Power Distribution Unit (PDU)
ARG24 Fall Technical Report
December 16, 2023
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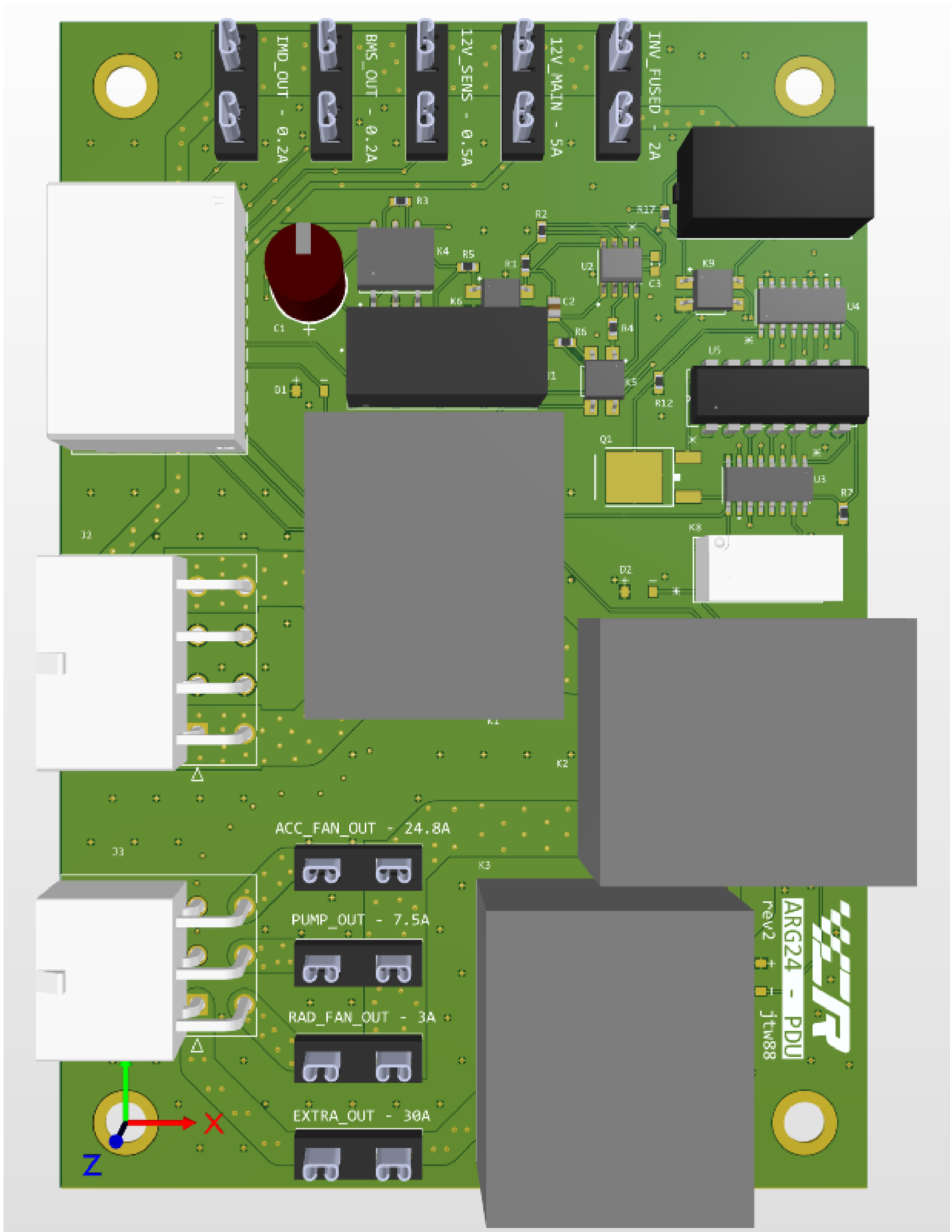


Subteam: Low Voltage
Subteam Lead: Jason Heller
Team: ARG24
Technical Team Lead: Arushi Nety

0. Introduction (10)

- The primary functions of the PDU are to control and deliver fused power to low voltage devices on ARG24 and switch power source between the low voltage battery and the DCDC. There is additional functionality for TSAL and Inverter control circuitry. Previously, this board was named the Fusebox, but due to the various features besides fusing on the board, a name change to Power Distribution Unit was deemed more accurate.
- This board is a necessary part of the car as it protects the low voltage system from overcurrent protection faults as outlined in rules
- <u>Rules:</u>
- EV.7.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.
- EV.7.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must:
    - Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or greater than the system voltage.
    - Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects.
    - Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects.
- EV.7.6.3 Each parallel element of multiple parallel battery cells, capacitors, strings of battery cells, strings of capacitors, or conductors must have individual Overcurrent Protection.

1. Technical Overview (don't explain your design yet, and do not carry out any analytical methods) (20)

- The current needed for different outputs is calculated or estimated by other part designers and put into the ARG24 Power Budget (see folder). This was used to determine trace widths and fuse ratings, as well as component ratings for relays. The trace widths are calculated using the SaturnPCB toolkit, while the fuses are sized based on the lowest fuse size above what is needed for the circuit but below the rating of the trace. The TSAL design was reused from last year as there were no schematic changes necessary. The inverter circuitry was constructed using relay logic according to the inverter specification sheets.

