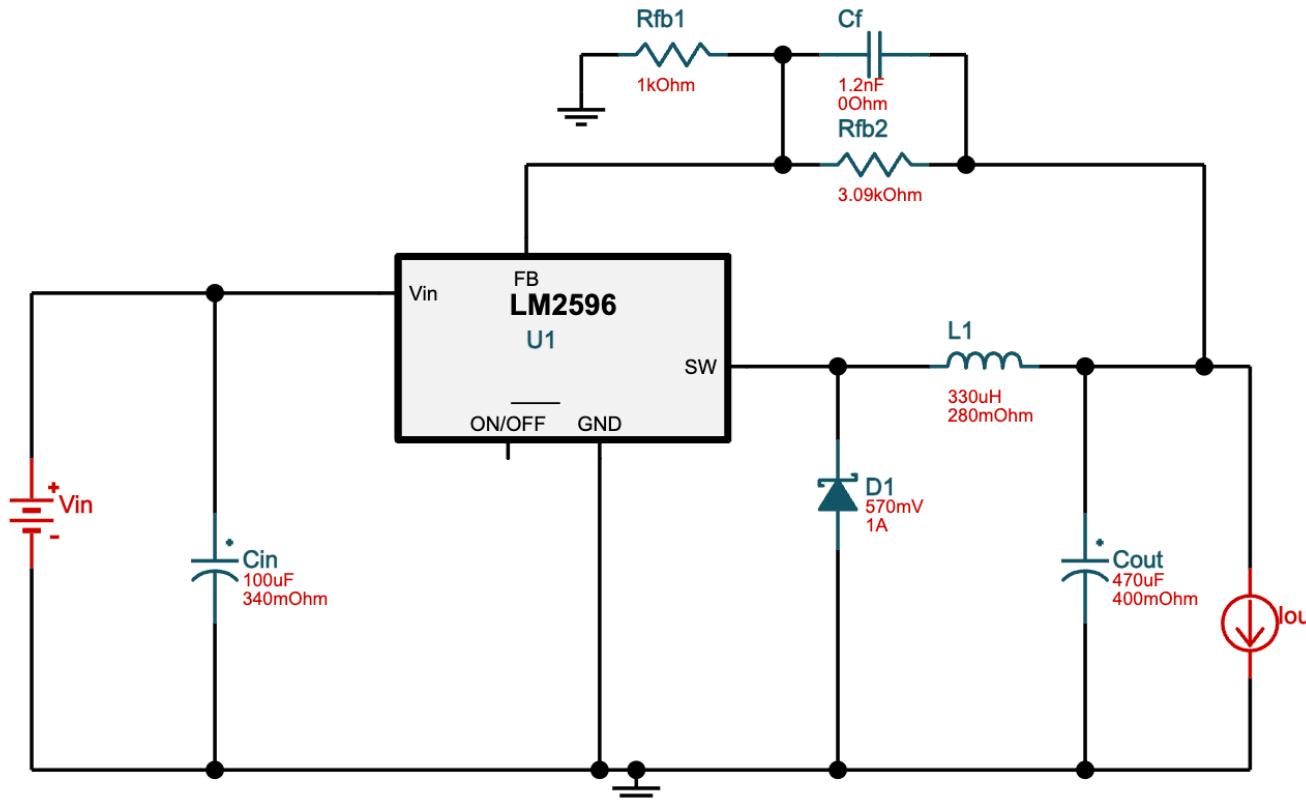
Miscellaneous:

- Heat Sink

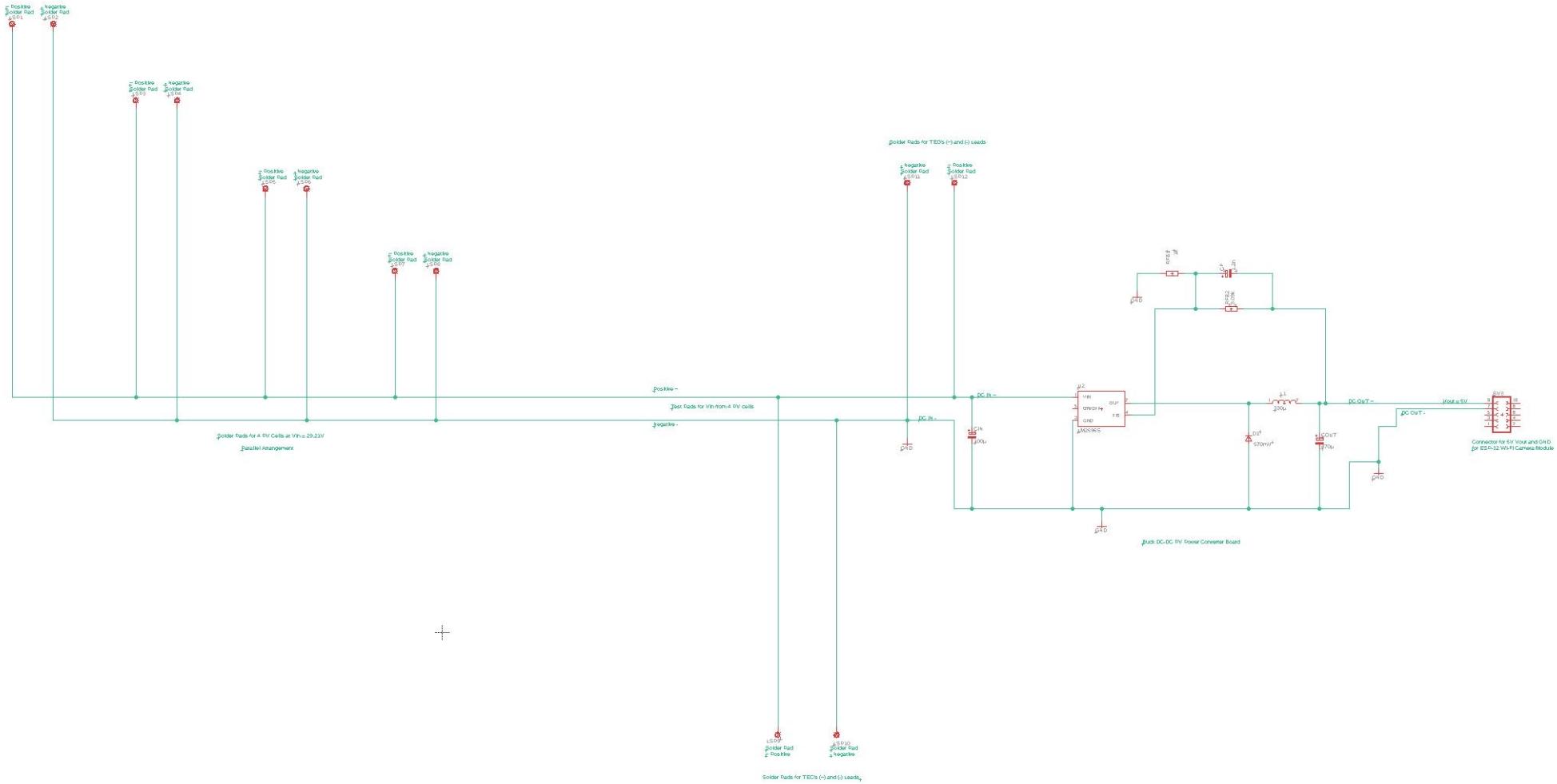


3. Buck DC-DC Converter

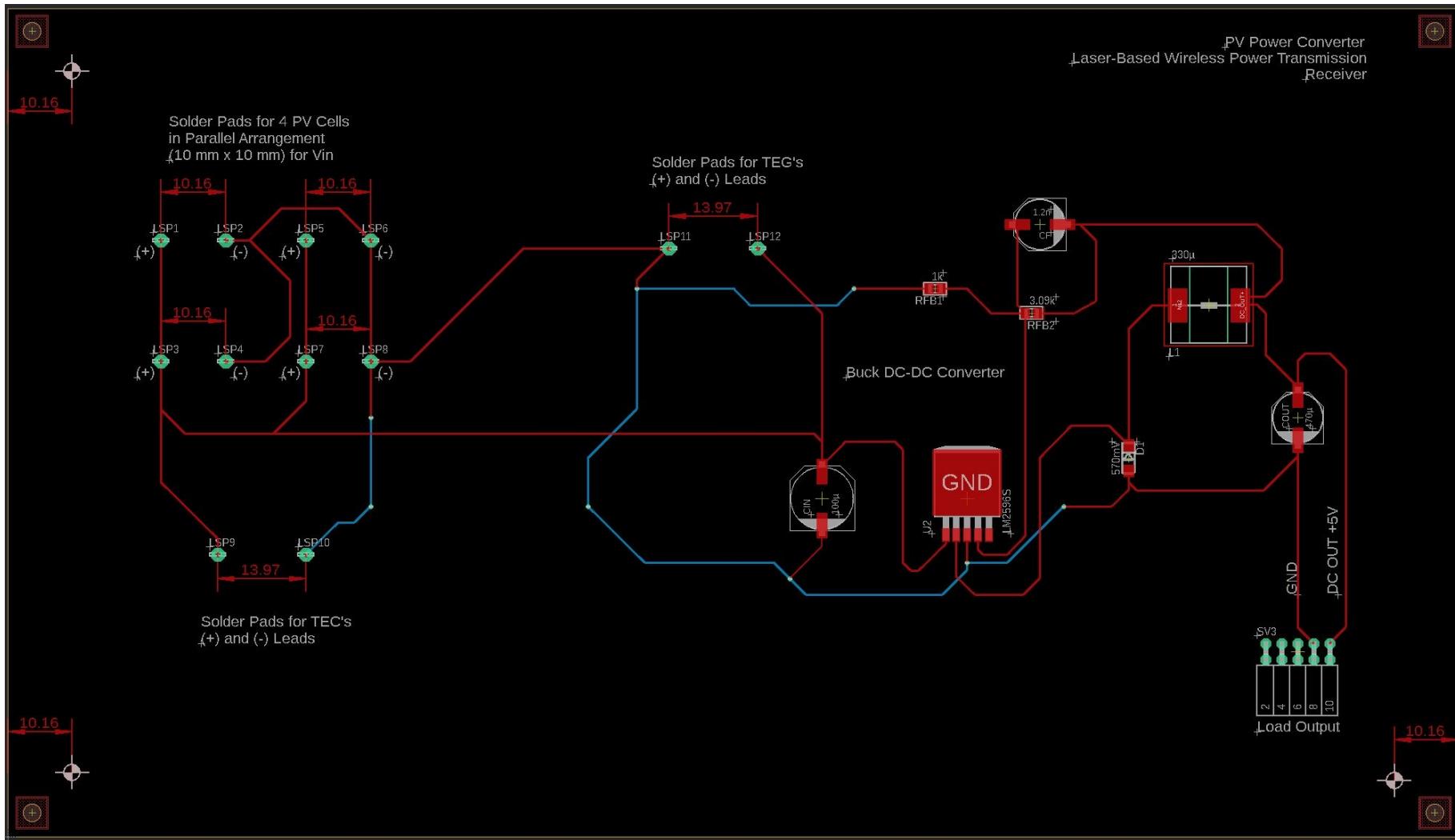
LM2596T-ADJ/NOPB - 25V-30V to 5.00V @ 0.18A. 69.4% Efficiency



