University of Waterloo Formula Electric Formula Hybrid 2024

Year in Review

Department of Mechanical and Mechatronics Engineering

A Report Prepared for:

The University of Waterloo

Prepared By:

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Figure 1: 2023 WFE (Waterloo Formula Electric) Team Photo

Figure 2: 2023 WFE (Waterloo Formula Electric) Vehicle Side Profile

The 2023 WFE team had been iterating on a similar vehicle platform since ~2019/2020. The team experienced tremendous disruptions during the COVID-19 pandemic but was able to emerge with a somewhat working vehicle in 2022 which was then refined in 2023. The 2023 platform used a 70s7p Samsung 30Q Accumulator, with dual rear Emrax 208 MVs being run independently by their own Sevcon Gen5 Size9 inverters. The team came 5th place in 2023, performing relatively well in autocross and acceleration despite some immense hiccups. A hub was broken the day before competition which also damaged the wheel speed sensors meaning the traction control algorithm which was necessary for the vehicle was useless. A new hub had to be manufactured mere hours before competition. Additionally at competition there was an insulation failure inside the motor due to water ingress which meant in the endurance event the vehicle faulted after a small number of laps.

Figure 3: Permanent Magnet side of Emrax 208 Motor that failed (notice significant orange residue (rust), indicative of water ingress)

Figure 4: Coil side of Emrax 208, insulation tests showed arcing between case and coils due to insulation degradation around the windings.

2 Formula Electric Plans for 2023/2024

Given Justin Vuong and I (Owen Brake) would be graduating in 2024, it was determined that if a vehicle platform change were to occur it needed to occur in 2023/2024. The primary goal was to transition the entire vehicle towards FSAE Electric Michigan compliance so we could compete in that competition which had significantly higher participation rate.

Given the change to a new competition with new rules, it became necessary to redesign the accumulator, one of the things we aspired to do was improve serviceability of the accumulator as well as increase the capacity. For the FSAE Electric Michigan competition there is no energy limit, so our goal was to be able to drive the endurance event as fast as we could drive the autocross event. Additionally looking at increasing the voltage to 600V for improved efficiency was a specific goal of mine.

3 Merger

In the 2023/2024 season the Waterloo Formula Electric team merged with UWFM (University of Waterloo Formula Motorsports) Waterloo's internal combustion FSAE team.

3.1 Leadership Structure

The leadership structure was initially setup as follows.

Title	Lead Name
Technical Lead	Owen Brake
Project Manager	Sophia Chen
Accumulator Box Lead	Chris Tseng
Accumulator Segment Lead	Rohan Sharma
Aerodynamics Lead	Jonathan Pileggi
Business Lead	Renuka Ravinder & Alex Chen
Chassis Lead	Taras Rawlinson & Zach Zammit
Electrical Lead	Ameena Abdulaziz
Firmware Lead	Justin Vuong
Powertrain Lead	Tarj Tandel
Suspension Lead	Morgan Judiesch

Table 1: Initial leadership structure

Though as will be discussed later, most of the people listed in this leadership structure would not be on the team or a lead by the end of the year.

3.2 Merged Team Dynamics

The initial merger was very rough, there was significant conflict over very small logistical issues and certainly a strong tribalism on the team between the old WFE and old UWFM team.

3.3 Effect on Vehicle Design

The effect of the merger on vehicle design was certainly non-trivial. A lot of components were significantly lighter, the chassis was more refined, the suspension was more advanced, the powertrain got a differential and generally more mechanical analysis was performed.

Part II

Year in Review

4 Vehicle Design

The 2024 vehicle was a 140s6p Samsung 30Q accumulator pack, with a single Cascadia CM200DZ driving an Emrax 228 MV.

Figure 5: Side of vehicle driving in testing

The new vehicle design I would say is overall quite a success, the accumulator performs well under loads, never reaching much above ambient temps in our testing. The new suspension and chassis had significantly improved handling of the vehicle. The acceleration of the vehicle when it's properly driving in testing is tremendous. Overall the new platform seems to be a successful transition and a performant new vehicle package.

5 Timelines

Timelines for the vehicle at the start were known to be very aggressive, previous alumni suggested that a 2 year design cycle was required to achieve a proper vehicle. My concern with this was that people would be a little too relaxed, and in the 2nd year all the real work would occur, additionally missing a competition can be very detrimental to a team in terms of member retention. Overall the timelines certainly slipped tremendously, the first testing event only occurred the day before we left for competition which overlapped with the pre-tech day.

6 Team Dynamics

It took a significant amount of time, but eventually the team was able to band together as a single unit and at competition the lines between UWFM and WFE really blurred and people were able to work better together as a team. I think having team social tremendously accelerated this process, often when working on a design team we can get caught up in the tribal politics and the small conflicts, when you see someone outside this workspace you begin to see them as a real human being. Things like pub crawls and trivia nights really improved team cohesion I believe and I think this should continue moving forward.

Figure 6: UWFE team winning Pub on King trivia night

7 Team Performance / Knowledge Transfer

7.1 Team Development

Over the 2023/2024 season the team did develop. The mechanical analysis of the team seems to have improved over previous years, though there is still considerable room for improvement especially in terms of systems level design. The electrical understanding of the team has seemed to decline over previous years due to the loss of some critical alumni.

From my perspective it seems that a lot of the younger members (<4A) have developed fairly decent execution skills in terms of they can follow explicit instructions and execute them, but this is only part of the equation of engineering. As a manager or system designer, you need to know what problems to anticipate and what problems to tackle. The knowing what to do is something the team needs to develop it's skills in. Additionally as is a common thread throughout this report, the validation side is underdeveloped, the team needs to develop their skills to ensure we're delivering a finished product that provably works, not just a product that seems like it should work.

7.2 Knowledge Transfer

There has been a lot of requests throughout this year to improve knowledge transfer. To this end, I am at a bit of a loss. In 2022/2023 I tried to do lessons on the Accumulator and Powertrain, I spent many hours developing these lessons and publishing them on my youtube channel. This yielded minimal results, my lesson from 2022/2023 season was telling people something is not how they learn. Using purely empirical observations the best members on the team historically got there by doing tasks, by working on the thing you get a better understanding of it. So part of my attempts for this 2023/2024 season was to be hands off in certain parts so the students could develop their skills to be better prepared for the future. For certain highly technical challenges which were impossible to be solved by the team I would hop in (cell fuse tester, cell testing, state of charge estimation, pack selection, etc.) but my goal was to be hands off. This relatively failed, I think as I was still on the team there was still an understanding that I could be used as a crutch. For example, simple things like: ESF comment responses, Powertrain + Accumulator cable sizing, procurement, inverter + motor selection were often left to me to solve rather than independent investigations and learning occurring. I would try to put off these tasks, but in the end based on timelines I had to expedite and complete them.

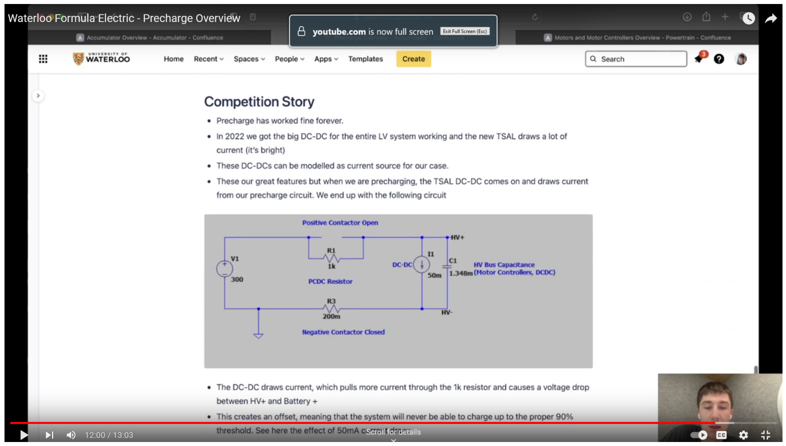

Figure 7: Screenshot of youtube video I (Owen) prepared to describe how precharge works Youtube Channel

Going forward I am not sure what the cure to this is. I think based on previous experience, it is true that people only learn when they're working on said task. Perhaps the team will develop significantly better skills when they're on the hot seat and don't have any more crutches to lean on, it's possible. I know the team is going to try to use Notion for documentation and project tracking purposes. I think this is a fine suggestion the one warning I would provide based on previous experience is that the team is extremely human resource limited. Often for PM work and documentation development the burden is placed on the most technically developed students, this means less work gets done on the car, and by less work I mean a lot less work. We used to use JIRA and a large percentage of the work of a lead every week was updating JIRA tasks no one would ever read, it would occasionally help with documentation but was incredibly time consuming and usually documentation efforts were poor.

7.3 4th Year Dilemma

One thing that happened in this 2023/2024 season was something we've not seen before on the Formula Electric team because we haven't really had a cohort of 4th years in a while due to the pandemic. What occurred this year is there were a bunch of fairly skilled 4th years who would work on their tasks and many even led subteams, but a few months into the 4A term they dropped off the team. Each member has there own specific reasons but in general the factors are: FYDP, difficult courses, grad trips, 4th year life. From my own personal experience being in 4th year and working on the team was incredibly difficult. I chose difficult courses and a very difficult FYDP, trying to balance these efforts with team work was incredibly difficult, it took a tremendous physical toll on me which most students would not tolerate, they'd simply drop it.