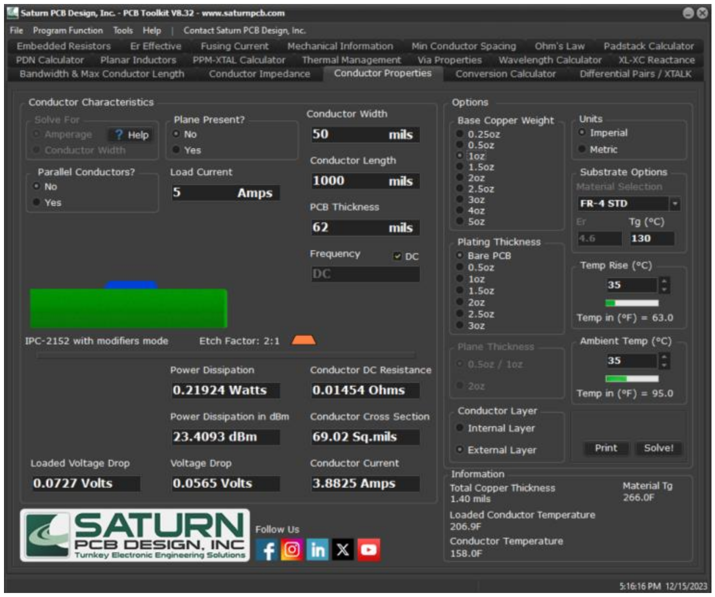


Figure 1: Saturn PCB Toolkit

2. History of Past Designs (don't explain your design yet) (10)

- Begins with a broad team history of your part/system (i.e., the general evolution of the system, mentioning the unique approaches used in the past, with citation).
- Before ARG15, an off-the-shelf fuse block and relay block were used in place of the fusebox. The team switched to a custom made fusebox as PCB CAD software became accessible. Current monitoring was also implemented for the first time. In ARG17, MOSFET relays were researched but decided against due to lack of appropriate testing. By ARG18, a custom fusebox was still a relatively new concept for the team, but had been decided as a worthy design part due to the size reduction compared to off the shelf fuseboxes. With the addition of the DCDC being a low voltage power source in recent years, off the shelf fuseboxes became infeasible as they were unable to accommodate switching between two power sources, meaning a board would be required just for switching power for a large off the shelf fusebox. On ARG22, an inverter power interrupt signal (IPIS) was added to the LV system to protect the motor inverter during car shutdown.
- Next, summarize the recent evolution of your part/system (which will pertain more to ARG24's interests). This should be a bit more specific, spending some amount of time to describe the large changes, and the results of how those parts/systems performed.
    - Discuss why the component selection has changed. This should create a coherent recent evolution path. Include pictures/CAD images and citations.
    - Relate this back to team goals. Why are parts changing?
- Again, this is (hopefully) a compilation of the summer prep, and should also have been part of your DCR/PDR/ADR, but this should require a little more explanation/citation.

3. Data (10)

- As with Jason Heller's ARG23 Fusebox design, most of the data that went into the design of the PDU had to do with the calculations of the trace widths for each trace that holds high current. Using the Saturn PCB Toolkit, I was able to calculate trace widths. I decided to use all four layers for high current traces as the LV battery and DCDC inputs were switched early on after entering the board. For both revisions of the board, we decided to go with a 1oz/1oz/1oz/1oz board, because it was able to withstand the current across four layers without majorly increasing the board size. We considered increasing trace width to 2 oz across all layers to reduce trace width even more but decided against this as it would be more expensive and would not result in significantly more space due to the relay sizes. The trace calculation results for each power input and output are below (across 4 layers, unless noted otherwise):

<u>Inputs</u>
BATT_IN: 250 mils (40.8 A)
DCDC_IN: 250 mils (40.8 A)

<u>Outputs</u>
ACC_FAN_OUT: 150 mils (30 A)
PUMP_OUT: 150 mils (30 A)
RAD_FAN_OUT: 150 mils (30 A)
EXTRA_OUT: 150 mils (30 A)
IMD_OUT: 10 mils (5.7 A)
BMS_OUT: 10 mils (5.7 A)
12V_SENS_FUSED: 10 mils (5.7 A)
12V_MAIN_FUSED: 30 mils (11.3 A)
KL15/KL30_BATT: 35 mils (6.2 A) (Only two layers for these outputs, all inverter power is collectively fused to 2 A)

- As for testing, a testing plan was developed to ensure the brought up boards fulfill all requirements [8]. This testing mostly consists of simulating input signals with a power supply, and ensuring that relays switch when they are supposed to. Additionally, the TSAL circuitry was tested to make sure the operating frequency was correct and that the frequency did not increase by a significant amount over the time of use. Lastly, IPIS logic was tested to make sure the inverter would receive the correct signals. The inverter datasheets were unclear and we will need to connect the PDU with the IPIS to confirm that what we have setup will safely and properly control the IPIS.