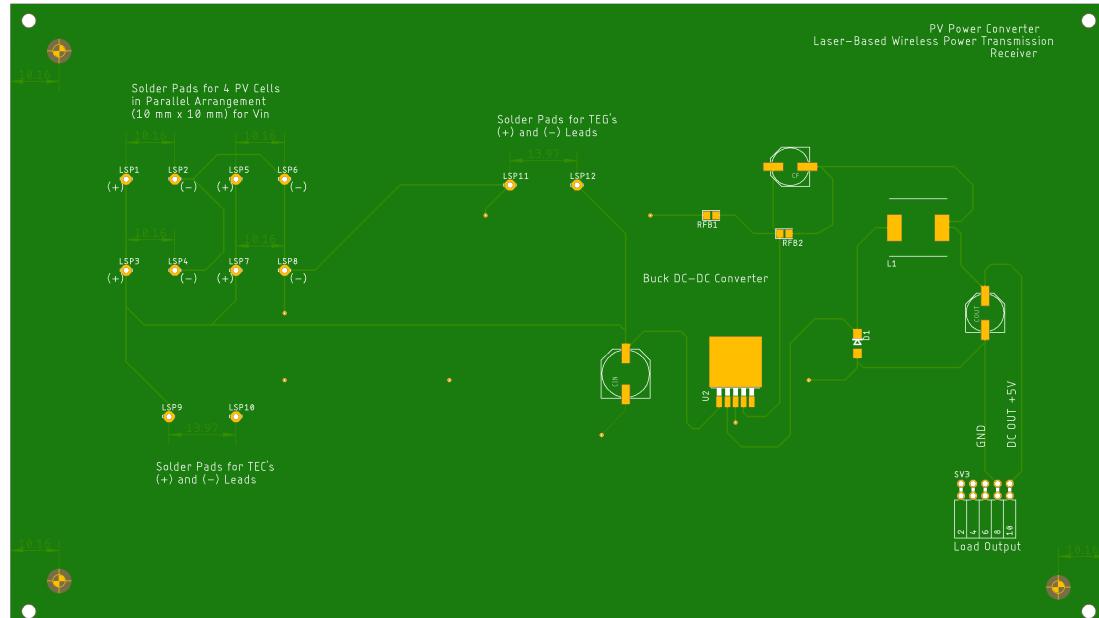
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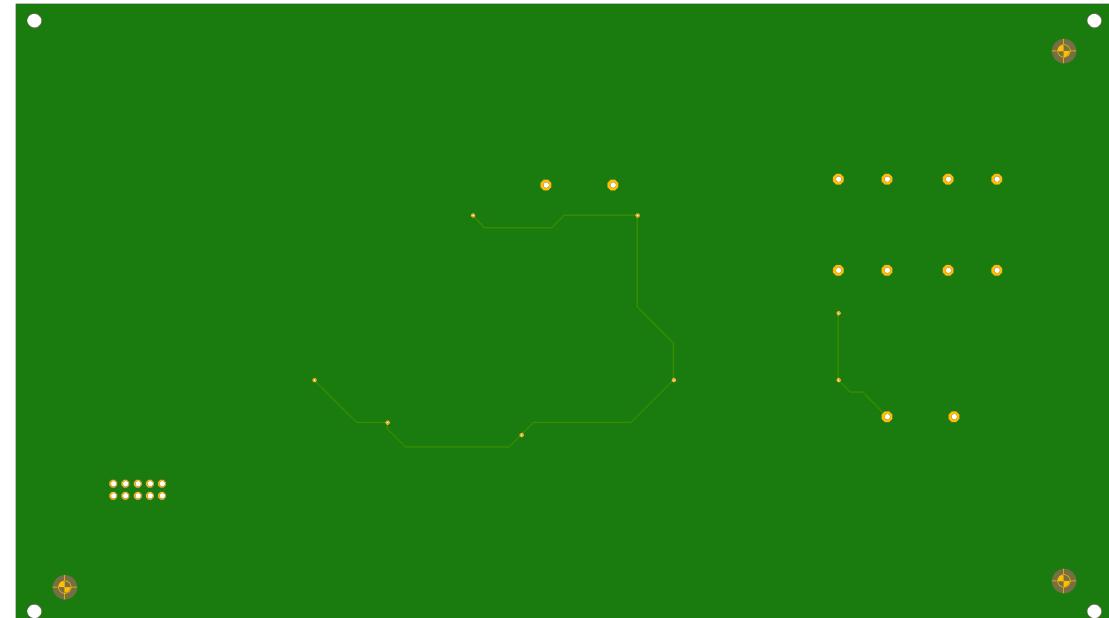
3.



3.



Top



Bottom

4. Design Specifications, 2.5 cm x 2.5 cm PV Cell Form Factor, 4-PV, Parallel; Extension Board: Configurable for Externally Adaptive Load Circuitry

Peripherals:

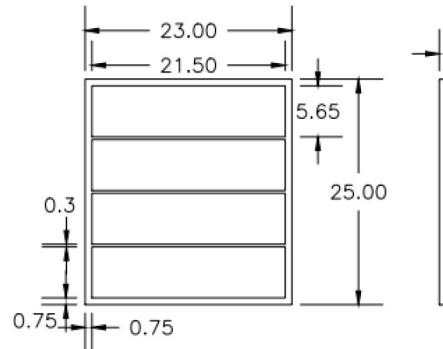
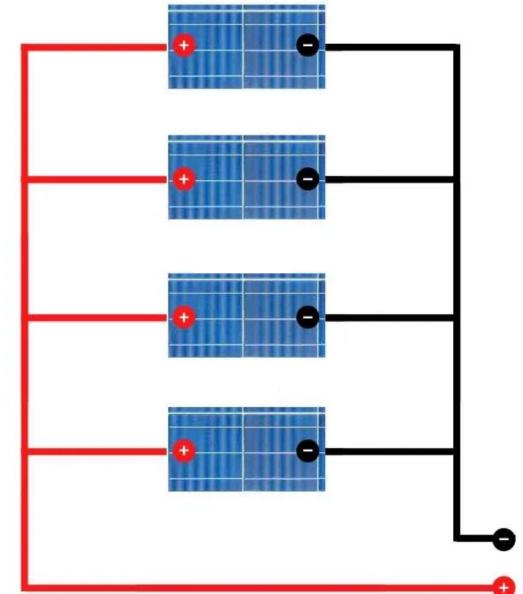
- **Inputs:**
 - PV Array: 2 leads (+ and -) x 4 PV cells = 8 leads
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- **Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

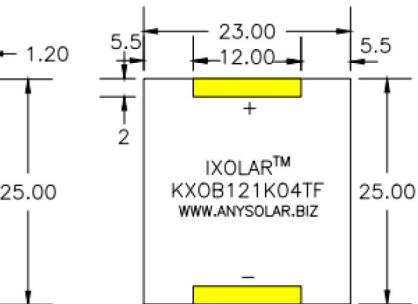
- Pads for soldered PV cells
- I/O Ports as Female Connectors

Voltage Requirements:

- **Input:**
 - Each PV cell has a 0.0472 A current output at P_{mpp}
 - Each PV cell has a 2.23 V voltage output at P_{mpp}
 - Each PV cell has a 0.1053 W maximum power output
- **Output:** 5 V at 180 mA or 0.18 A = 0.9 W