The issue of 4th years dropping off the team is 2 fold. Primarily they are the most skilled, and losing them on the team means the team is going to perform worse because we lack their knowledge and skills, this affects design, manufacturing and system integration. The secondary reason this is an issue is 4th years might take on a bunch of responsibility, do some work, then leave the team and now the rest of the younger members have no insight into the analysis or decisions made in that component. This means when it comes to manufacturing or system integration or design discussions, the team is fairly lost.

The question of how to deal with this is tricky. One argument, which is what the Rocketry team did this year, was you get the 4th years to enter an advisory role, they are hardly involved on the team at all, not really performing any analysis except in hard edge cases, they are just giving the team advice when they come to them. This means the 4th years can stay on the team without feeling a huge work burden, and the younger cohort can develop their skills. I think this strategy is the most appealing, but depending on the composition of the 4th year cohort and younger generation it may mean the vehicle does not go to competition because the team lacks the skills from said 4th years. Another strategy is you just get 4th years to do an easy FYDP (or coast on their own FYDP), take relatively easy technical electives and then they'll have time to work on the team. This strategy requires the consent of said 4th years, which might be difficult to get, but in practice most 4th years take easy courses and coast or do an easy FYDP so this is still a viable method. In the end I don't have any answers here, it's a phenomenon I observed this year, I think it's probable it will occur next year as well and I don't have any clear answers or guidance, hopefully they stick around.

Part III

Formula Hybrid 2024

8 Lead up to Competition

The lead up to competition was a very difficult time. The car was not in a ready state at all. The high voltage cabling for the powertrain was not complete until $<$10 days before competition and as will be discussed later it was not properly done at all and a workaround to partial completion was performed at competition. Accumulator rules compliance, with things like stickers, TSMP connections, charging, etc. were not completed until $<$7 days before competition. The segments itself weren't properly fitted into the box until ~10 days before competition.

Much of this delay stems from a significant amount of work being completed by 4th year students (Justin and I) who were blocked by FYDP symposium deadlines and exams through late March-Early April. Unfortunately the team has a significant knowledge gap in many areas, primarily system integration so most things are not completed unless we are working on them.

The first testing event where the vehicle moved forward occurred on April 27th (the day before we were supposed to be at electrical pre-tech). We would drive up the next day and miss electrical pre-tech so we could have this day of testing which was very helpful but it also put us on a slower timeline through inspections.

Figure 8: Pre-comp testing (day before departure)

9 Competition

Before going into the intimate details of competition I'd like to start with a broad overview of how insane competition is so we can do better going forward. Justin and I would do 20-22 hour shifts and would alternate naps of 2-4 hours every single day for the entirety of competition. Before driving ~10-12 hours to New Hampshire I got about 4 hours of sleep. This insane level of sleep deprivation is incredibly unhealthy and unsafe, Justin and I both experienced significant physical effects including visual and audio hallucinations, headaches, body pain, incredible mental stress and incredible fatigue. My hope is going forward at future competitions the team does not have to experience this, but I suspect this is to be expected going forward otherwise the team will fail.

9.1 Changes made at Competition

I don't wish to go in to tremendous detail. But effectively, as has happened in previous years, there were non-trivial changes made at competition, this is something the team should be avoiding. Namely: Phase Cable Box, LiPo mounting, motor grounding, grounding wires, suspension grounding, energy meter, etc. A significant amount of time was spent making changes at competition to vehicle design, pretty much everything listed was possible to anticipate and could have been avoided with more proper planning, use of time and proactivity.

9.2 Inspection

All inspections went pretty smoothly. The mechanical team did a great job and breezed right through mechanical tech, it was indicated to me that the judges were significantly more relaxed than last year given last year we got dinged for a bunch of minor things.

Figure 9: Taras applying mech tech sticker

For electrical tech it's important to consider that at Formula Hybrid there are 2 sets of judges, the strict ones and the relaxed ones. Last year we got a relaxed one who skipped almost every single test, this year we got the head, hardest judge, Tremont Miao, he used to work at Analog Devices. At one time he brought up "I wrote this rule to prevent....".

We failed electrical pre-tech for 2 main reasons: failure to ground suspension, and failure to properly discharge. The failure to ground suspension is discussed later, it's a fairly understandable lapse in rules non-compliance, the team now knows about it and is working to correct this. The failure to properly discharge stems from 2 main source: phase cable box installation and PC/DC relay schematic change. As is discussed later, the phase cable box installation generated a tremendous amount of EMI which likely induced an additional magnetic field which kept the relay open, the reason this hypothesis is stated is this behaviour of failure to discharge in an appropriate time did not occur until the phase box was installed, additionally, it only occured at "Ready to Drive" not at the HV (Energized) state. The PC/DC relay schematic change is an additional necessary change to ensure discharge under any possible condition.

Figure 10: Electrical Pre-tech documentation discussion with Tremont Miao

Figure 11: Electrical Pre-tech demonstration with Tremont Miao (TSAL failing to discharge in time)

Justin and I worked hard to remedy the 2nd issue, while the suspension team worked hard to get relatively good grounding. Eventually we were able to breeze through pre-tech again, then we progressed to electrical tech. Electrical tech went quite smoothly but we failed during the testing phase, when we would bring the car to Ready to Drive it would almost immediately fault. This stems again from the phase box installation which generated a tremendous amount of EMI such that the car could not stay at Ready to Drive stably for more than a few seconds without faulting. We got permission to run the car on the stands, brought it back to the garages, performed some voodoo magic and got it to work. As a side note one of the voodoo magic tricks I performed was I randomly just removed the motor thermistor connection to the inverter and the car developed some sense of nominal stability and could work for more than a few seconds without faulting. I hesitate to state with significant confidence the reason behind this but it's likely EMI by conduction through improper grounding which is connected to the issue of the motor being poorly grounded.

Once the EMI issue was "tempered" we went back to electrical inspection and breezed right through it.

Then was the rain test, which the car passed with seemingly no issues.

For the noise test, given the addition of the 2nd buzzer to the car, as we marginally passed last year, we seemed to pass with sufficient margin.

For the tilt test there were some issues though I do not have a ton of visibility on this as I showed up late. To my understanding with the current vehicle setup the car had a marginal amount of tilt at maximum angle of the tester. This was remedied by removing some air from the tires and playing with some suspension configurations to yield a car that did pass tilt to the satisfaction of the judges, supposedly this is legal and after that test you can then fill the tires again and retune the suspension, which is odd to me, but they accepted it.

Figure 12: Tilt test of vehicle

Figure 13: Demonstration of failed tilt test of vehicle (note visibility under right rear wheel)

The brake test took some time, it was partially due to the EMI issues causing the vehicle to fault at the start line, it was partially due to triggering the BOTS when the brakes were slammed and perhaps also due to some soft brake lines. Eventually though we were able to lock all 4 wheels and the car passed the brake test.

Figure 14: Team getting ready for brake test

Finally we were all certified and all the remained was egress which was relatively simple given the car cockpit has significantly more room and at Hybrid we had no sidepods or diffusers so there was no big need to jump.

9.3 Design Event Performance

The design event we performed relatively poorly at. We did make it to design finals but performed quite poorly if I recall in the design finals. I believe this stems from a lack of proper understanding from the broad spectrum of the team on overall system design and electrical fundamentals. During the design event I was often called over by people to explain things to judges that are relevant to their own specific subteam. Going forward the team leads need to ensure they fully understand their own subsystems to a deep level, understand why each decision was made, why these cells, why this gear ratio, etc.

Figure 15: Design event discussions

I think going forward if you want to be proper in the design presentation here is what you need to do. Prepare a 10 page document on overall vehicle design, begin with what points we are trying to collect, lap sims, overall system analysis. Then breakdown into system level accumulator speccing, powertrain speccing, suspension components. Finally you can break down into hyperspecifics, how do you ensure accumulator temps are low enough, how do you run your state of charge algorithm, what's the efficiency of your powertrain, field weakening, regenerative breaking. All these things with the perspective of overall vehicle design and winning a competition is what they want to see, so I think it's important to prepare this document with data as speaking off the top of your head is difficult and the judges (Tesla judges) want to see hard data to prove your decisions.

The team does a bunch of really cool technical things which other teams do not do: custom BMS, custom state of charge algorithm, cell impedance testing, segment cooling data, custom segments, fully distributed custom

ECUs, traction control, CAN logging, endurance mode, etc, etc. We always seem to get design finals because we do cool things the team is just not prepared for design finals because the subteam leads don't fully understand their own subteam, they don't have a full view of how their subsystem integrates with the whole and the real question of "why?".

9.4 Dynamic Performance

The team performed relatively poor in dynamic events.

The team was able to get 1 acceleration run in, due to the EMI issues the driver was instructed to take it easy at low speed as this was known to trigger EMI issues, so the acceleration off the mark was quite slow, and the result was something like 5.5s.

The team was not able to get a full autocross lap in, the team seemed to be moving quite quickly but the car would fault very likely due to these EMI issues.

Justin and I worked through the night and day after the acceleration and autocross events to get a working endurance run, and we did successfully implement a firmware workaround on the car such that it would not fault as it did in autocross. The team ended up completing 7 laps of the endurance track, but was black flagged due to numerous gate violations. This is simply a result of low driver practice, training and being cooked from 0 sleep for a full week. This is the most number of laps the team has completed in the endurance event in recent years, it was done at a considerable speed (faster than some of the top racers) and all signs pointed to the potential for a full endurance completion. As a side note though, the energy meter never worked in our vehicle, we had no way of tracking energy usage but the hope was if the driver drove slowly we could pull CAN logs after and prove we were under the energy limit.