4. ARG24 Design(50)

- Much of my design follows the general idea of the designs that were present on ARG21, ARG22, and ARG23, with changes to allow the PDU to support the current goals of the team. All changes from the design last year are to pursue the team's goals of safety, improved design, reduced size, and better serviceability. As in

ARG23, I used the newer IPC-2152 formulas, which are more updated to allow for safer designs. This year, the DCDC converter of ARG23 is an OTS component mounted onto its own board which shares an enclosure with the PDU (the power distribution box or PDB), unlike last year when the DCDC was integrated with the fusebox. The PDU is able to switch between power coming from the DCDC and the LV battery, allowing us to alleviate the strain on the LV battery during endurance runs, because high current components will get their power from the accumulator rather than the LV battery. The PDU does not include current monitoring this year due to lack of data use in ARG23, although a blown fuse indicator was added in the second revision (unsuccessfully implemented). One final change on the PDU from the fusebox last year is the selection of connectors. The ARG24 PDU will use a Horizontal 20-pin D2100 (J1) and multiple Molex Megafits (J2, J3). This change was made to reduce board size and ease serviceability and assembly within the PDB.

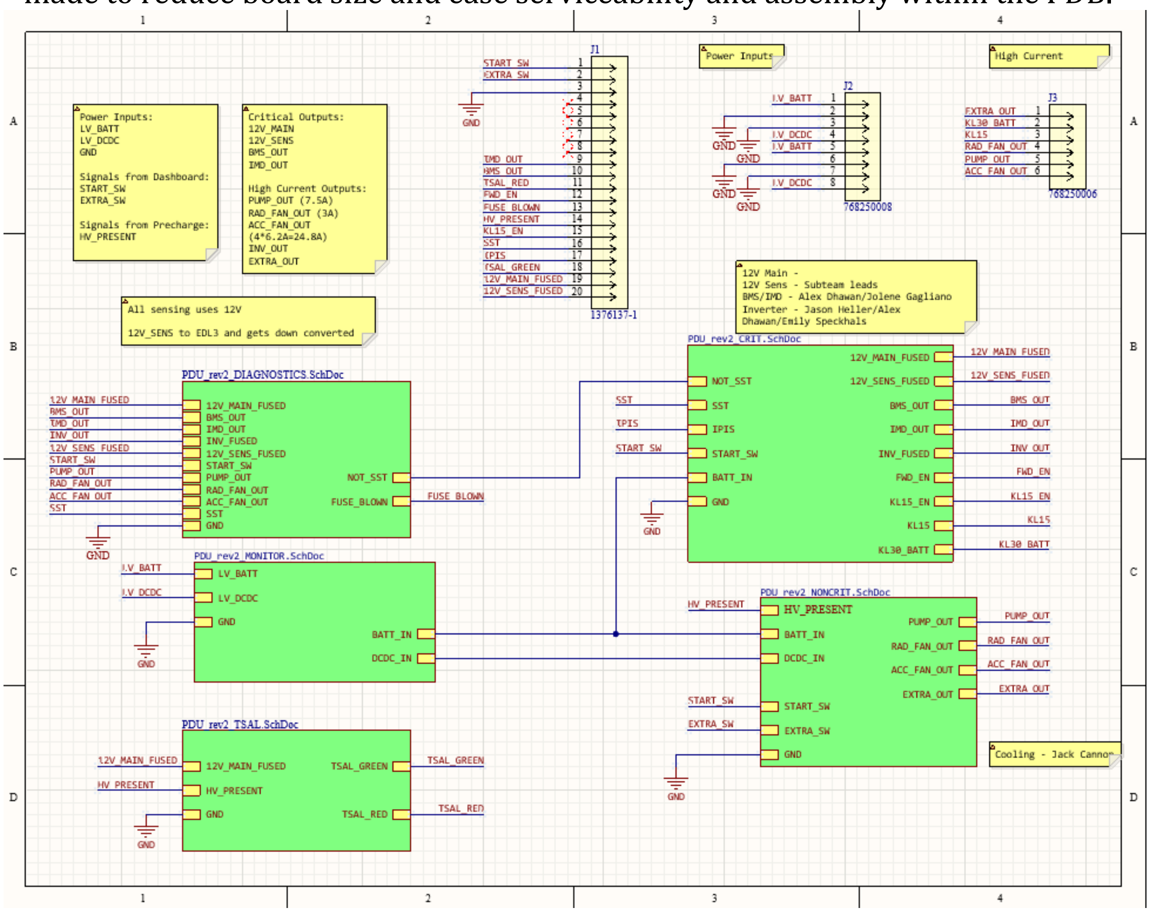


Figure 2: PDU Rev 2 Top Level Schematic

- For the critical power paths on the PDU (12V_MAIN_FUSED, BMS_OUT, IMD_OUT, 12V_SENS_FUSED, and INV_FUSED), all of the power comes from the LV battery. Because these are critical systems, they are not switched from the LV battery to the DCDC to ensure that the power is never interrupted. Every power path begins with a fuse, to satisfy the rule to provide overcurrent protection [1]. As with last year, there is circuitry to protect the inverter due to problems on ARG22 with killing the inverter when the car shuts down while at speed, and the inverter not having time to shut down before it loses power. Logic has been added to the PDU similarly to the ARG23 fusebox to protect the inverter (see bottom right of schematic below). In following the datasheet, the FWD_EN signal is switched from open to ground when the user wants the ability to drive, which is signaled by shutdown circuit being closed and start switch being enabled/high. This is controlled by a latching relay so that the START_SW does not have to stay on for the inverter to stay active and the shutdown circuit going open will open the circuit. KL30_BATT is the 12V constant voltage which is on when the shutdown circuit is closed and open when the IPIS signal is high. KL15 is switched 12V and also is on when the shutdown circuit is closed, open when the IPIS signal is high. Lastly, KL15_EN is safety switched 12V, when shutdown circuit is open KL15_EN is 12V, but when shutdown circuit is open KL15_EN is floating and the inverter declares a hardware gate fault and disables the PWM from the inverter. Altogether, the circuitry allows the inverter to turn on when shutdown circuit (SST) is closed and START_SW is high, disable PWM when SST is open, and turn the inverter off after the inverter is safe to fully turn off using the IPIS signal. This will hopefully protect the inverter from breaking similarly to our circuitry on ARG23.