Front-side View details



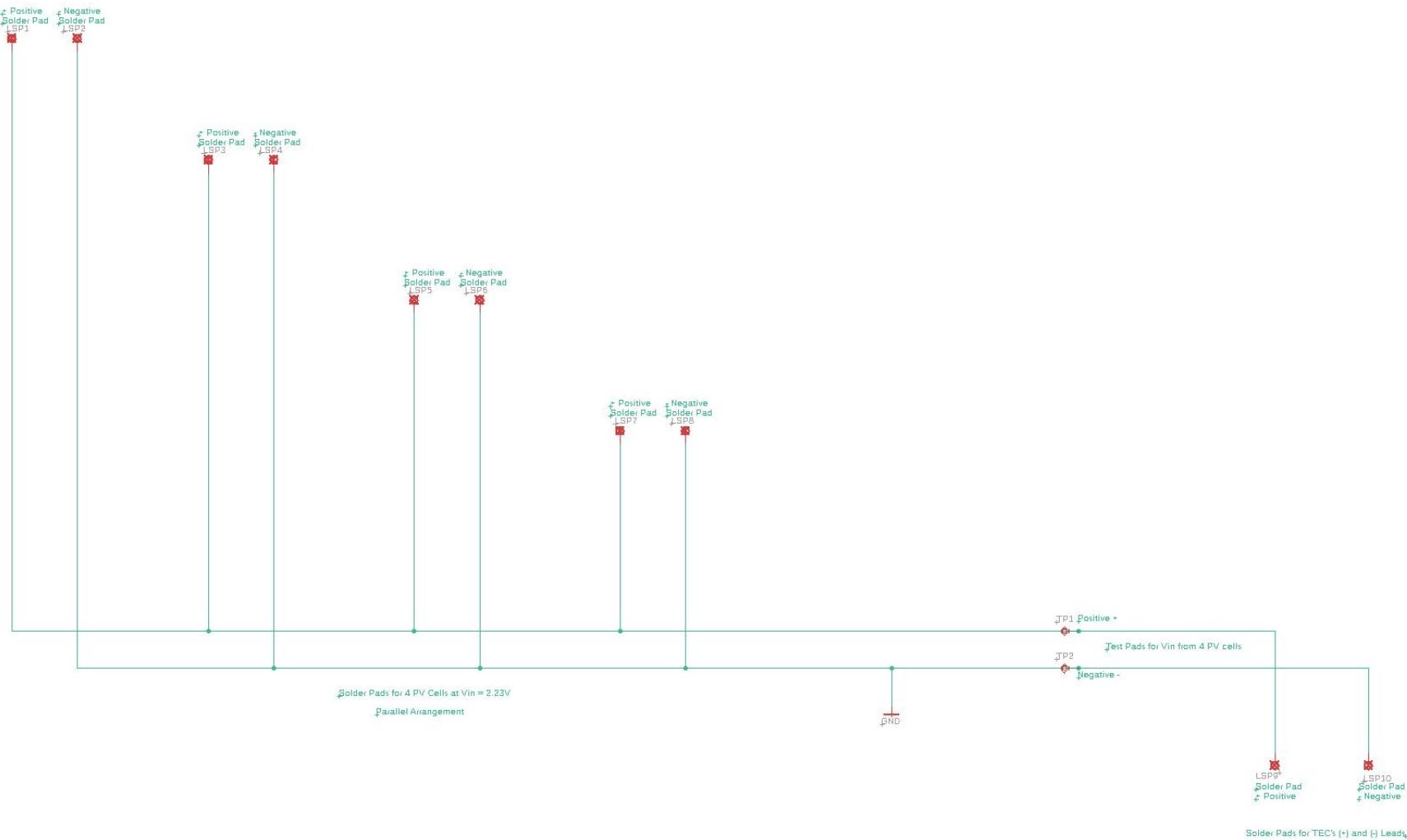
Back-side View details

Miscellaneous:

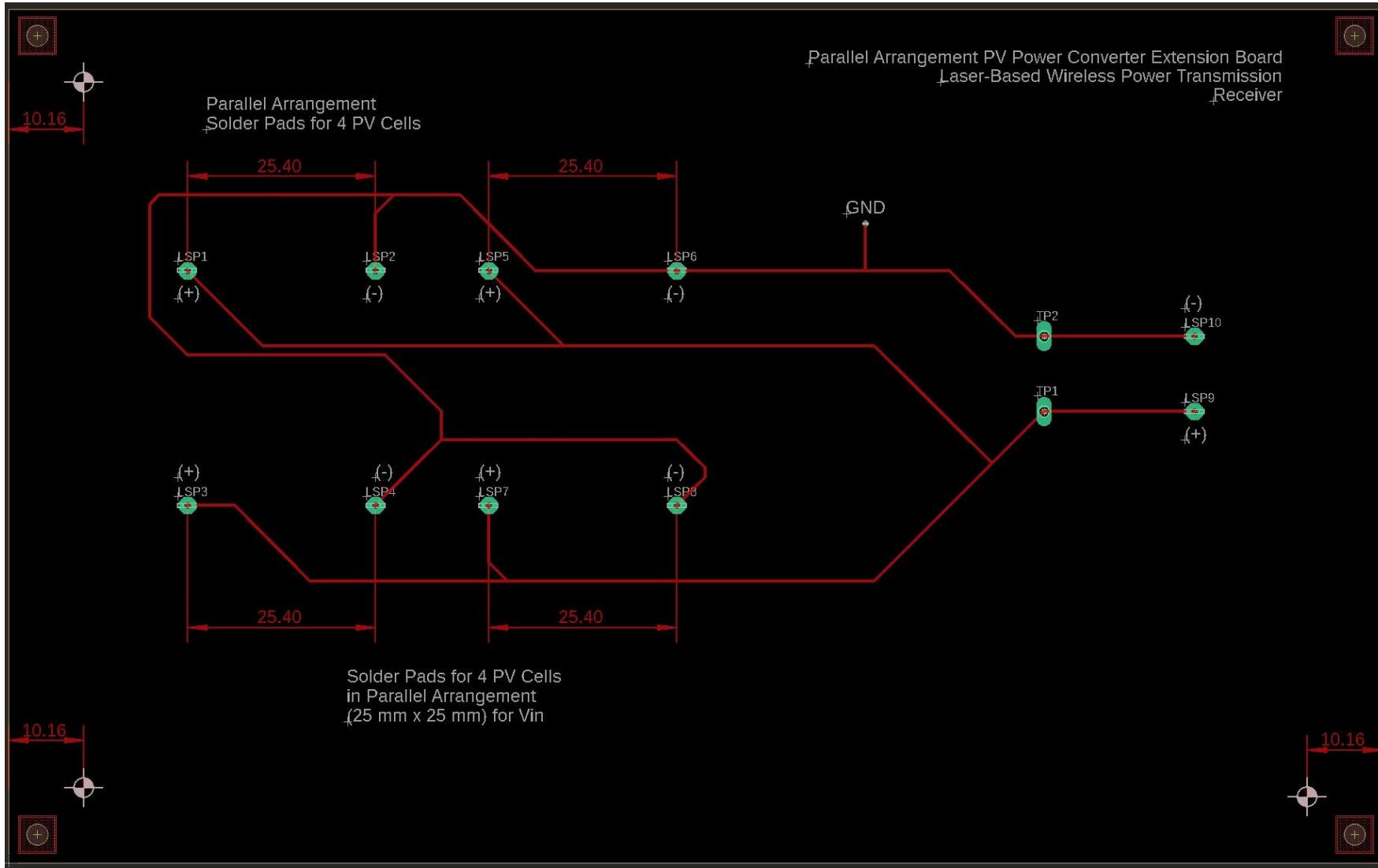
- Heat Sink

*Required Separately: **Boost DC-DC Converter circuit: 2.23 V to 5 V**

4.



4.



5. Design Specifications, 2.5 cm x 2.5 cm PV Cell Form Factor, 4-PV, Series; Full Backplane Board

Peripherals:

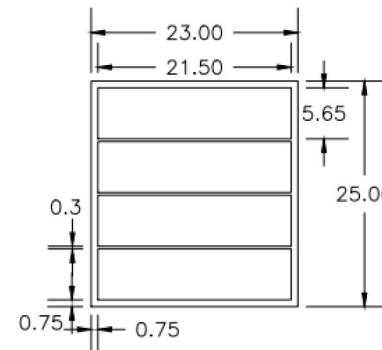
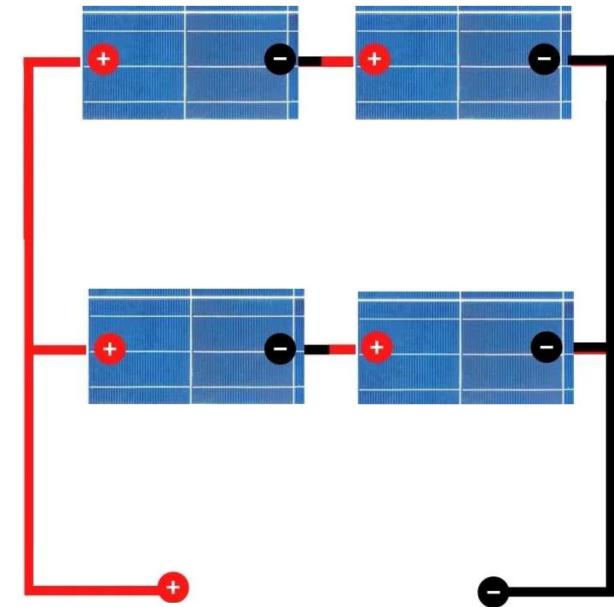
- Inputs:**
 - PV Array: 2 leads (+ and -) leads
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

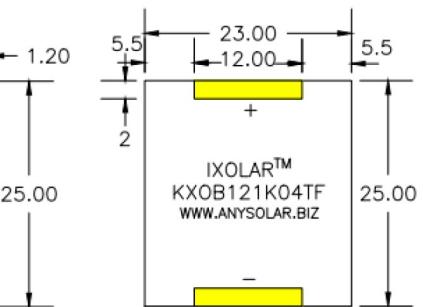
- Pads for soldered PV cells
- PWM Control DSP, MCU, or FPGA for Switch Control
- Buck DC-DC Converter** circuit with Low-Pass Filter: **8.92 V to 5 V**
 - R, L, C, MOSFET Switch (Voltage-Controlled)
- I/O Ports as Female Connectors

Voltage Requirements:

- Input:** 8 - 30 V:
 - Each PV cell has a 0.1053 W maximum power output
 - Each PV cell has a 2.23 V voltage output at Pmpp
 - Total $V_{out} = 2.23 \text{ V} \times 4 \text{ PV cells}$; Voltage output = 8.92 V for a series connection
 - Total current = 0.0472 A current output at Pmpp for a series connection
- Output:** 5 V at 180 mA or 0.18 A = 0.9 W



Front-side View details



Back-side View details

Miscellaneous:

- Heat Sink

6. Design Specifications, 5 cm x 5 cm PV Cell Form Factor, 4-PV, Series; Full Backplane Board

Peripherals:

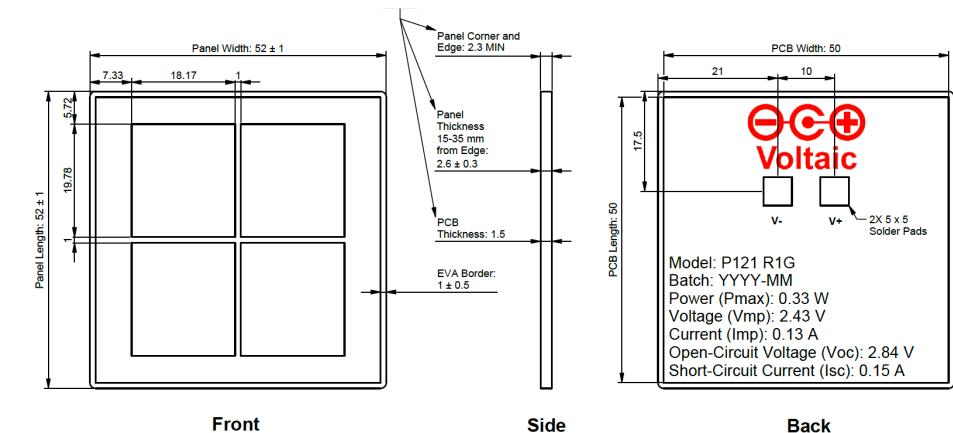
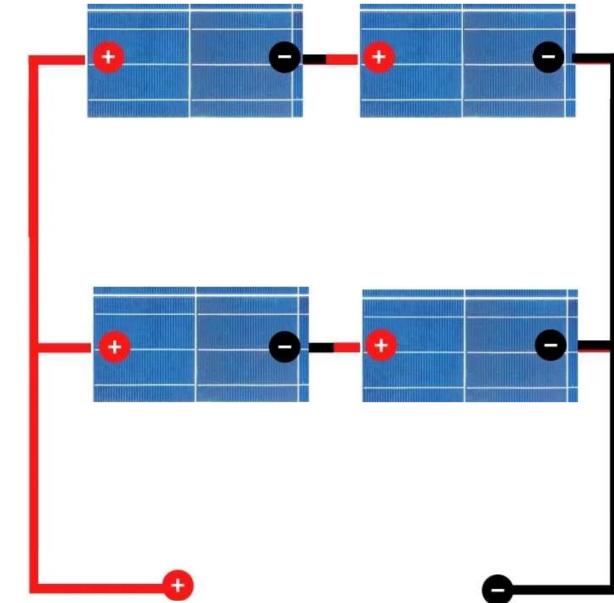
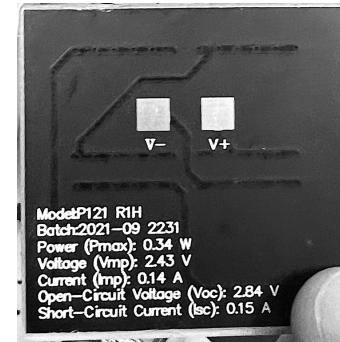
- Inputs:**
 - PV Array: 2 leads (+ and -) leads
 - TEG module's 2 leads (+ and -)
 - TEC
- Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

- Pads for soldered PV cells
- PWM Control DSP, MCU, or FPGA for Switch Control
- Buck DC-DC Converter** circuit with Low-Pass Filter: **9.72 V to 5 V**
 - R, L, C, MOSFET Switch (Voltage-Controlled)
- I/O Ports as Female Connectors

Voltage Requirements:

- Input:** 8 - 30 V:
 - Each PV cell has a 0.34 W power output
 - Each PV cell has a 2.43 V voltage output
 - Total $V_{out} = 2.43 \text{ V} \times 4 \text{ PV cells}$; Voltage output = 9.72 V for a series connection
 - Total current = 0.14 A for a series connection
- Output:** 5 V at 180 mA or 0.18 A = 0.9 W

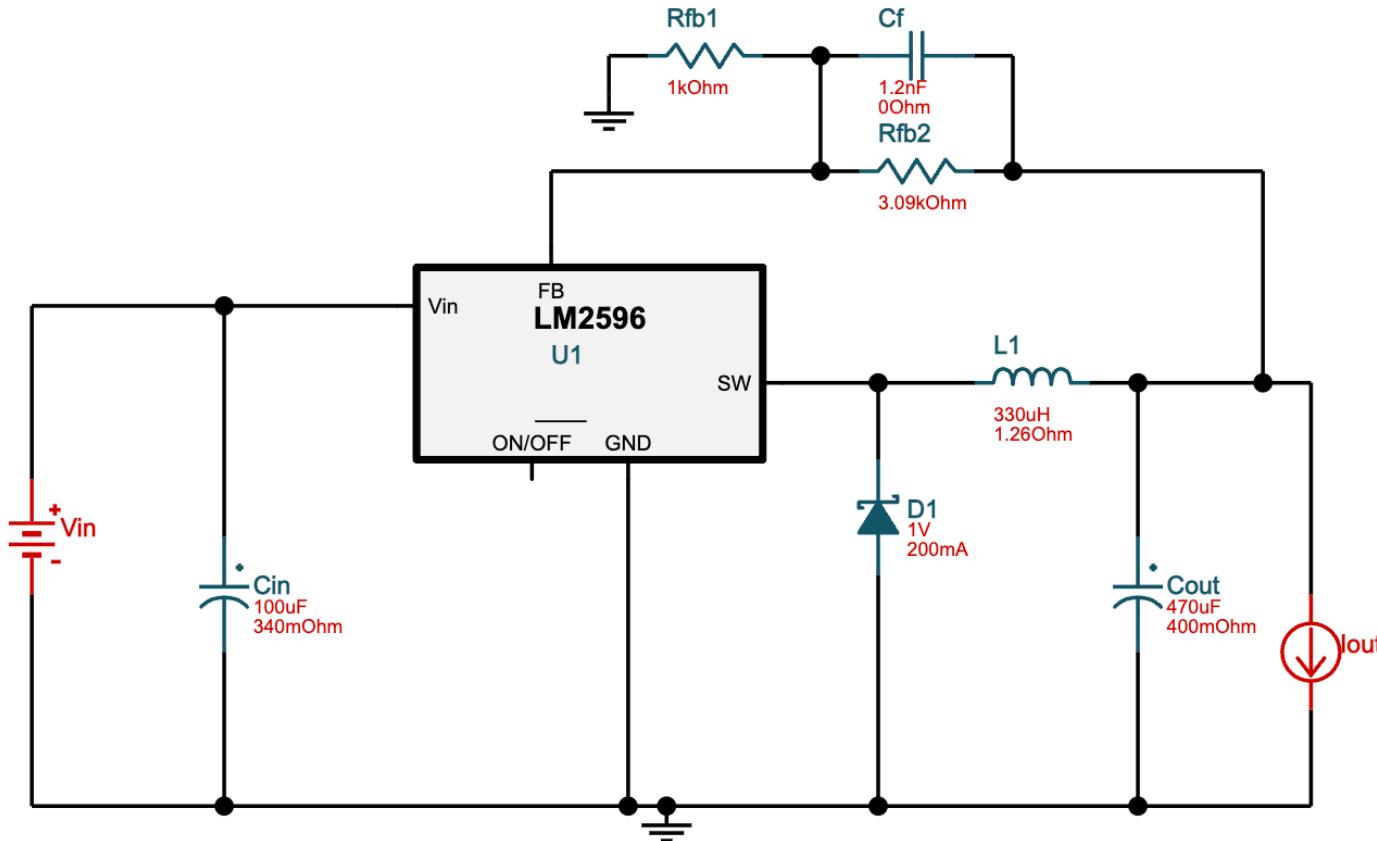


Miscellaneous:

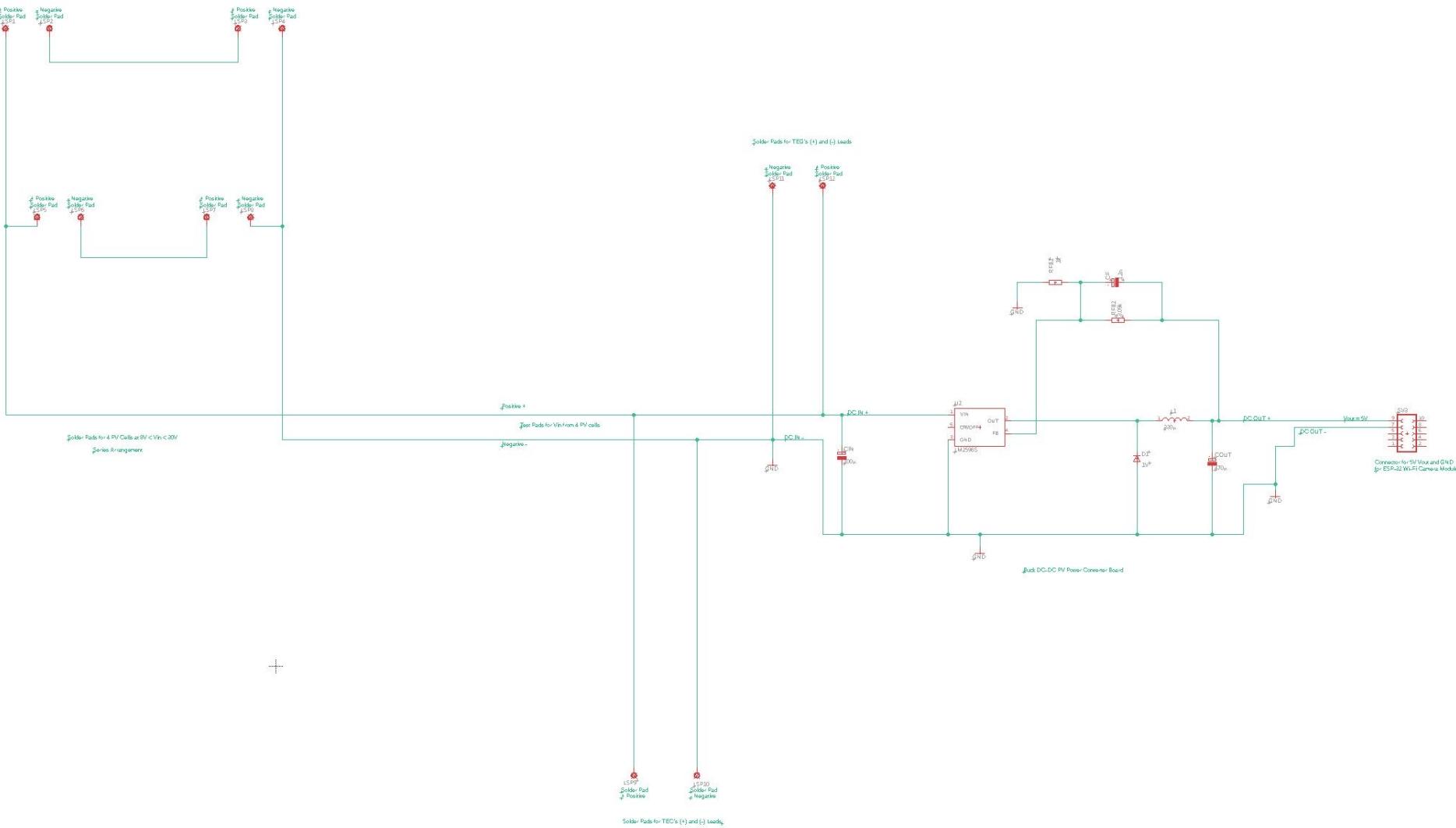
- Heat Sink

5 & 6. Buck DC-DC Converter

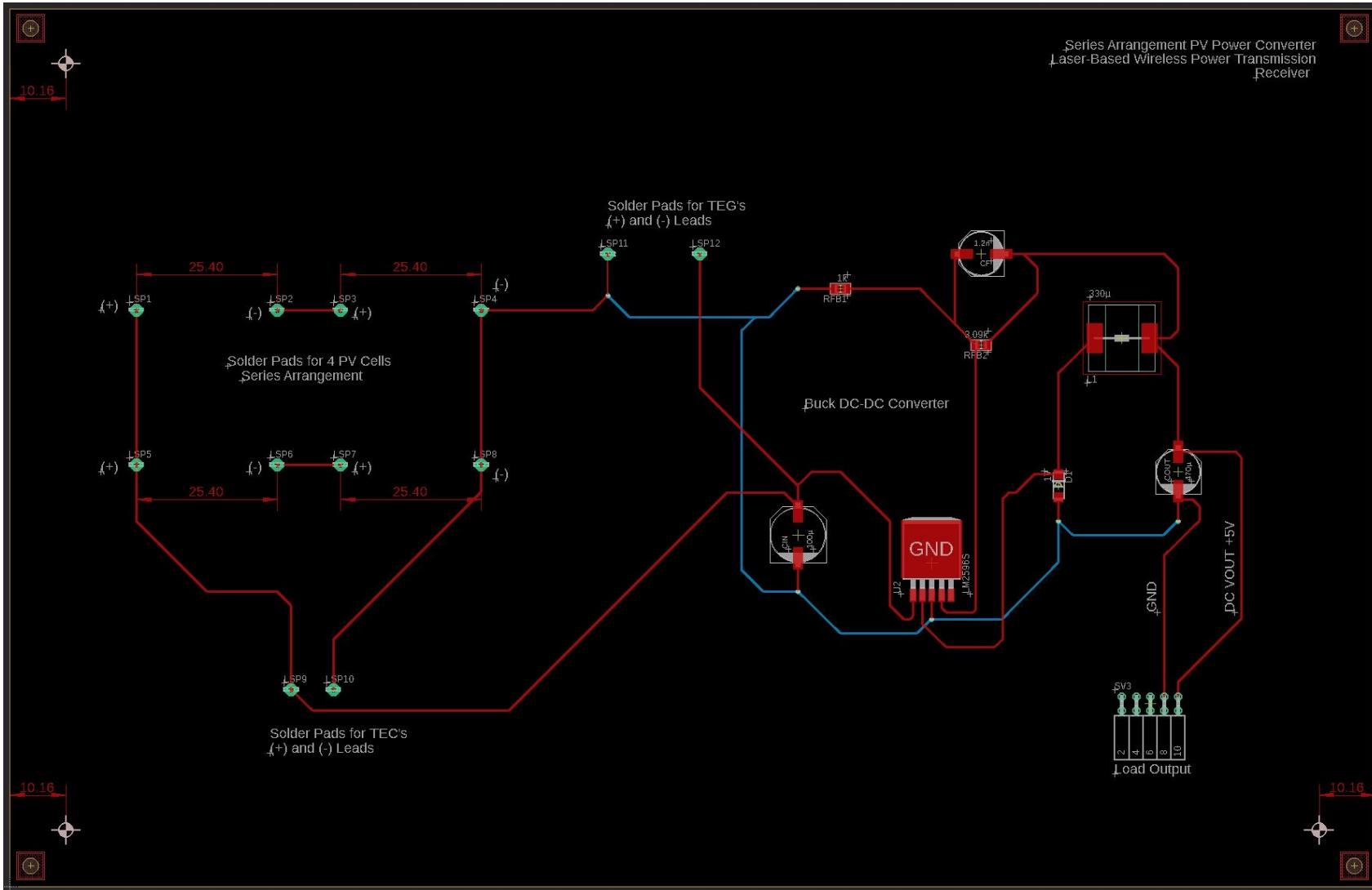
LM2596T-ADJ/NOPB - 8V-30V to 5.00V @ 0.18A. 68.8% Efficiency



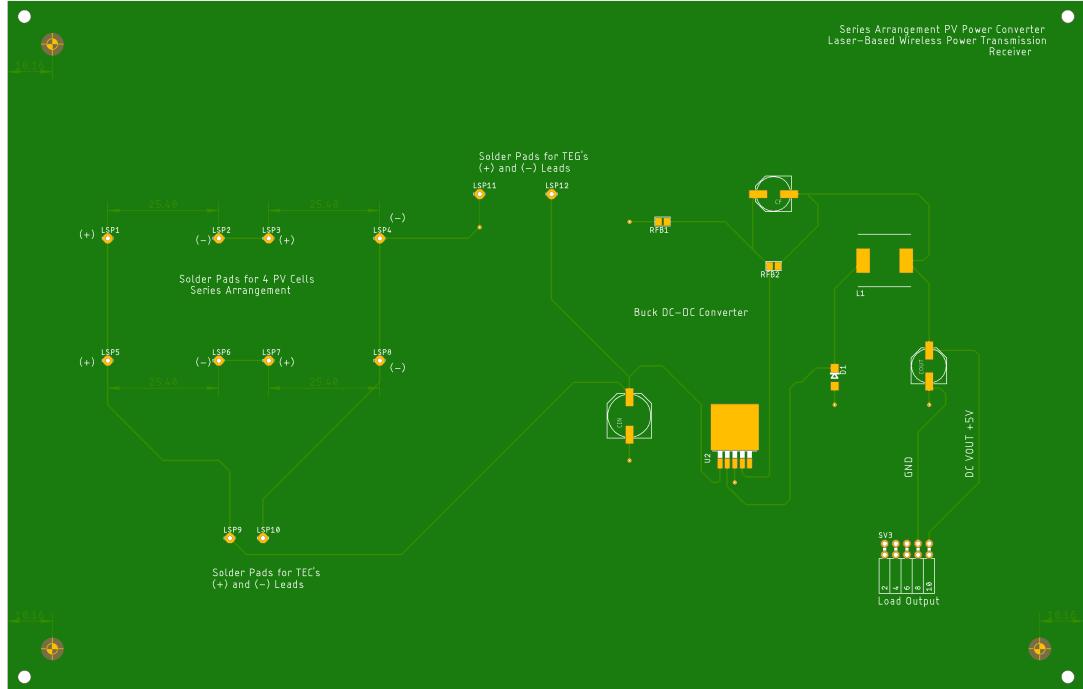
5 & 6.



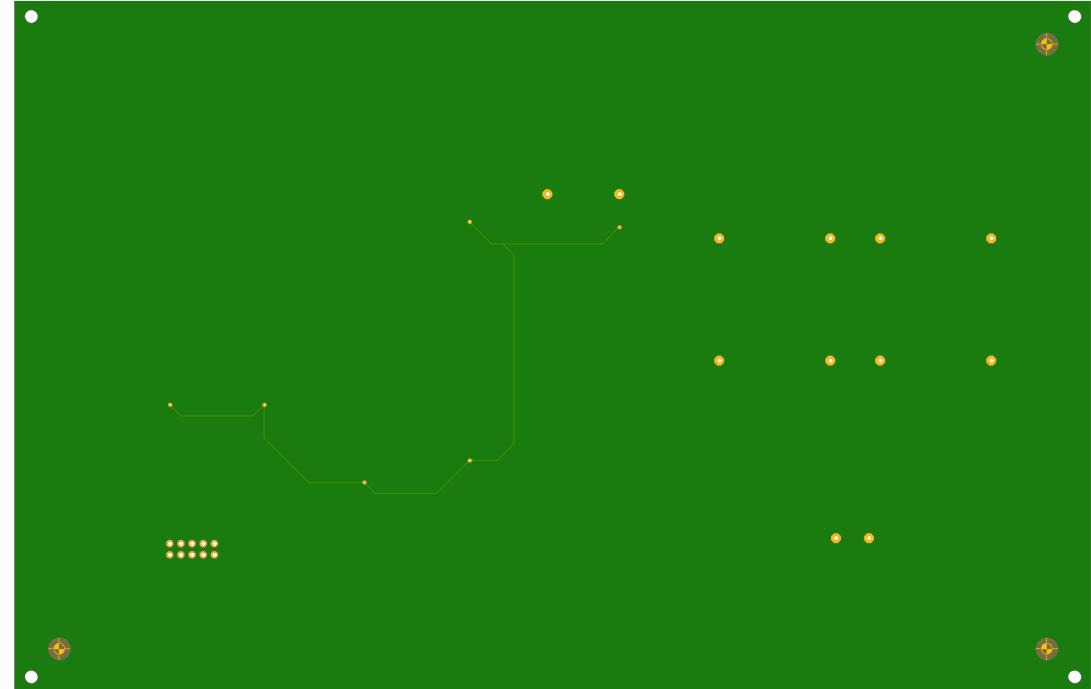
5 & 6.



5 & 6.