Figure 16: Front of Vehicle in Endurance with Justin Driving

10 Post Competition

After competition the team had a great celebration, the house we got in New Hampshire was fantastic and it seemed most people had a good time.

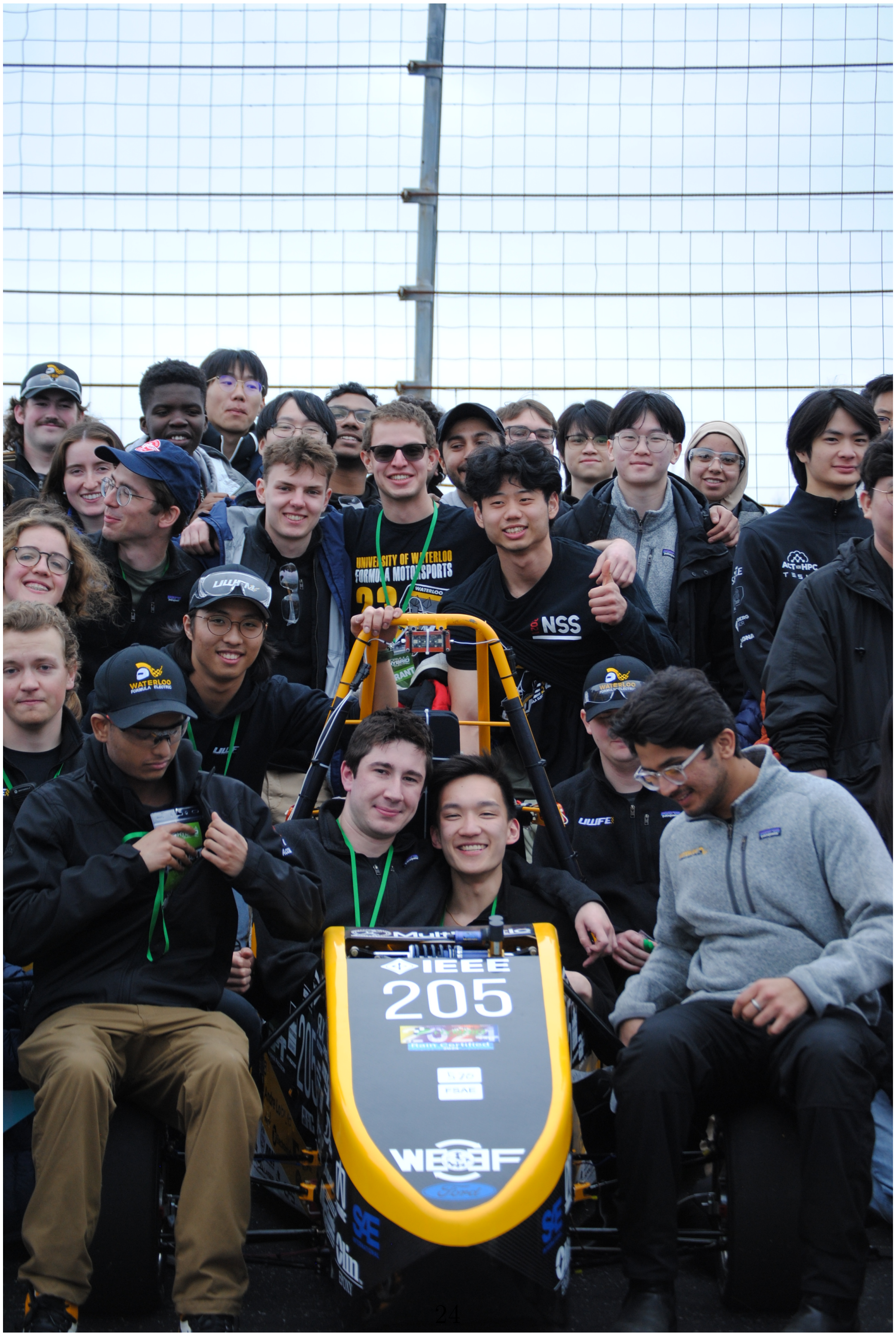

Figure 17: Team Picture

Figure 18: Team Picture 2

Overall competition was quite a slog, as expected we were unprepared and due to certain “griefing” events our performance was significantly limited. It does seem this iteration of the car has tremendous potential, but it was hampered by poor preparedness, sloppy work by a few and general lack of system level understanding of the team. These are luckily all things that are fixable.

Part IV

Issues + Root Cause Analysis

11 Phase Cable Box

11.1 Issue + Timeline

The phase cable (HV) box is the most critical reason the vehicle did not compete at competition, such a small change is what crippled the vehicle and resulted in only 2 events being run and being performed relatively poorly at.

The backstory of the phase cable box goes as follows. Mere days before competition (perhaps 2 if my memory serves correct) the powertrain team "discovered" that there needs to be a waterproof enclosure around the phase lugs. to the motor This is in fact something that has be known but it appears this was completely forgotten. The day before competition, the phase cable box was manufactured last minute and was installed at competition. The design for the phase cable box was setup to use the HVP 3 position connector. The powertrain team was not prepared to manufacture this assembly, did not have the appropriate crimper, appropriate crimps, cabling or assembly ready. This meant after many hours of installation at competition, they had to machine a special plate and use the cable glands that were used in the 2023 car. This modification of the design also made the box completely unserviceable such that any changes would take in excess of 5 hours. All of these modifications and changes took an incredible amount of hours such that the team was very late to competition and had no time to perform proper pre-comp testing in New Hampshire.

Figure 19: HVP800 3 position connector, initially expected to be mounted on the HV box, aborted at competition due to lack of preparation.

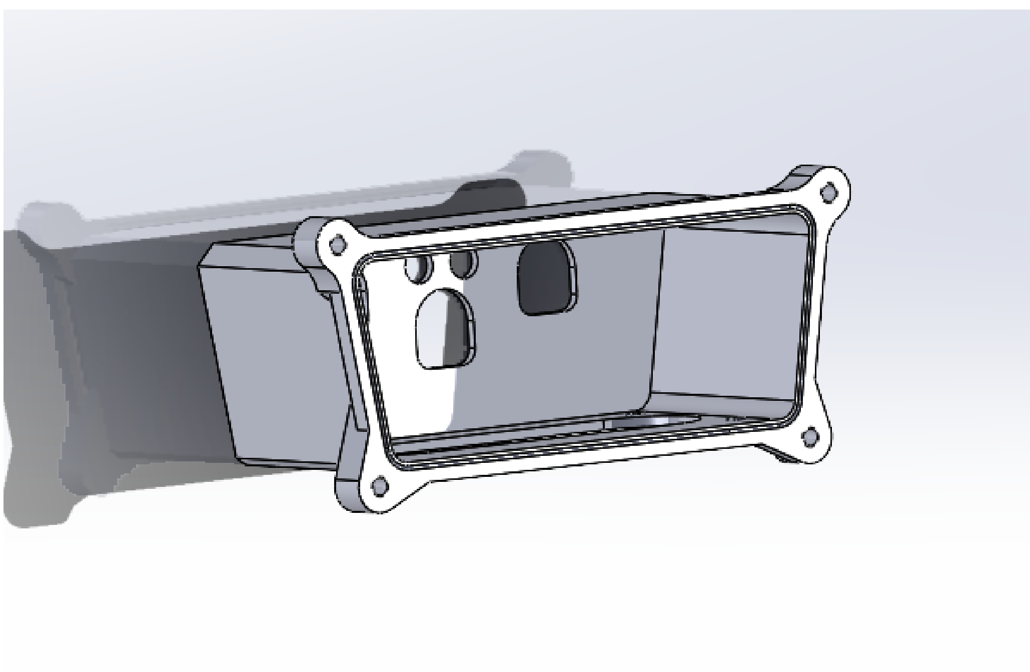

Figure 20: HV Box which hold the 3 phase cables

Not only though did this change remove an incredible amount of testing and validation time away, it also introduced a new issue. Now with the phase box installed there is a tremendous amount of EMI being generated and coupled into the inverter. The EMI would cause the resolver readings to be off which would cause instability in the inverter's control loop and cause a hardware overcurrent fault inside the inverter. Resolving EMI issue is a non-trivial issue, it's something Justin and I had to deal with earlier but we had sufficient time and were able to implement a fix for the previous issue. Now we are at competition and the car cannot stay at "Ready to Drive" for longer than 5 seconds without faulting because of the addition of this box. The exact reasoning for the introduction of the issue is unclear and will require EMI investigations, it's possible it's due to HV coupling, it's possible and perhaps most likely due to poor grounding. The issue of grounding will be discussed in the "Motor Grounding" section, but the gist is, the powertrain was completely rules non-compliant given the motor and phase box were not at all grounded. Attempts were made at competition to ground them, but due to the poor grounding performed this did not vastly improve the EMI issue.