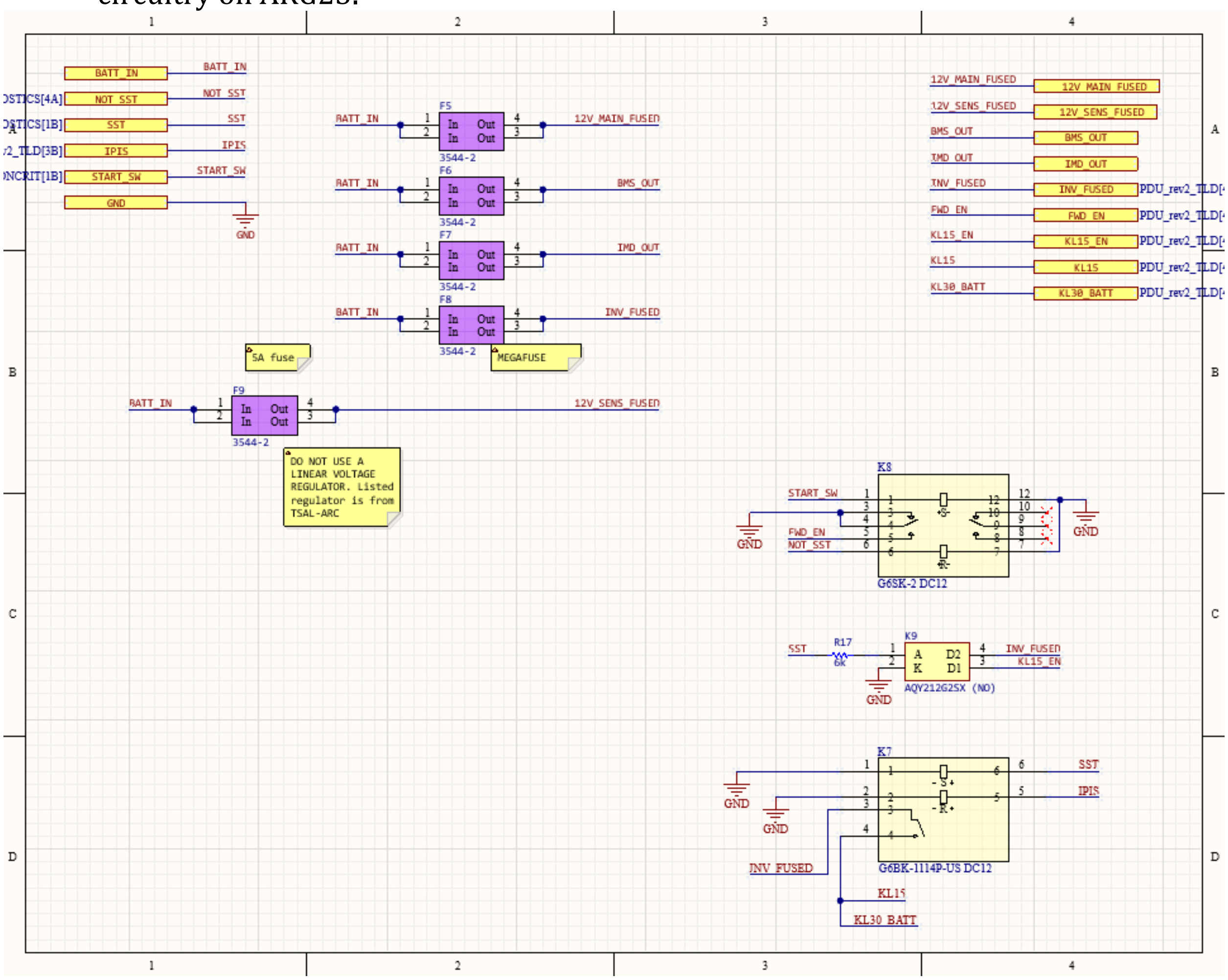


Figure 3: PDU Critical Schematic

- Next, the noncritical part of the schematic is the regulating circuitry for noncritical high current outputs. The signal from the precharge board, HV_PRESENT, provides the signal that switches the power from the LV battery to the DCDC power. This means that the pump, extra, radiator fan, and accumulator fan power lines will get power from the LV battery until HV is present, and then the power will come from the DCDC. This is done with 1 single pole double throw relay, that is controlled with the HV_PRESENT signal and outputs the NONCRIT_POWER_SEL signal. Next, the NONCRIT_POWER_SEL signal goes to two high current single pole single throw relays, one for PUMP_OUT, ACC_FAN_OUT, and RAD_FAN_OUT, one for EXTRA_OUT. The start switch signal START_SW controls whether or not the pump, accumulator fan, and radiator fan get their respective powers. The extra switch signal EXTRA_SW controls whether the EXTRA power line gets power. This line is reserved for any powered component that we have not accounted for yet, like test components that draw a significant amount of current.