Top



Bottom

7. Design Specifications, 5 cm x 5 cm PV Cell Form Factor, 4-PV, Series; Backplane Extension Board

Peripherals:

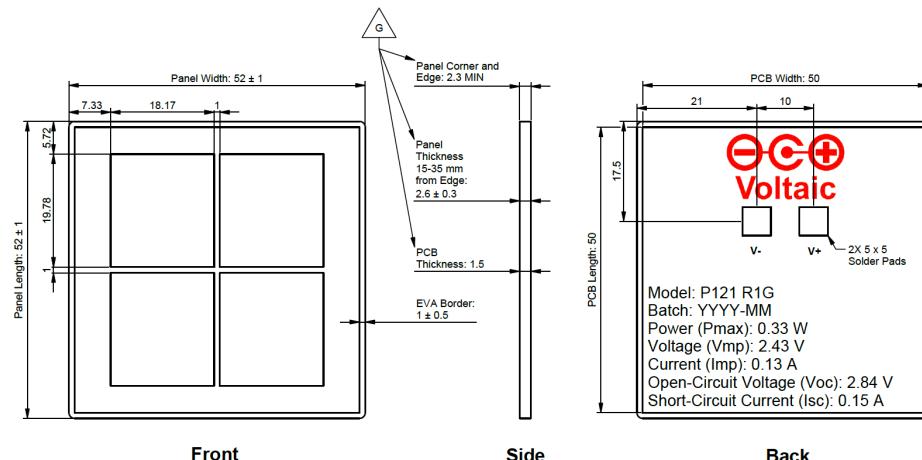
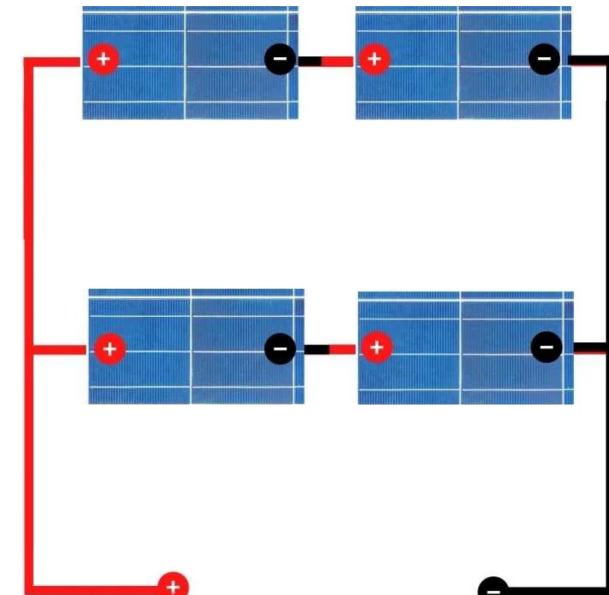
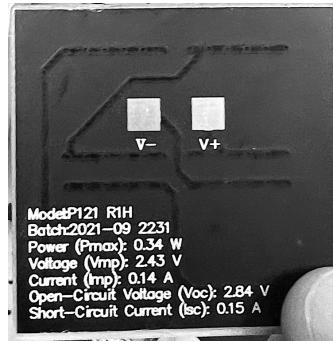
- Inputs:**
 - PV Array: 2 leads (+ and -) x 4 PV cells = 8 leads
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

- Pads for soldered PV cells
- I/O Ports as Female Connectors

Voltage Requirements:

- Input:** 8 - 30 V:
 - Each PV cell has a 0.34 W power output
 - Each PV cell has a 2.43 V
 - Total $V_{out} = 2.43 \text{ V} \times 4 \text{ cells}$; Voltage output = 9.72 V for a series connection
 - Total current = 0.14 A for a series connection
- Output:** 5 V at 180 mA or 0.18 A = 0.9 W

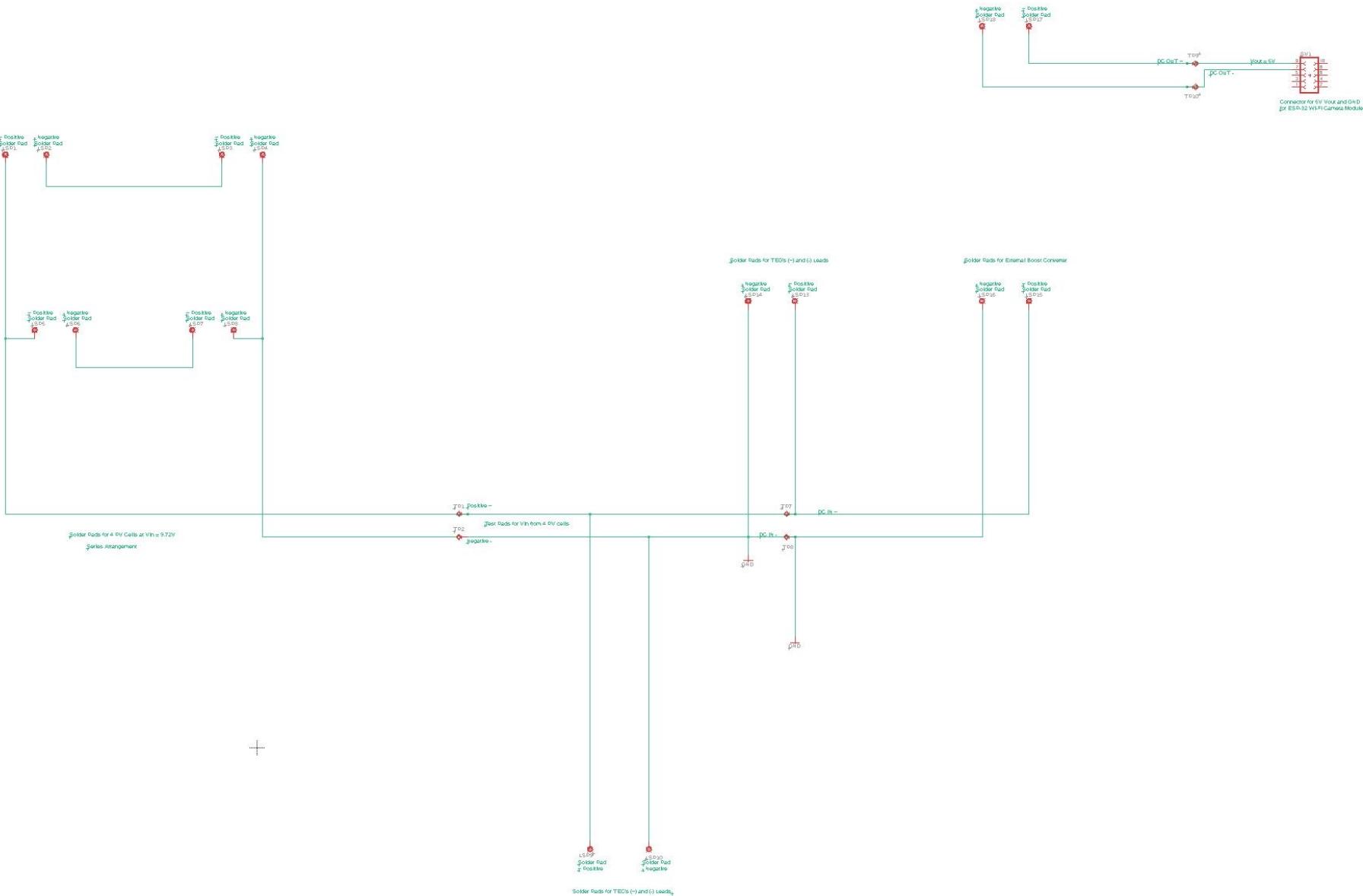


Miscellaneous:

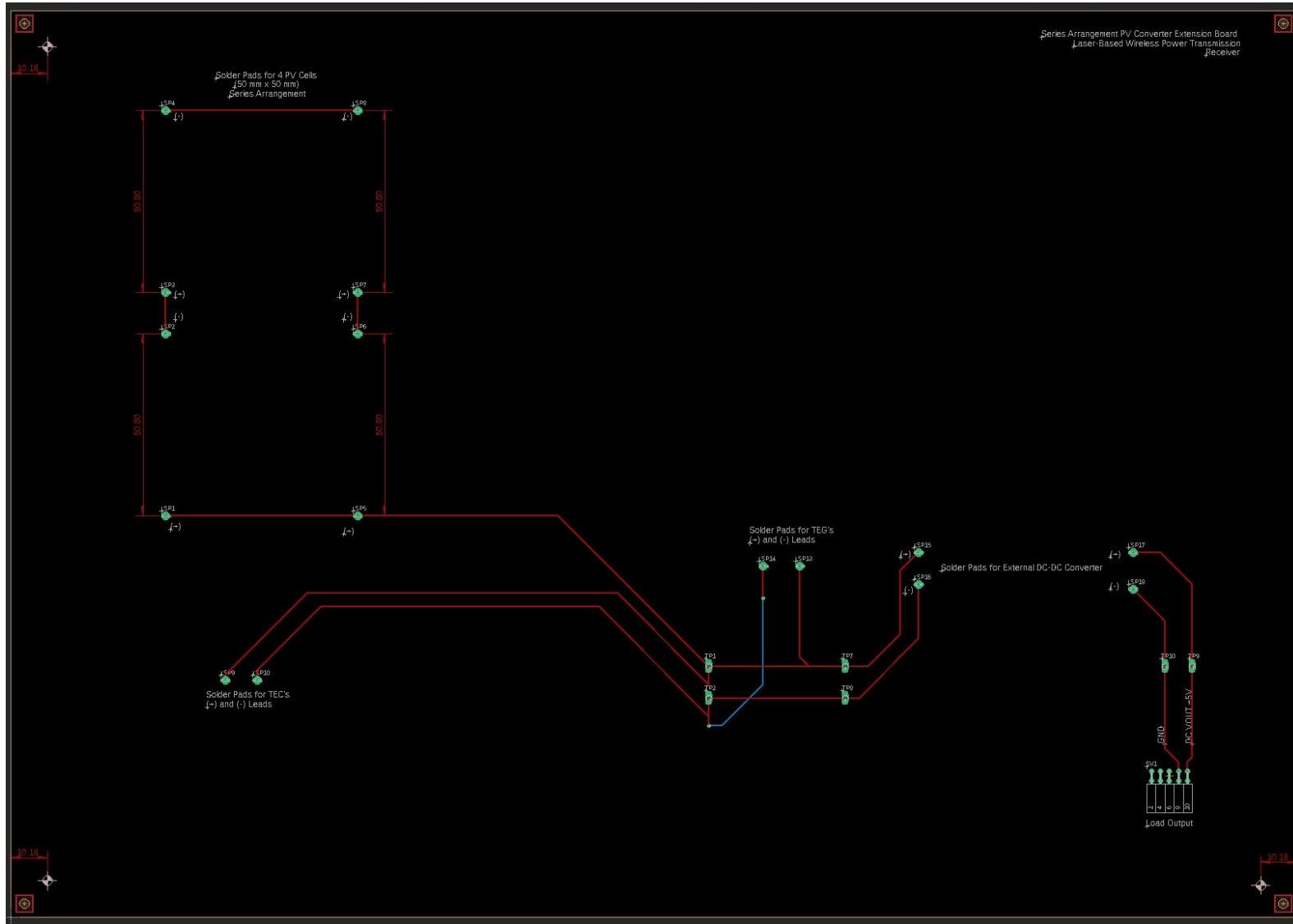
- Heat Sink

*Required Separately: **Buck DC-DC Converter circuit: 9.72 V to 5 V**

7.