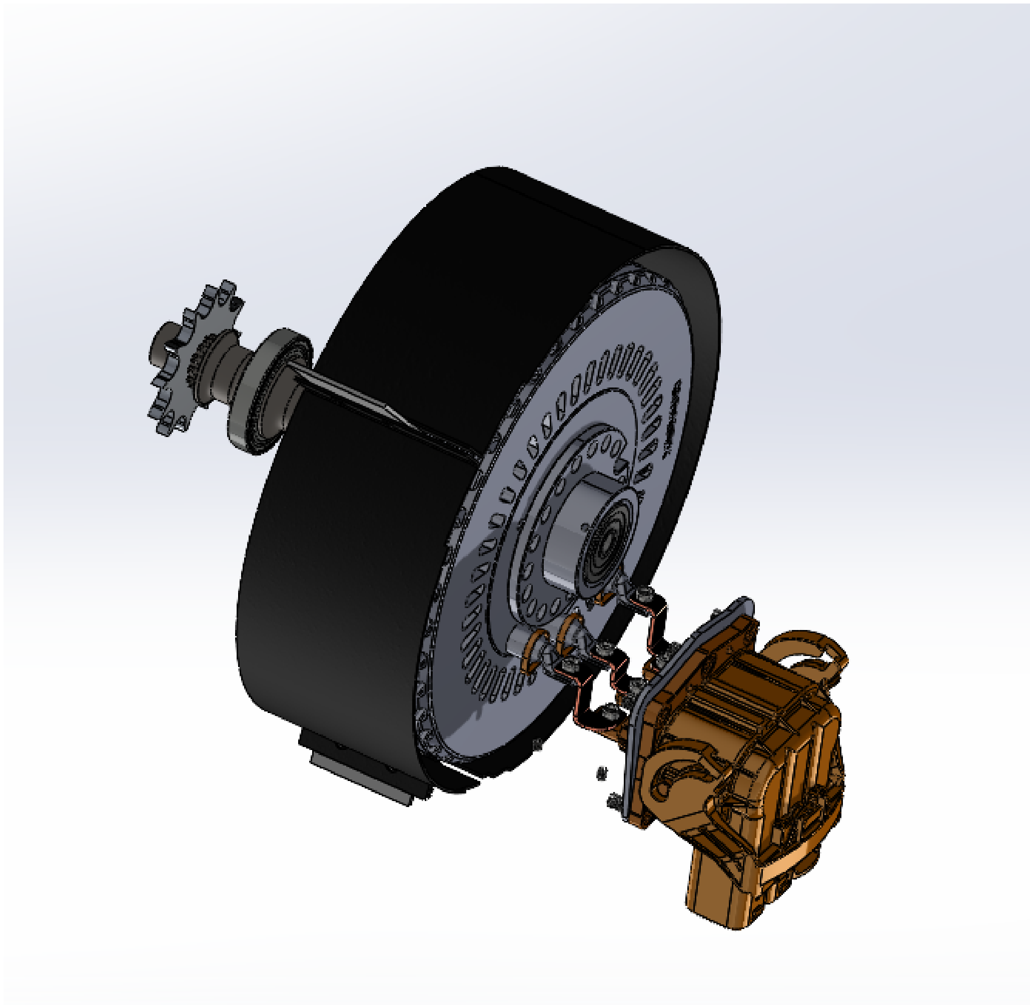

Figure 21: Motor Assembly with missing HV Box

After insane late nights, we were able to develop a slight fix in where the thermistor wires were disconnected and this yielded marginal vehicle stability, but under almost any load the vehicle would fault. The change implemented was whenever a motor controller fault occurred the firmware would power cycle the inverter. This is a bad change, it posed a threat to vehicle stability, drivability, component health and vehicle health. However, it was a necessary change to drive the car and yielded a car that was able to compete in endurance.

11.2 Moving Forward

Overall, this issue was crippling to the team at Formula Hybrid competition and unfortunately caused us to slide significantly in the rankings. However, we have learned lessons and will implement them to hopefully avoid for future generations and for the Formula SAE Michigan competition. The immediate next steps are for Owen and Justin to investigate the EMI issues and develop a solution for this (this likely is due to poor motor grounding, discussed later). A new HV box should be designed and manufactured given the current one does not meet it's specific design constraint of waterproof and it's incredibly unserviceable.

As will be discussed often in this report, the powertrain team needs to develop stronger ownership of the electrical side of powertrain and develop a proper understanding of it. A good powertrain team has an understanding of HV electronics, EMI, grounding, crimping, connectors, etc. This seems to be lacking on the powertrain team and going forward effort must be made to improve these skills (solutions will be discussed later).

There also needs to be a critical understanding among all members that changes **cannot** be made at competition. The fact that this simple addition to the car was pushed so long into the timeline and added at competition cannot be accepted by a successful team, the team cannot be doing these things at literally the last minute.

12 Accumulator Box Manufacturing

12.1 Timelines

A fairly disturbing thing happened when I returned from the December break working on FYDP to sync with the accumulator team. When I returned there was an unwelded box with no one assigned to the task and no work being performed on it. This was deeply concerning given the tight schedules of the welders at E3. Within the first few weeks of January I had to accustom myself with what was left to complete on the accumulator box and worked on completing and delegating tasks to get that complete.

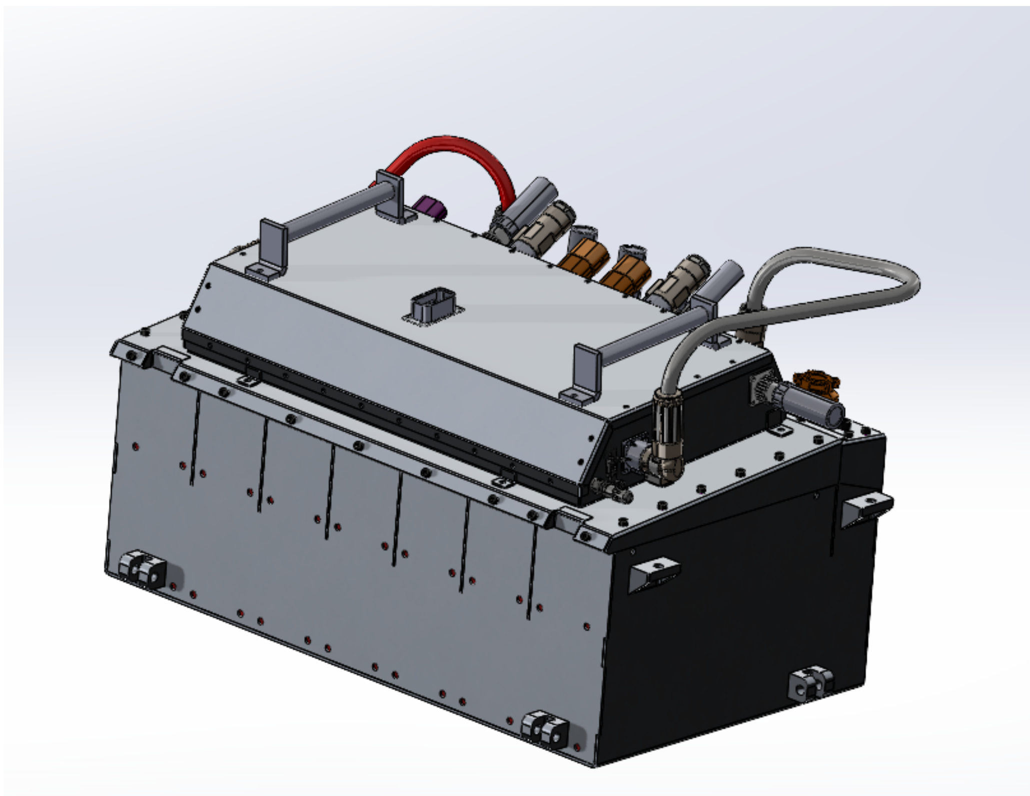

Figure 22: Accumulator Box

This is something that should not happen on a professional team. Had I not identified this issue, it's unclear to me what would have happened, likely there would be 0 progress on the accumulator box for many weeks. The accumulator team needs to really develop their autonomy skills, I cannot and should not be hand holding the accumulator through design and manufacturing. The accumulator team must accustom itself to setting it's own timelines which it can meet and working to hit those goals.

12.2 Tolerances

This connects in with the segment manufacturing discussion but the accumulator box design tolerances did not match up to reality. Effectively with the added nomex, the segments did not fit in the accumulator box at all and significant rework on the segments was required to achieve fitment.

13 Accumulator Polarity

A very scary thing happened when Justin and I went to precharge the car for the first time, luckily we had the DC inverter connections disconnected and had appropriate firmware checks. When we went to precharge the vehicle, precharge immediately faulted as it recognized that the polarity of the accumulator was inverted. This is a firmware check that we implemented to be extra cautious and one that most teams do not in fact implement. Had this check not been implemented the inverter would have been broken and every single HV component in the accumulator would've been broken and we likely would've popped the pack fuse or some cell fuses.

The entire accumulator setup including the SMD locations had been designed inverted such that the positive side of the box connected to the negative side of the E-box. Additionally, the inverter harnessing had been cut inappropriately such that the positive side of the inverter was designed to be connected to the negative side of the E-box.

This was a safety issue, a threat to the entire accumulator and all HV components. Going forward the team needs to ensure they are performing full end-to-end system integration, my suspicion is that multiple small changes accumulated to get us to this point. Proper validation needs to be performed at all stages of design, manufacturing and assembly. Checking that positive is on the correct side of the vehicle is a step that should have been made multiple times but that check was not properly performed.

14 Accumulator Connectors (Powerlok)

A very large setback for the accumulator was in relation to the connectors. Additionally in January it was discovered that not a single high voltage connector was ordered. This poses tremendous risk as these connectors have very long lead times. The desired connector the powerlok 120 with $16mm^2$ cabling was completely unavailable from any distributor and discussing with amphenol, they had no stock and had lead times on the order of 10+ weeks, well outside an acceptable timeline. Had this not been noticed in January it's possible that the team would not have been able to compete at all given how scarce HV connectors are in the individual distributors (mouser, digikey, etc.). Luckily I found the Powerlok 300 had some appropriate stock, this required us to increase our gauge to $35mm^2$ adding mass and reducing servicability of the car, but it was an acceptable solution.