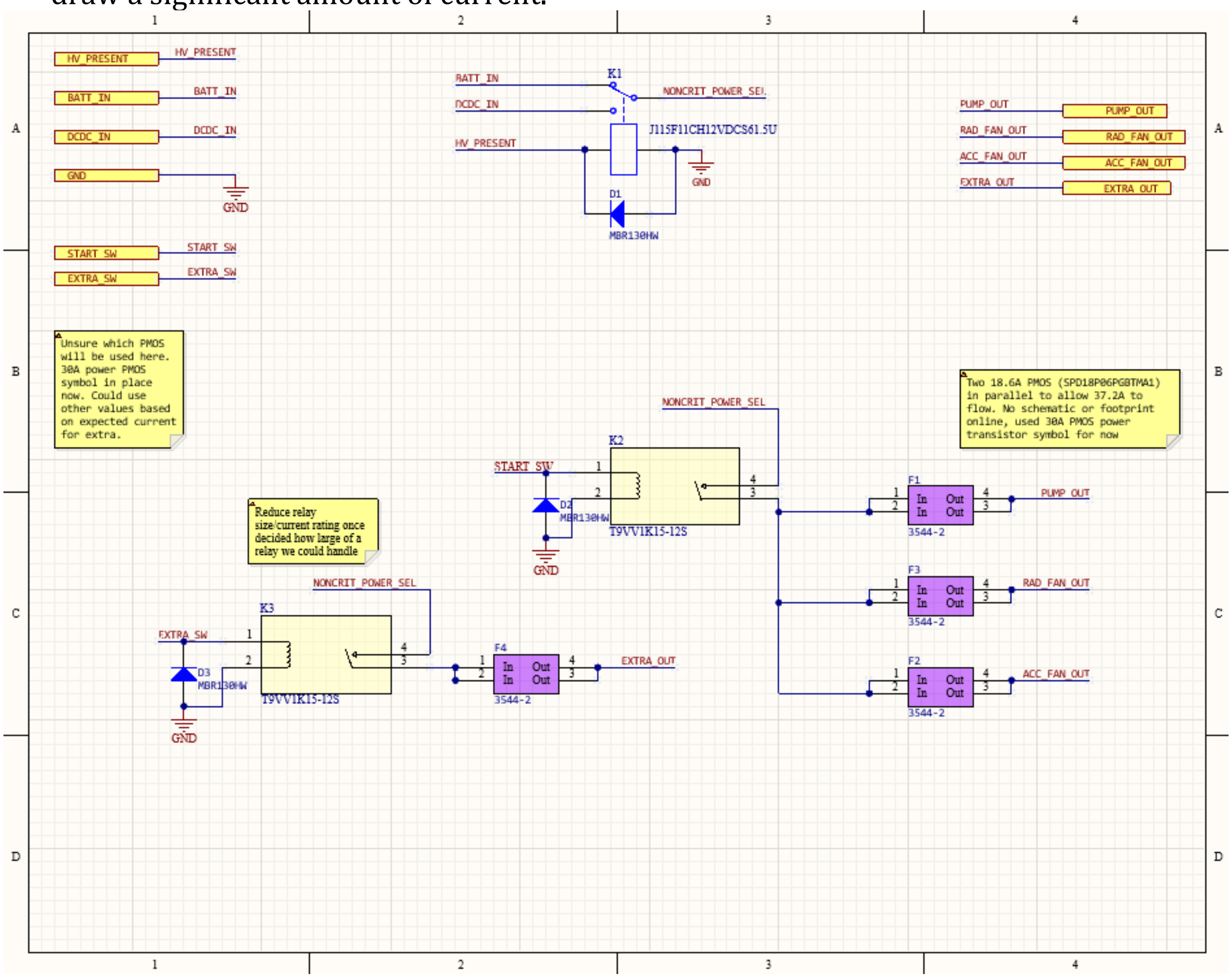


Figure 4: PDU Noncritical Schematic

- There was a diagnostics schematic added in the second revision to detect when a fuse is blown and send a signal to the ECU. All fused signals went through inverters then to an OR gate which was then output to ECU. In hindsight, one NAND gate could replace this setup although one single input single output inverter would be necessary for the inverter control signals mentioned previously. This did not work on the second revision of the PDU but is not system critical so will not be prioritized (not worth ordering a whole new board just to fix this issue).