7.



8. Design Specifications, 2.5 cm x 2.5 cm PV Cell Form Factor, 4-PV, Parallel; Backplane Extension Board

Peripherals:

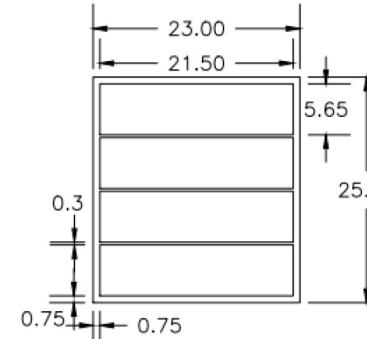
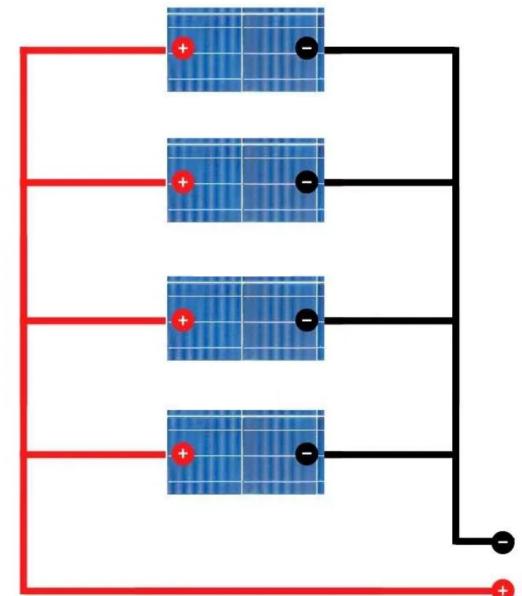
- **Inputs:**
 - PV Array: 2 leads (+ and -)
 - TEG module's 2 leads (+ and -)
 - TEC module's 2 leads (+ and -)
- **Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

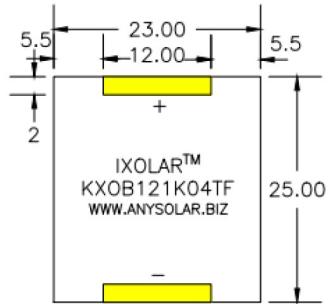
- Pads for soldered PV cells
- I/O Ports as Female Connectors

Voltage Requirements:

- **Input:**
 - Each PV cell has a 0.1053 W maximum power output
 - Each PV cell has a 2.23 V voltage output at P_{mpp}
 - Total $V_{out} = 2.23 \text{ V}$ for a parallel connection
 - Total current = $0.0472 \text{ A} \times 4 \text{ PV cells} = 0.1888 \text{ A}$ for a parallel connection
 - Total power = $2.23 \text{ V} \times 0.1888 \text{ A} = 0.421024 \text{ W}$
- **Output:** 5 V at 180 mA or 0.18 A = 0.9 W



Front-side View details



Back-side View details

Miscellaneous:

- Heat Sink

*Required Separately: **Boost DC-DC Converter circuit: 2.23 V to 5 V**

9. Design Specifications, 5 cm x 5 cm PV Cell Form Factor, 4-PV, Parallel; Backplane Extension Board

Peripherals:

- Inputs:**
 - PV Array: 2 leads (+ and -)
 - TEG module's 2 leads (+ and -)
 - TEC
- Outputs:**
 - ESP-32 Wi-Fi camera

Internals:

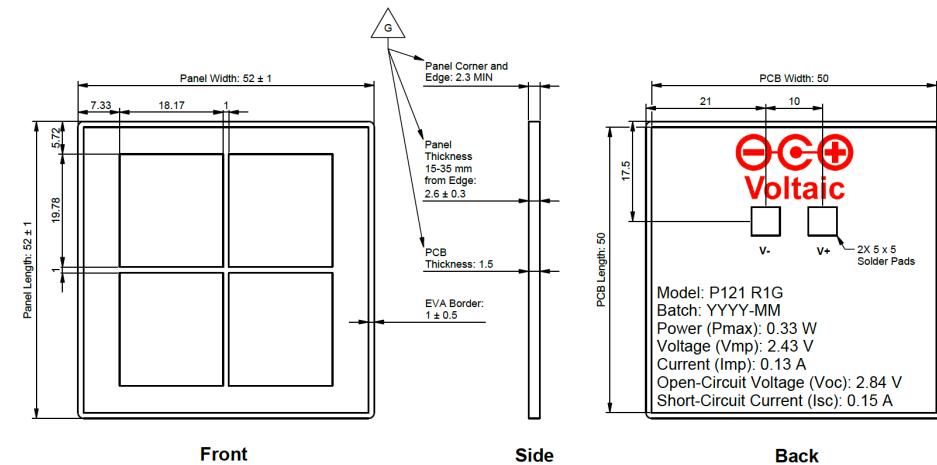
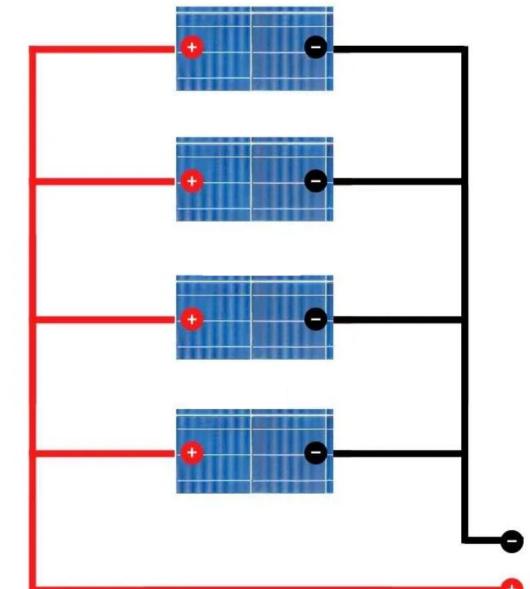
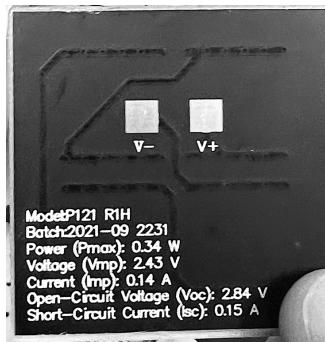
- Pads for soldered PV cells
- I/O Ports as Female Connectors

Voltage Requirements:

- Input:**
 - Each PV cell has a 0.34 W power output
 - Each PV cell has a 2.43 V voltage output
 - Total $V_{out} = 2.43 \text{ V}$ for a parallel connection
 - Total current = $0.14 \text{ A} \times 4 \text{ PV cells} = 0.56 \text{ A}$ for a parallel connection
 - Total power = $2.43 \text{ V} \times 0.56 \text{ A} = 1.3608 \text{ W}$
- Output:** 5 V at 180 mA or 0.18 A = 0.9 W

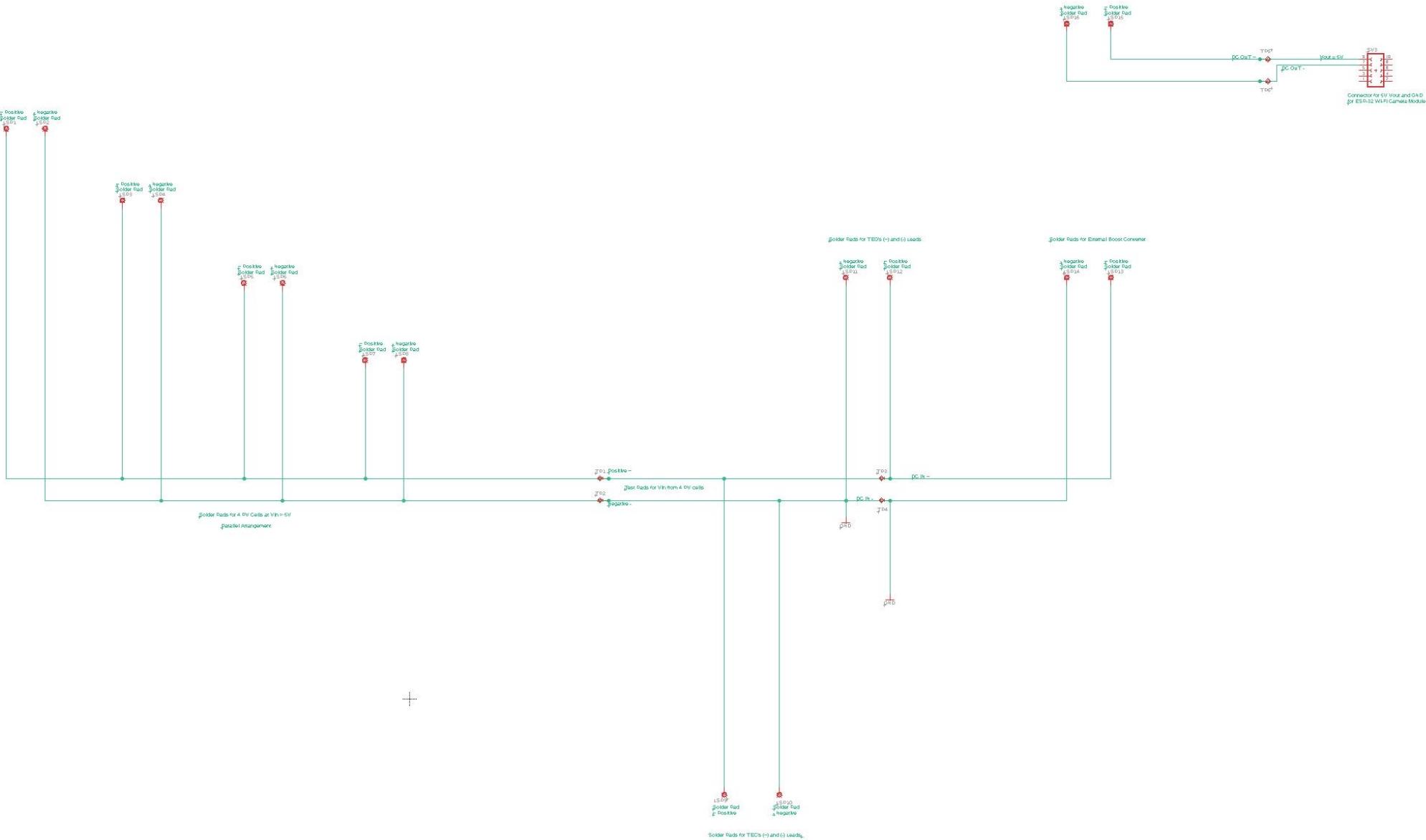
Miscellaneous:

- Heat Sink

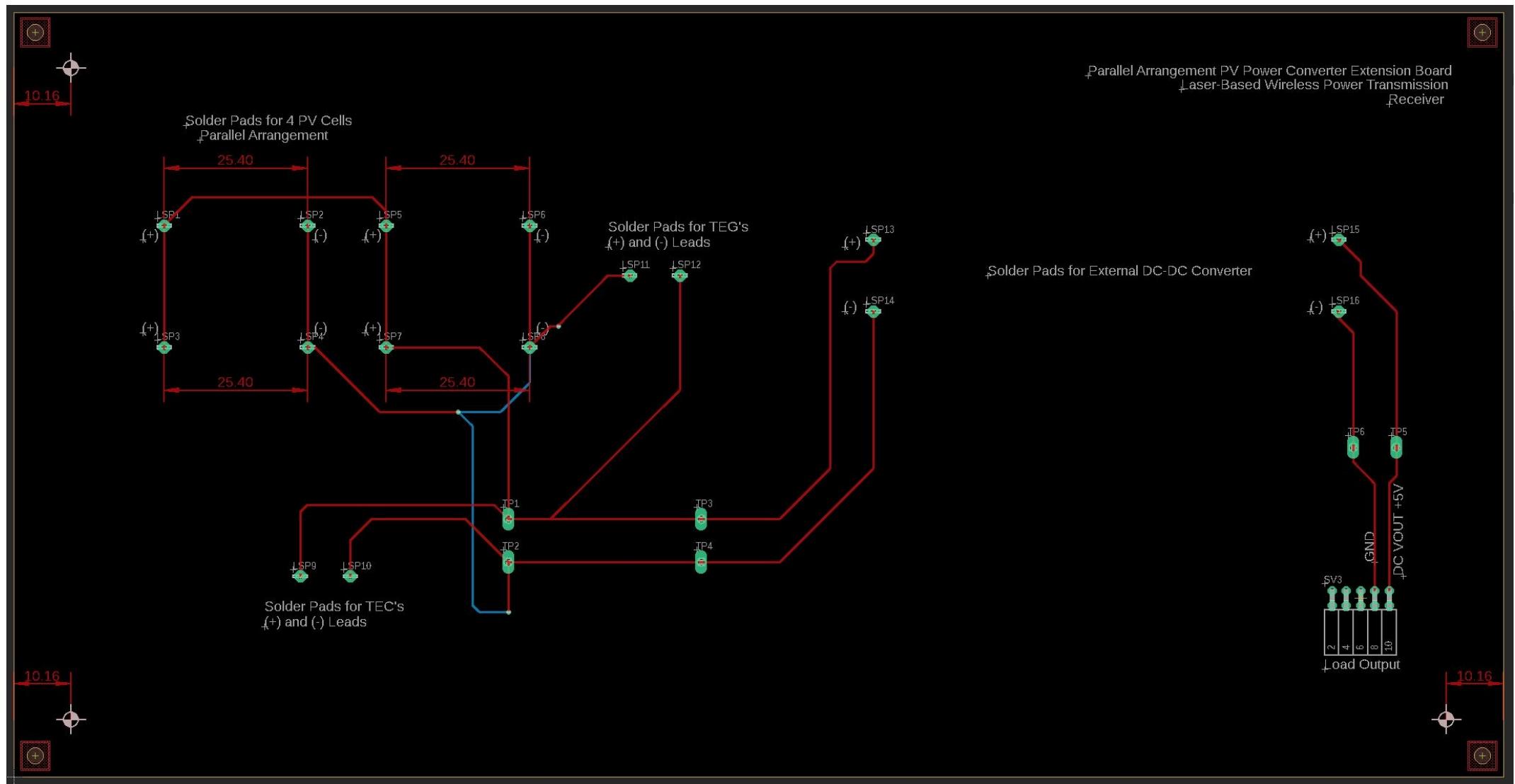


*Required Separately: Boost DC-DC Converter circuit: **2.43 V to 5 V**

8 & 9.



8 & 9.



Printed Circuit Board Design Standard Performance Considerations (IPC-2221A)

From IPC-2221A Specifications (May 2003):

- General Requirements on Trace Thicknesses and Tolerances (pg. 4)
- Local and Global Fiducials Clearance and Placement (pg. 34-36)
- Mechanical Mounting Hole Placement and Dimensions (pg. 33)
- Power distribution considerations (pg. 37)
- Method of heatsink mounting (e.g., adhesive bond, rivet, screw, etc.) to printed board (pg. 50-52)
- Fabrication: 8 Board Panelization (pg. 36)

(Source: [http://www-eng.lbl.gov/~shuman/NEXT/CURRENT DESIGN/TP/MATERIALS/IPC-2221A\(L\).pdf](http://www-eng.lbl.gov/~shuman/NEXT/CURRENT DESIGN/TP/MATERIALS/IPC-2221A(L).pdf))

PCB Fabrication: Panelization and Files Generation

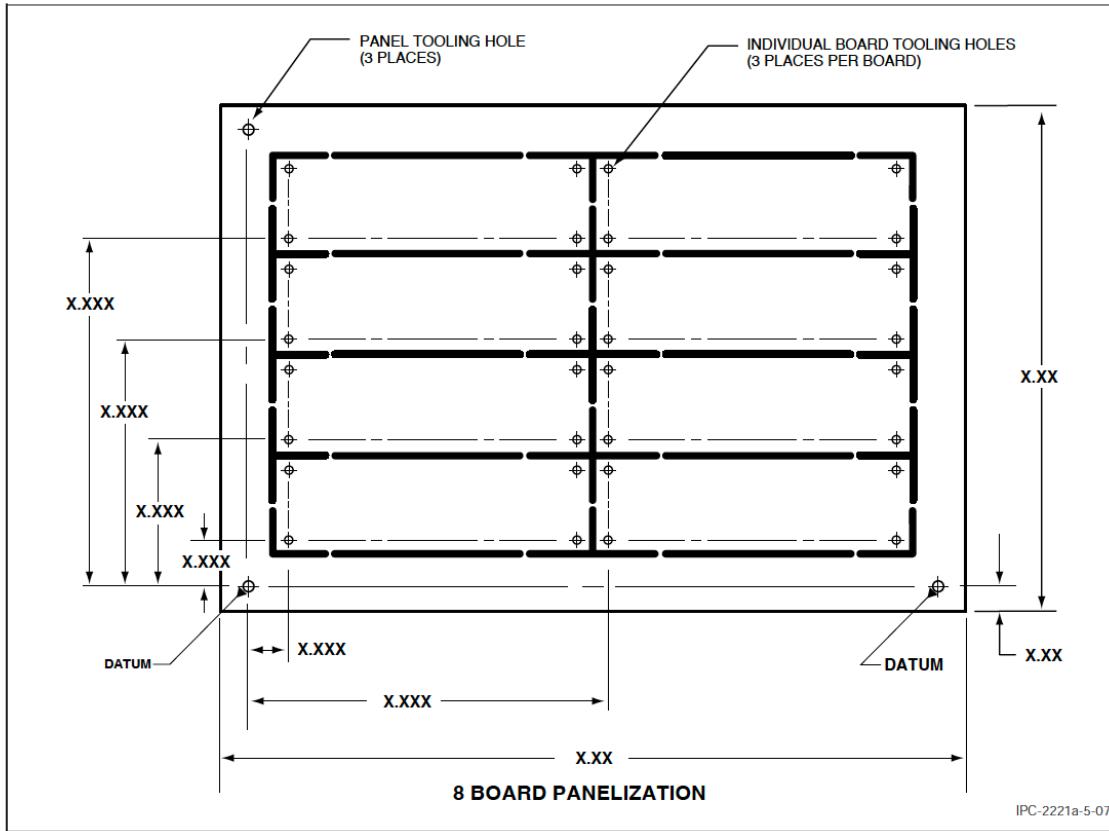


Figure 5-7 Fiducials, mm

Files Generation Requirements from EAGLE:

1. Download and store predefined CAM files (EAGLE Versions provided by JLCPCB)
2. Generate files for PCB fabrication:
 - 2a. Use CAM Processor in EAGLE
 - 2b. Load CAM Job File and Process Job
 - 2c. Locate ZIP File with Gerber and Drill Files with JLCPCB Naming Conventions
 - Delete unnecessary .gpi and .dri files
3. Download a 3rd-party Gerber Viewer Application for final inspection:
 - 3a. Export Gerber/Drill Files into a Gerber Viewer
4. Generate BOM and Centroid Files for SMT for Surface Mount PCB Assembly Service

(Source: <https://support.jlcpcb.com/article/137-how-to-generate-gerber-and-drill-files-in-autodesk-eagle>)