This is a major mess up on the accumulator team and going forward this cannot happen as it threatened the entire vehicle's functionality. The accumulator team needs to work on managing tasks, assigning them to specific people and ensuring completion. The issue of connector procurement was brought up at multiple meetings and it was said that it would be handled but the task was never actually completed.

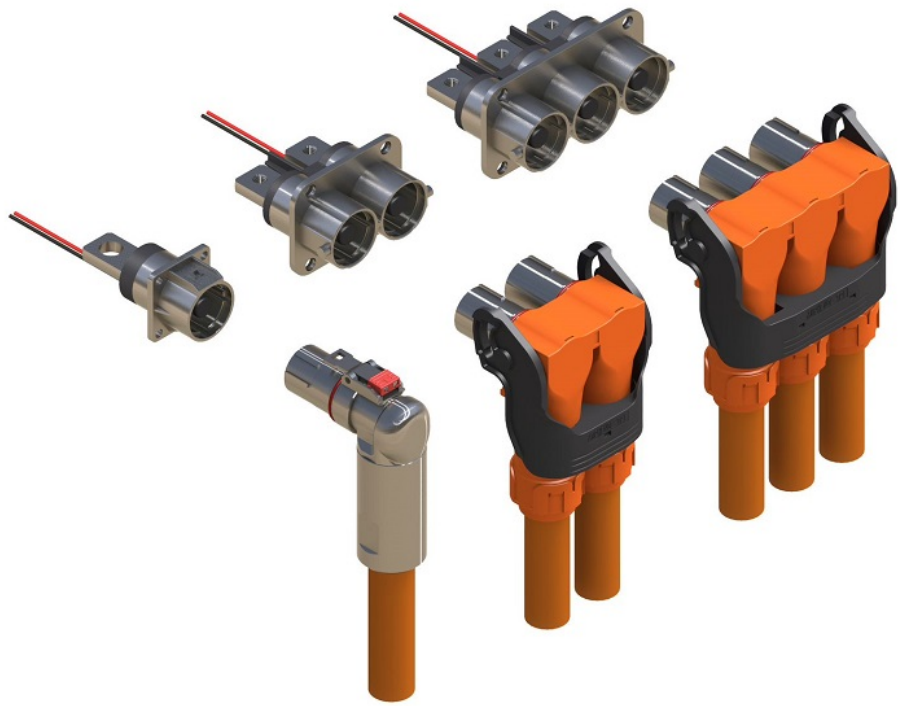

Figure 23: Powerlok Connectors

15 Suspension Grounding

One of the non-compliant grounding components on the vehicle was the suspension. Multiple suspension components were not appropriately grounded and that caused us to fail electrical pre-tech inspection. The suspension team is aware of this and is working on solutions, they were also aware of this ahead of time to competition and just banked on the inspectors not testing it. I am leaving this in the report so future generations can understand that they will test this as they know it's difficult to be compliant here. Going to Formula Hybrid you must ensure you meet every edge case of every rule, they are very strict and know the edge cases which typically trip up teams.

16 Phase Cable Ordering

A major issue that happened multiple times on the vehicle as well as occured on the dyno was phase cables having incorrect ordering. Given the very poor serviceability of the phase cable box this became a very pressing issue as incorrect phase cable ordering would have a turn around time of 4 hours, so all in approximately 8 hours of time would be wasted in installing phase cables because they were installed incorrectly. This section is left in as a reminder to the powertrain team and to future generations, the phase cable order matters. Do not trust your gut, there is a 1 in 8 chance you get it randomly. On Cascadia's website there is a document for setting up the Emrax motor where it explicitly details to you which order to put the phase cables from the inverter to the motor, ensure this is done properly. This also comes back to lack of validation the people installing the phase cables did not validate or do a 2nd check. A simple look at documentation would easily reveal the mistake, yet it was made multiple times when installing the phase cables. Measure twice, cut once.

Figure 24: Emrax motor (phase connections are the black, red and blue connections)

17 Dyno Phase Cables

A major safety, timeline and vehicle threat was caught on the dyno. During dyno tuning, multiple days were consumed attempting to tune the inverter to the 228 motor we had procured. After a few days of failed tuning it was eventually identified that a critical mistake was made in crimping the high voltage cabling. When the dyno team hooked up the inverter to the motor, they cut back both insulation layers and then wrapped the GLV shielding around the copper conductor, this resulted in the high voltage connections being shorted directly to GLV ground, which in the case of the inverter is the case itself. The motor controller tuning was failing because there was high voltage being coupled directly to the chassis of the inverter, this is a major, major, major safety issue.

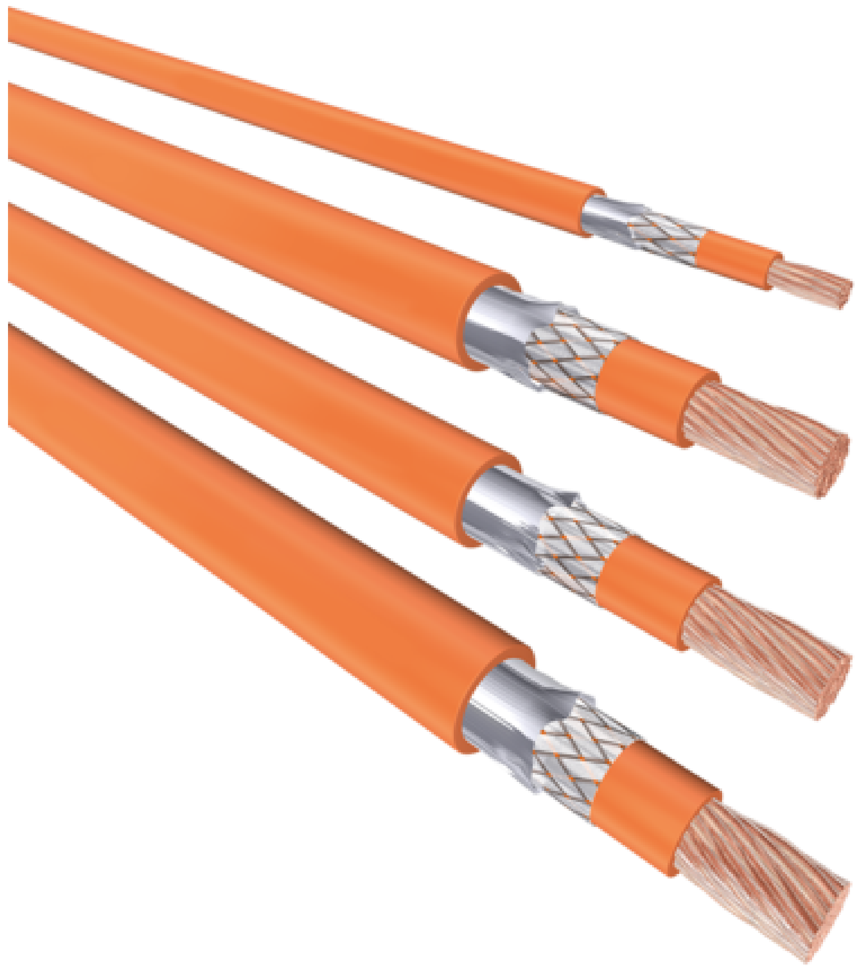

Figure 25: Shielded High Voltage Cables. The bright orange is the insulation. The copper color is the actual conductor connecting the high voltage systems. The silver color is the aluminum shielding which is to be connected to GLV ground.

Upon removal of this shielding from the copper conductor the tuning went along just fine, but there was a serious threat posed by this crimping method.

The method for cutting and crimping these high voltage connections is documented online rigorously. This failure also demonstrates a fatal misunderstanding on the powertrain team of how the high voltage connections are supposed to work. How can the powertrain team spec high voltage cabling if they think the shielding should be connected to high voltage? Going forward as will be stated further, significant investment must be placed into the various subteams to improve their electrical understanding, in particular the powertrain team. Additionally, members need to work on their validation and critical thinking skills, when a member is clearly doing this for the first time they need to read documentation online and truly understand what they're doing before jumping ahead and doing it. Not double checking something like this could have resulted in a serious safety issue or permanent damage to the inverter, despite the fact it did lose multiple days on the vehicle timeline.

18 Crimps

Overall the wire harness was done fairly well. There were still some major issues in relation to crimping and wire management, which caused delays to the vehicle. Despite me (Owen) having stated multiple times that whenever we get a new connector on the vehicle we must ensure we get the appropriate crimping tool and depinning tool, it seems that members decided this was unnecessary. This proved to be incorrect. The HVD IL crimps were so bad they fell right out of the connector, this is because they were not done using the appropriate tool, instead they were brute forced using pliers. The microfit crimps were also quite terrible and would frequently come out of the connectors. We do not have the depinning tool for the motor controller harness and this posed a burden as it limited the changes we could make to the motor controller harness when performing debugging. There are other examples that happened throughout the term but it's not critical to list every incident, they were frequent and caused by the following: lack of appropriate tooling, insufficient number of backup crimps.