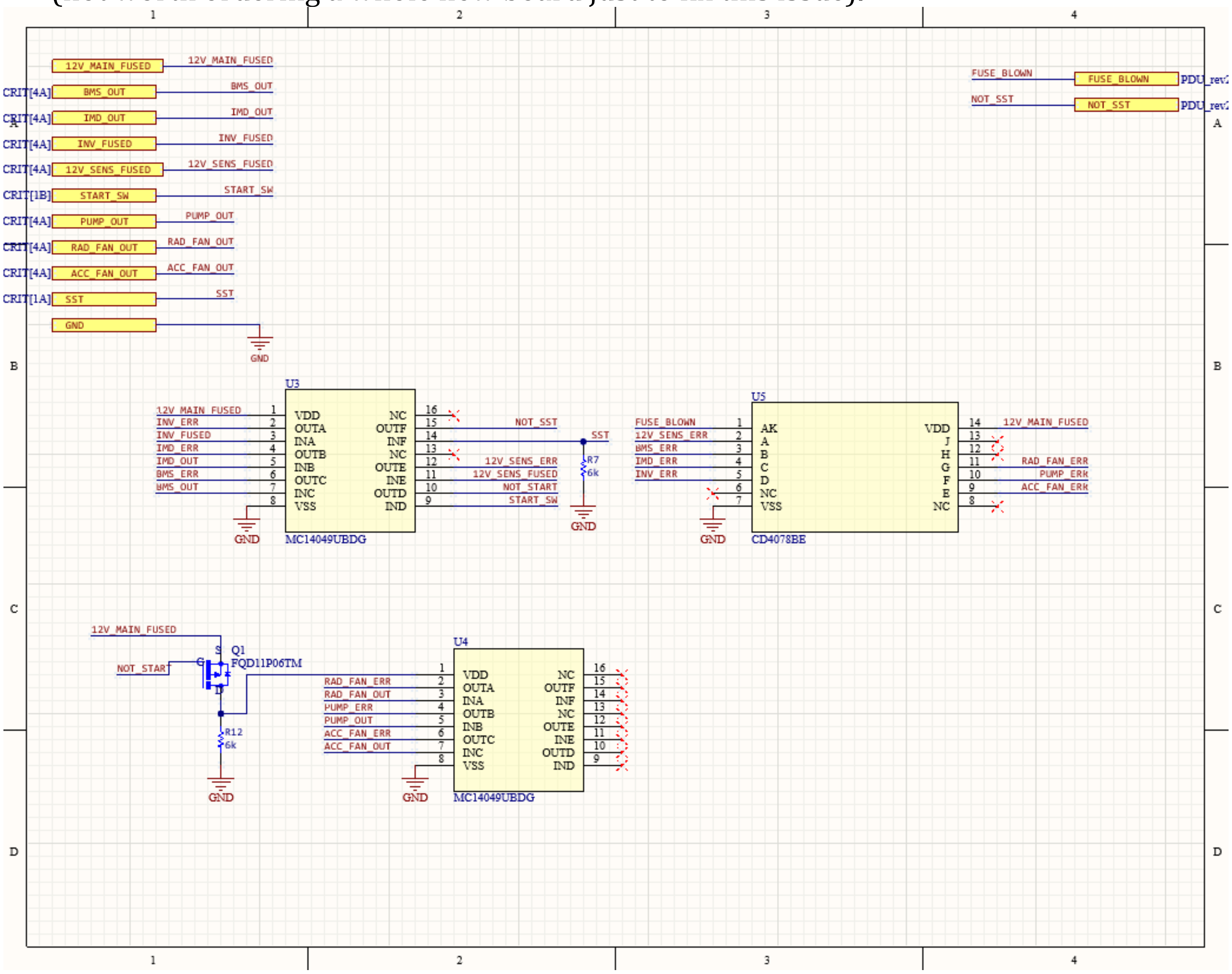
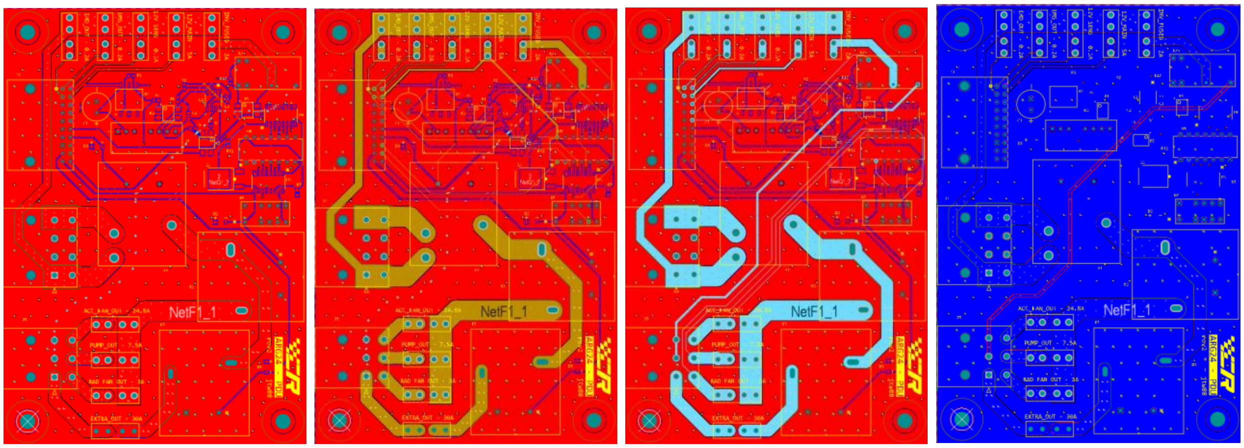
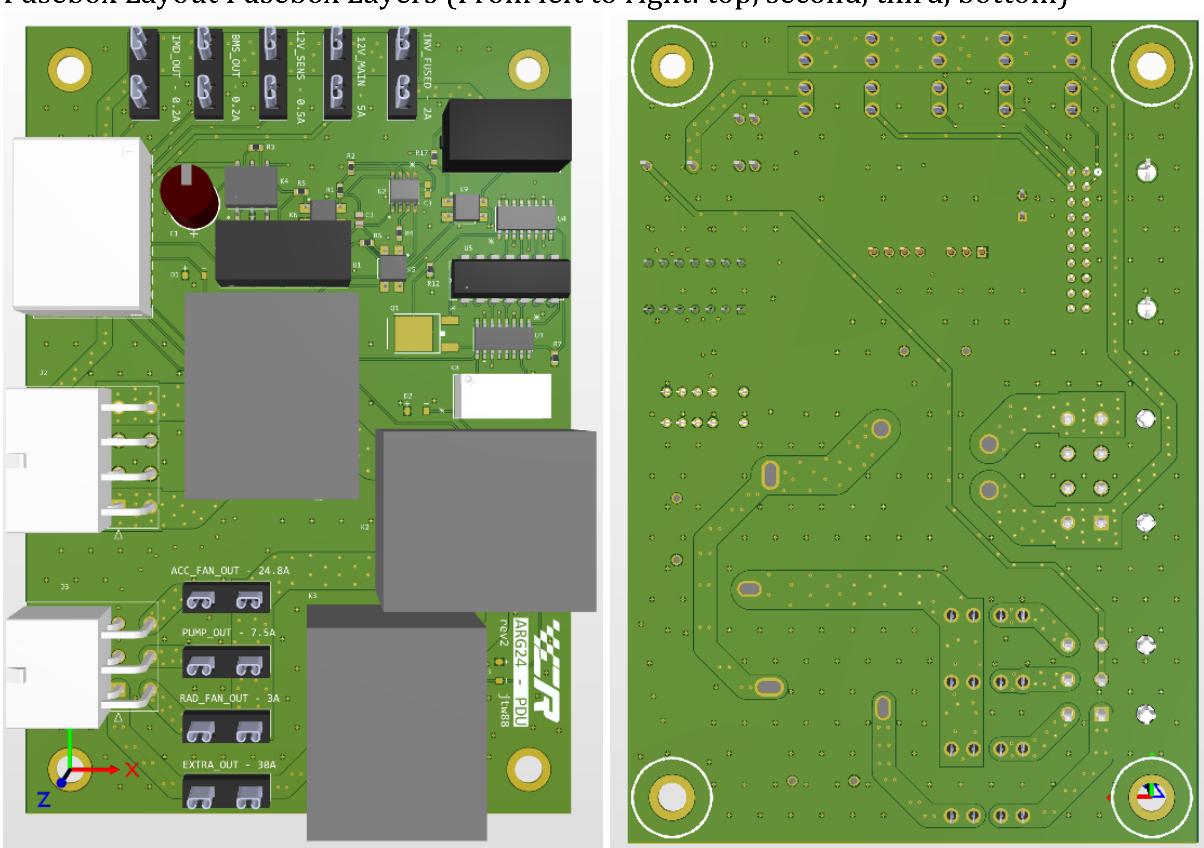