It's critical that the electrical team learns from their mistakes in this regard. I stated multiple times that there was no need to sacrifice quality for budgeting, so it's very unclear to me why these items were not procured. The electrical team going forward needs to understand that sacrificing basic quality for cost is incredibly counter productive, bad crimps pose a safety hazard to the driver and delay the car substantially. Whenever a part is acquired we need all the appropriate tooling for said part, if this is distasteful then the team should reconsider acquiring that new part.

Figure 26: Molex Crimp Tool

19 HVD IL

In the team's ESF it was documented that interrupting the HVD would cut the interlock loop as shown in the following diagram.

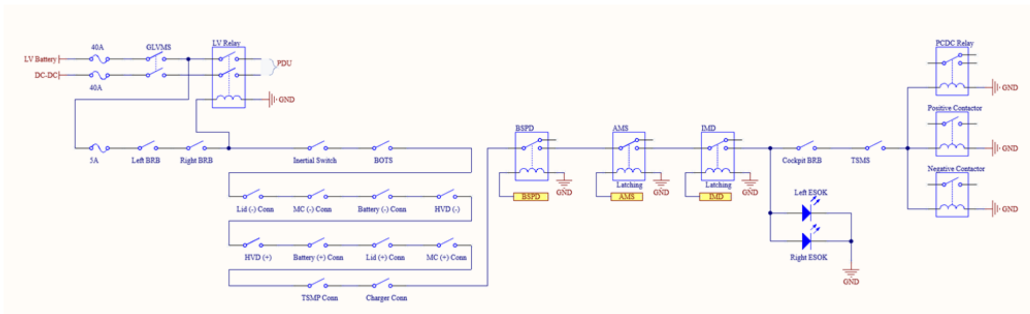

Figure 27: Interlock loop as documented in ESF, with HVD IL depicted.

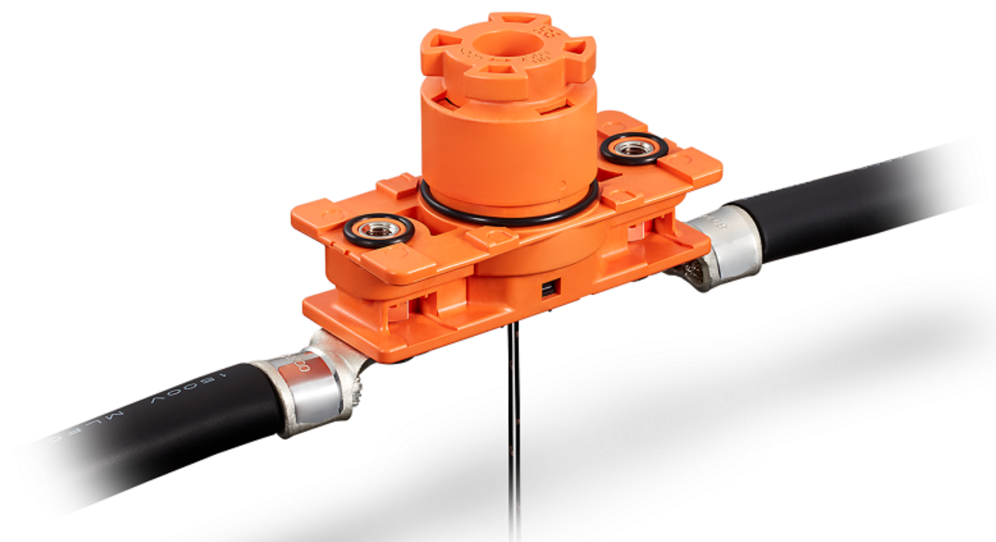

Figure 28: Hirose MSD, the HVD used on the car. The HVD IL is the black wire exposed underneath the orange enclosure.

Repeatedly it was requested that the HVD IL be appropriately connected. This was never effectively implemented, everytime we had the accumulator on the car and disconnected the HVD the IL loop would remain connected.

Part of the issue is connected to the previous discussed issue of crimps, but after that issue was remedied it's simply an issue of failure of validation. The root cause of this is failure of crimps, solder joints and general electrical connections. However, the real issue is failure of validation. Multiple times the rear lid was given to members and it was returned as "connected properly now". However, this is clearly false and easily disprovable using a multimeter, the IL was not actually closed and the HVD was skipped in the IL loop which posed a design flaw, minor safety issue and potential inspection failure given our ESF did not match our vehicle design.

Members need to understand that work as an engineer is not following a set of basic instructions. An engineer's job is to receive a problem, brainstorm a solution, implement said solution and then validate that the problem has been fixed. It seems many members skip steps 2 and 4, they receive the problem, implement a solution and perform no validation.

20 PC/DC Relay

During electrical inspection the team failed during one of the demonstrations. The demonstration failed was while at "Ready to Drive" hit the side BRBs, this should cause the TS system to discharge within 5 seconds. Hitting the side BRBs appropriately deactivated the GLV system but failed to discharge the TS system in an appropriate time, it took approximately 1 minute. This 1 minute time frame matches with a discharge against the parasitic discharge resistor in the motor controller. This was indicative that the positive and negative AIRs had opened, but the PC/DC relay had not returned to the discharge state. This is a very peculiar issue as the relay is a normally open relay in the discharge state, given there is evidently no GLV power being supplied to the relay how can it remain open? The schematic shown below is the PC/DC schematic for the 2024 BMU.

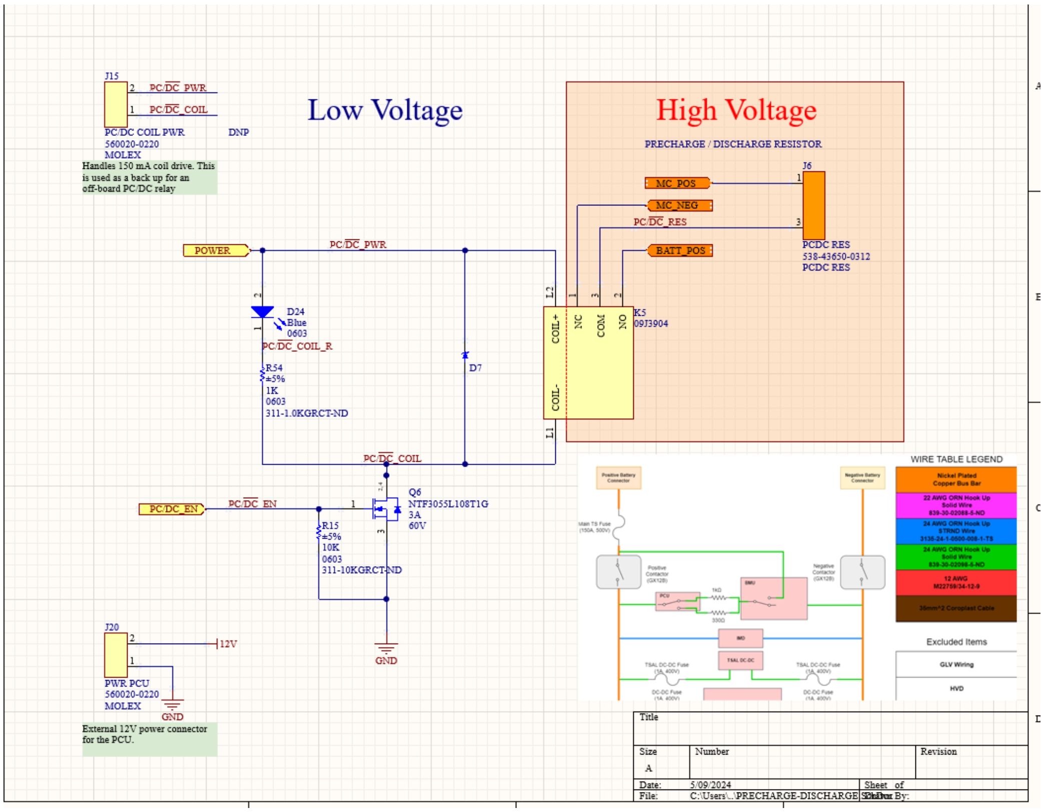

Figure 29: PC/DC Relay on 2024 BMU

The issue was that the PC/DC schematic was virtually copied from the previous 2021 BMU project and the relay was swapped out. There was a failure in analysis in that the relay was swapped for a high voltage relay to support the 300->600V architecture change but analysis was not performed on the flyback diode. The relay has a very low dropout voltage of ~0.5V. However, the forward voltage of the flyback diode is around 540mV for any real current. What was likely happening is when the power to the relay is disconnected the diode actually keeps the coil conducting by providing a path for current to flow while not bringing the voltage below the drop out voltage.

The solution is likely to spec a better diode, but what was done at competition was a 10$k\Omega$ resistor was put in parallel with the relay coil to fully discharge the coil and provide a path for conduction besides the diode. This seemed to fix the issue. Though it should be noted this issue had not arisen previously as it was exacerbated by the EMI changes from the powertrain changes see other sections for more information.

This oversight was caused by lack of analysis spent on the BMU. This is a flaw in the logic of designing the BMU where it was assumed that the old schematics were perfect and good, so we should just make minor adjustments. The issue is, an older designer designed these PCBs with certain design decisions, those are not documented in the design as that would be too verbose and time consuming, and when we change the system design the previous assumptions become invalid. The old PC/DC relay had a very large dropout voltage in the single digit volts, thus this was not at all a concern. Another factor which should be considered is that this iteration of the BMU despite the very minor changes required took ~12 months to complete, and respins are still being sent out as of the writing of this document. Given the efficiency of prior generations of the electrical team it's likely we overestimated the capability and efficiency of the current electrical team to produce PCBs, going forward ambitions should be scaled back.

21 Segment Manufacturing

21.1 Lexan Walls

It was suggested that rather than using the GPO-3 walls for our segments we could use Lexan, a lighter polycarbonate. The thought was it would decrease mass as the GPO-3 walls do add considerable mass to the accumulator.

Figure 30: Lexan Segment Walls

The issue is that there was a concern that without annealing the lexan walls would shatter under some of the loads the accumulator experiences, thus significant effort was spent attempting to anneal the material without warping. The accumulator segment team lost about 3/4 months of time, I finally put my foot down and forced them back on the trial of GPO-3 on January 9 and the Lexan investigations began in late September. The investigation should have been aborted far earlier, segment timelines delayed vehicle testing tremendously. Had I not reverted the team back to GPO-3 we would not be attending competition, there's a point where the mass savings no longer outweigh the pushing of the timelines, which probably occurred in October or early November.

The accumulator team needs to ensure they are maintaining realistic timelines, it's not realistic to start milling GPO-3 in January to create segments. There is an argument that mass savings should be a focus on the car, but currently the team suffers most from lack of reliability and testing, the dominant effect on our vehicle performance is not the kilograms of waste mass in the accumulator it's the lack of testing.

21.2 Fused Ring Terminal (Flex PCB) Integration Issues

At the start of April I had an event I had to attend for a week, I requested that everything with the accumulator be done by the time I returned so I could integrate it all. I was reassured that everything was complete, yet when I returned and plugged in the AMS boards, there were a lot of cell voltage reading errors. This is because the ring terminal pcbs I had designed were not properly integrated and 0 testing was performed on the segment, it was simply written off as "done" because it looked okay via visual inspection. The only one that was fine was the one I had originally brought up.

A lot of the ring terminal PCBs had cold solder joints, no proper solder joint, poor crimps, frayed wires and lifted pads. I agree that soldering flex PCBs can be a difficult task, but an important step when bringing up a simple PCB like this is running a basic functionality test, simply measure the resistance between the crimp and the bus bar itself and ensure it has a good connection, if it doesn't redo it. I myself made some bad ring terminal

PCBs at the start but discarded them before installation because I ran this check. This took a tremendous amount of time to fix as I had to tear apart all but 1 segment, identify which sense wires were broken, re-solder the PCBs, recut and crimp the wires.

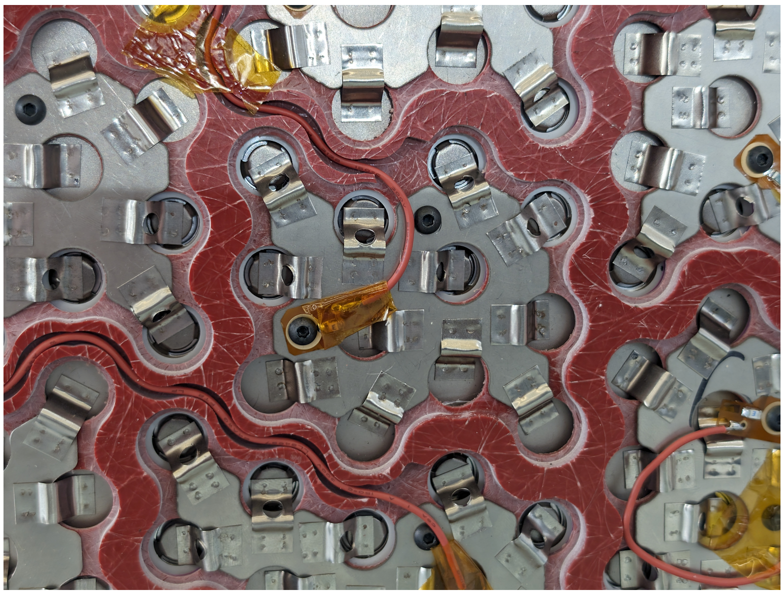

Figure 31: Ring Terminal PCB on segment

The segment team needs to run full end to end testing of all their components, it's a serious issue at this point, identifying the issue when you're assembling the segment is a lot easier fix then fixing all the broken ones at the end. The segment team should also be comfortable with running proper integration testing, that is attaching the AMS boards and reading values from them, this is something the team will need to do to run tests when I'm gone.

21.3 Crimps

Just as with the ring terminal flex PCBs the thermistor crimps were also done incorrectly, in fact inside the accumulator right now there are likely some floating thermistor connections based on the AMS data we've read back. The duraclik crimps were evidently visible from outside the connector when looking down on the segment, wires would easily fall out when tugged on. Crimps would dismantle when tugged on. Efforts need to be put on validation. It's fine to make a poor crimp, but you should run the pull test on the crimp, run a continuity test on the crimp to determine if it's a good or bad crimp and discard it if it's poor. You need to run full end to end testing, measure the resistance across the thermistor on the PCB. Actually hook up the AMS boards to a BMU and validate that the thermistor and voltage readings are correct.

21.4 Assembly Issues

There were quite a few assembly issues with the accumulator segments, enough that I can't really go over all of them. I shall go over the main one which is in terms of dimensions. When fully assembled the segments are too wide and too long. Too long to the point that the segments did not fit inside the accumulator box when they were to be dropped in. One of the issues I identified was the terminal isolation plate was designed to be an exact press fit into the segment. When it was 3D printed due to slight tolerances it became practically an interference fit.

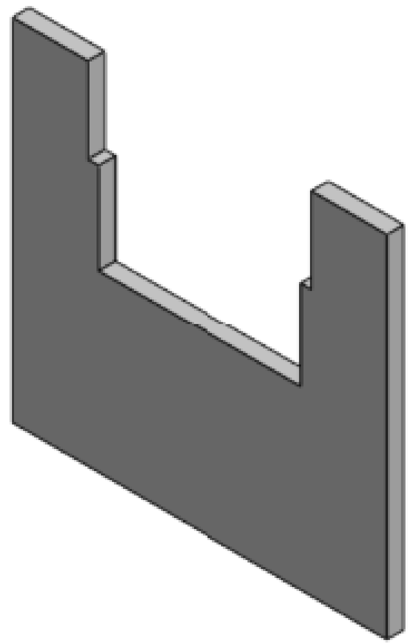

Figure 32: Terminal Isolation Plate

Rather than reprinting the piece, in the segment it was just placed into the segment such that it protruded forward and didn't properly fit. This caused the axial segment walls to bow out at the top and meant the segment would not fit inside the accumulator box. So what I had to do was tear apart every segment (this requires removing AMS boards and AMS shield and AMS plates and all the G-10 walls. Once the segment was torn apart I had to remove the segment terminal connectors, remove the terminal isolation plate and sand down the plates until they fit back inside the segment. This was an incredibly time consuming process which took well over 40 hours, of working about 6 or 7 all nighters. There were a few other minor methods I used to get the segments to eventually fit inside the box but they were all very time consuming and easily put back first shakedown about a week.

These small things are the types of things which should not happen on a professional team. If you are 3D printing a component, you must factor into it the tolerances, this piece definitely did not need to be press fit in. When installing the component, understand what it does and what effect it has, the fact it was installed such that the connectors would bow out of the segment and bow the G-10 walls is not really acceptable. The fact that the segments were never actually placed into the box with nomex before I did it, is another example of failure of validation.

The accumulator team needs to work on their **manufacturing, deisgn and validation skills.**

22 Board Mounting and Accessibility

Board mounting and accessibility is something that the team has struggled with for the past few years. It's something which has never really caused major issues but cumulatively has wasted lots of time on the team. Cumulatively many hours have been spent opening difficult enclosures or accessing poorly integrated low voltage boards. I will highlight individual cases of specific issues I observed, but in general the lesson to be taken is the chassis team should work closely with the firmware and electrical team to design a vehicle that is easy for system integration and debugging.

22.1 PDU

The PDU for the past at least 4/5 years has always had the hirose programming port mounted in the same spot. This is the worst spot to have the progamming port as it requires the full GLV harness to be disconnected to access it. It's practically unusable.

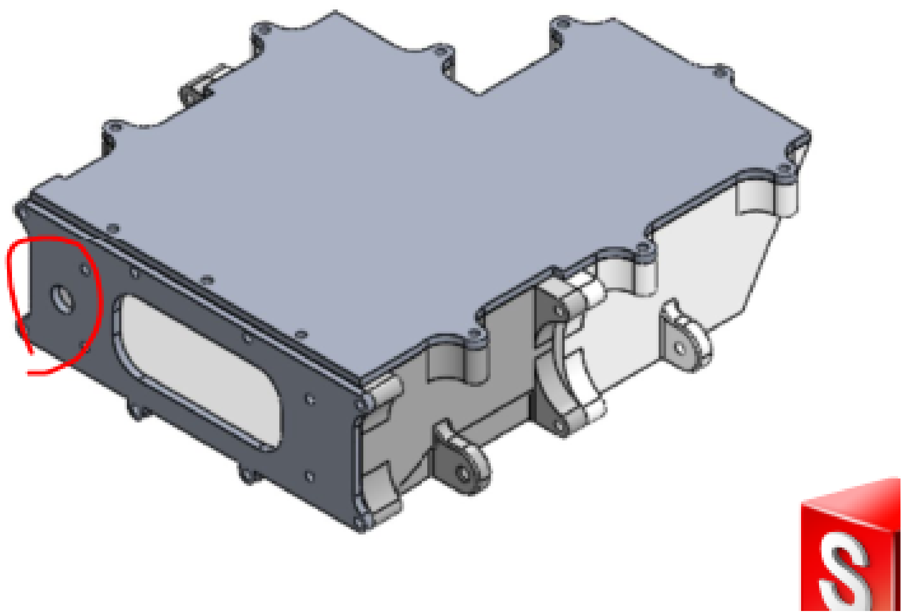

Figure 33: PDU enclosure with hirose port highlighted

This became increasingly more pressing this year as disconnecting the PDU harness is incredibly difficult this year given the placement of a certain chassis tube. Currently the method is whenever we need to program or debug the PDU we have to remove the top lid of the PDU and access the PCB, this is time consuming and could be fixed very simply by moving this port.