Figure 5: PDU Diagnostics Schematic

- For the layout, I used the trace calculations talked about earlier to determine how wide each trace should be. The traces span different combinations of all four layers, to make sure that each power trace can handle the currents. The vias on the power traces are to stitch the power across multi-trace layers, so the current is evenly distributed across them. In years previous to ARG23, because there was only one connector, the power traces had to loop around the board, making the layout very complicated. To allow for all connectors on one side of the board for ease of the enclosure design and assembly this year, we are using Molex Megafit connectors for high current inputs and outputs to reduce connector size and allow the power to flow in a loop. All of the traces not holding high current power are 10 mil, following standard PCB design techniques. Each fuse block has a label on it on the silkscreen to make it easier to replace the fuses in the case of a blown fuse. There is also a ground pour on the top and bottom layers to connect all of the ground nets.



Fusebox Layout Fusebox Layers (From left to right: top, second, third, bottom)



Fusebox 3D Model Top (Left) and Bottom (Right)

Fusebox Bringups (Revision 1 left, Revision 2 right)

5. Components Overview

Rev	Part Description	Seller PN	Manufacturer PN	Board QTY	Unit Price	Inventory	Designator(s)
1	CONN HEADER VERT 12POS 2.5MM	A29812-ND	1318126-2	1	$4.26	0	P1
1	45A HORIZ. (BOT) RA LP CONTACT	2243-1336G1-ND	1336G1	9	$1.10	10	J1, J2, J3, J4, J5, J6, J7, J10, J11
1	45A HORIZ PCB RA CONTACT 1=1PC	2243-1337G1-ND	1337G1	4	$1.44	10	J8, J9, J12, J13
1	RELAY GEN PURPOSE SPDT 50A 12V	2449-J115F11CH12VDCS61.5U-ND	J115F11CH12VDCS61.5U	1	$4.12	0	K1
1	RELAY GEN PURPOSE SPST 40A 12V	PB2352-ND	T9VV1K15-12S	2	$7.73	0	K2, K3
1	SSR RELAY SPST-NC 1A 0-60V	212-LCB710SCT-ND	LCB710STR	1	$5.61	0	K4

1	SSR RELAY SPST-NO 1.25A 0-60V	255-6062-1-ND	AQY212G2SX	2	$5.38	0	K5, K6
1	FUSE BLOCK BLADE 500V 20A PCB	36-3544-2-ND	3544-2	9	$0.78	3	F1, F2, F3, F4, F5, F6, F7, F8, F9
1	DIODE SCHOTTKY 30V 1A SOD123	1655-MBR130HWCT-ND	MBR130HW	3	$0.38	0	D1, D2, D3
1	DC DC CONVERTER, 1W,12VDC	2725-UWF1212S-1WR3-ND	UWF1212S-1WR3	1	$8.29	4	U1
1	IC OSC SINGLE TIMER 3MHZ 8-SOIC	296-40262-1-ND	LMC555IMX/NOPB	1	$1.66	8	U2
1	RES 2K OHM 5% 1/10W 0603	311-2.0KGRCT-ND	RC0603JR-072KL	1	$0.10	20	R1
1	RES 240K OHM 5% 1/10W 0603	311-240KGRCT-ND	RC0603JR-07240KL	1	$0.10	18	R2
1	RES 6.04K OHM 1% 1/8W 0603	RNCP0603FTD6K04TR-ND	RNCP0603FTD6K04	3	$0.10	10	R3, R4, R5
1	RES SMD 10K OHM 5% 1/4W 0603	RHM10KDCT-ND	ESR03EZPJ103	1	$0.13	21	R6
1	CAP ALUM 100UF 20% 50V RADIAL	399-6621-ND	ESW107M050AG3AA	1	$0.41	0	C1
1	CAP CER 22UF 25V X5R 0805	1276-CL21A226MAYNNNECT-ND	CL21A226MAYNNNE	1	$0.25	2	C2
1	CAP CER 1UF 25V X7R 0603	311-1802-1-ND	CC0603KRX7R8BB105	1	$0.24	4	C3
2	CONN HEADER R/A 20POS 2.5MM	1376137-1	1376137-1	1	$7.48	0	J1
2	CONN HEADER R/A 8POS 5.7MM	WM11972-ND	768250008	1	$3.82	0	J2
2	CONN HEADER R/A 6POS 5.7MM	WM11971-ND	768250006	1	$2.96	0	J3

2	RELAY GEN PURPOSE SPDT 50A 12V	2449-J115F11CH12VDCS61.5U-ND	J115F11CH12VDCS61.5U	1	$4.12	0	K1
2	RELAY GEN PURPOSE SPST 40A 12V	PB2352-ND	T9VV1K15-12S	2	$7.73	0	K2, K3
2	SSR RELAY SPST-NC 1A 0-60V	212-LCB710SCT-ND	LCB710STR	1	$5.61	0	K4
2	SSR RELAY SPST-NO 1.25A 0-60V	255-6062-1-ND	AQY212G2SX	3	$5.38	0	K5, K6, K9
2	FUSE BLOCK BLADE 500V 20A PCB	36-3544-2-ND	3544-2	9	$0.78	3	F1, F2, F3, F4, F5, F6, F7, F8, F9
2	DIODE SCHOTTKY 30V 1A SOD123	1655-MBR130HWCT-ND	MBR130HW	3	$0.38	0	D1, D2, D3
2	DC DC CONVERTER, 1W,12VDC	2725-UWF1212S-1WR3-ND	UWF1212S-1WR3	1	$8.29	4	U1
2	IC OSC SINGLE TIMER 3MHZ 8-SOIC	296-40262-1-ND	LMC555IMX/NOPB	1	$1.66	8	U2
2	RES 2K OHM 5% 1/10W 0603	311-2.0KGRCT-ND	RC0603JR-072KL	1	$0.10	20	R1
2	RES 240K OHM 5% 1/10W 0603	311-240KGRCT-ND	RC0603JR-07240KL	1	$0.10	18	R2
2	RES 6.04K OHM 1% 1/8W 0603	RNCP0603FTD6K04TR-ND	RNCP0603FTD6K04	3	$0.10	10	R3, R4, R5, R7, R12, R17
2	RES SMD 10K OHM 5% 1/4W 0603	RHM10KDCT-ND	ESR03EZPJ103	1	$0.13	21	R6
2	CAP ALUM 100UF 20% 50V RADIAL	399-6621-ND	ESW107M050AG3AA	1	$0.41	0	C1
2	CAP CER 22UF 25V X5R 0805	1276-CL21A226MAYNNNECT-ND	CL21A226MAYNNNE	1	$0.25	2	C2

2	CAP CER 1UF 25V X7R 0603	311-1802-1-ND	CC0603KRX7R8BB105	1	$0.24	4	C3
2	MOSFET P-CH 60V 18.6A TO252-3	SPD18P06PGBTMA1CT-ND	SPD18P06PGBTMA1	1	$1.36	1	Q1
2	IC INVERTER 6CH 1-INP 16SOIC	MC14049UBDGOS-ND	MC14049UBDG	2	$0.65	2	U3, U4
2	IC 8-IN NOR/OR GATE 14-DIP	296-3521-5-ND	CD4078BE	1	$0.74	0	U5
2	RELAY GEN PURPOSE SPST 5A 12V	Z2596-ND	G6BK-1114P-US-DC12	1	$9.54	1	K7
2	RELAY TELECOM DPDT 2A 12V	Z2663-ND	G6SK-2 DC12	1	$4.67	1	K8

6. References

[1] Formula SAE Rules 2023 Version 2.0, 2022

[2] Saturn PCB Toolkit

[3] Standard for Determining Current Carrying Capacity in Printed Board Design, IPC Standard IPC-2152, 2010

[4] *Fall Technical Report* [Fusebox], Elliot Sotnick, ARG18

[5] *Fall Technical Report* [Fusebox], Lindsay Vincent, ARG20

[6] *Spring Technical Report* [Fusebox], Sophia Franklin, ARG22

[7] *Fall Technical Report* [Fusebox], Jason Heller, ARG23

[8] J. Wilcox, “S:\Reports\2024 Car\Fall Technical\Powertrain\LV\PDU\PDU_Rev2a_Testing_Plan_2.pdf”