22.2 WSBs

The WSB tabs are supposedly setup such that you have to jam in a screwdriver to remove it. I don't have a ton of visibility into this, but removing and mounting boards should be something very easy and not difficult, it has to happen often, and has to happen at competition.

22.3 VCU

I think the chassis team has seen this one, but the VCU is mounted in a position that makes it very unserviceable in it's current state.

23 Motor Grounding

The motor and all it's attached components: phase box, resolver, mount mount were all not grounded. This breaks competition rules which requires all metallic accessible components on the car to be grounded. The inspector especially stressed the importance of grounding things close to the TSV system which the motor mount very much is.

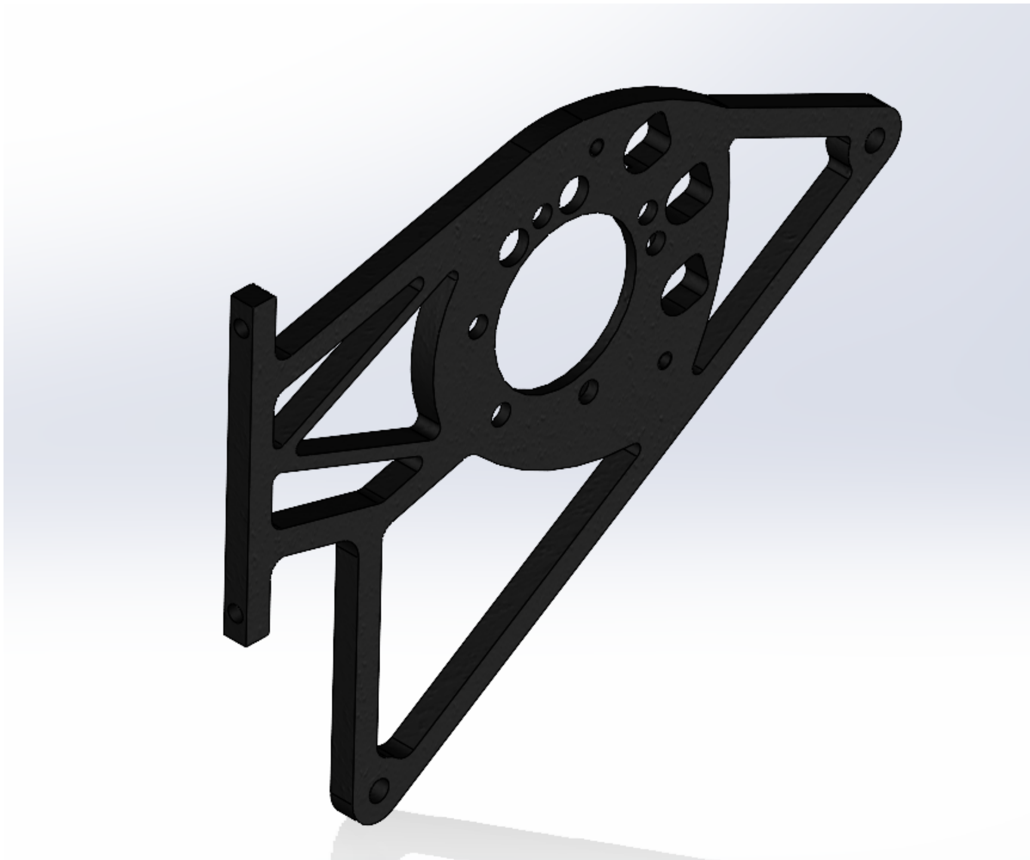

Figure 34: Motor mount

The root cause of the motor being ungrounded, was it was anodized which adds a dielectric layer around the metal preventing any contact to the motor. Not only is this rules non-compliant, it's unsafe and is possibly the cause of the significant EMI issues identified on the vehicle. This is simply an oversight in design. All elements on the car must consider grounding when it comes down to it, especially the powertrain team given it involves TSV components and can generate tremendous EMI. Going forward the powertrain team needs to develop it's electrical understanding, rules compliance and ensure grounding is factored into all of it's designs. Rules checking and validation is something that should be performed at every step of the design process and manufacturing process.

24 Powertrain/Chassis/Suspension Interference

I won't discuss too much at this point as it never yielded any practical effects on the vehicle but it's something which should be documented for future generations. The powertrain can interfere with a tube on the chassis under certain suspension conditions. Work should be done on the mechanically focused teams, especially powertrain to ensure the vehicle can operate without interference under any possible suspension condition.

25 Energy Meter

At competition when attempting to install the Formula Hybrid Energy meter, it was quite clear that it would not fit in our box. Multiple hours (~8) were spent integrating this into the E-Box at competition and it ultimately never worked. This blocked vehicle progress and testing. This is primarily the fault of the organizers for not providing more detailed information prior to competition, and for failing to match the spec of the FSAE michigan inspectors. Going forward for Formula Hybrid the team should be prepared for this change, we should have appropriately slotted bus bars, and ample space in the E-Box to fit this in. Additionally going forward, before FSAE Michigan the team should reach out to a team to test fit the FSAE Michigan energy meter in the car prior to arriving at competition.

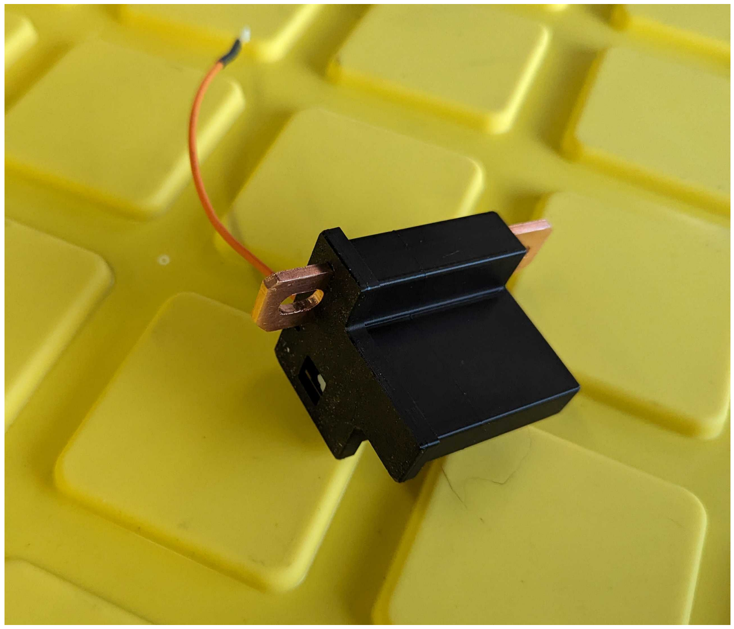

Figure 35: Formula Hybrid Energy Meter

26 Charge Cart

The charge cart is something that always seems to be mostly neglected by the team. The current charge cart looks marginally better than last year's but there are still significant issues. A big improvement that needs to be made to the charge cart is professionalism, it still looks like an accumulator holder with a junk drawer, work needs to be performed to get a charge cart the team can be proud of. I typically point to Delft, and I shall do it again, because it's a prime example of professionalism, as shown below Delft's charge cart has an enclosure and styling which causes it to appear professional and organized.

Figure 36: Delft's Charge Cart connected to their car

Beside the professionalism of it, there were some pretty major issues with charge cart integration to the rest of the car. Multiple times in bringup of the charge cart and attempting to charge it there would be hours of delay to debug some issue with it. The first big issue was in IL, I had to spend multiple hours rearranging the charge cart harnessing to yield an IL that would appropriately close, and open when the charge cart switches were triggered. This is a very simple thing to check and validate but that validation was not performed. All you need to do is attach a multimeter in resistance mode across the BMU IL pins in the GLV connector, trigger the e-stop or keyswitch and validate it opens the IL appropriately.

The second big issue was related to CAN, I had to spend many hours debugging CAN issues. Debugging CAN issues with the charger is expected the issue is, we should not be debugging them serially such that we're blocking vehicle progress. Twice when I got the charger, there were bad connections in the CAN lines such that there was no proper termination or just a complete open circuit to the BMU or to the charger. Testing CAN lines is a very easy thing to do, all you have to do is install both termination resistors, when you measure the resistance between the 2 lines on either end of the cable it should measure 60Ω, if it measures 120Ω then 1 termination resistor is disconnected, if it measures OL that means there's a bad connection somewhere along the line. The additional truth is the accumulator team should have improved system integration tasks such that when people are working on the vehicle, they can hook up an old BMU, and validate the charger CAN is communicating appropriately.

Overall, the accumulator going into this next year should focus on improving the professionalism of the charge cart. They should also work on their system integration skills, ensuring things are validated well ahead of time, ensuring the electrical and firmware systems are interfacing correctly is a non-trivial task that should be prioritized.

27 Brakes (BOTS)

The brakes on the car have been an issue on the car for the past few years. There is frequently air in the brake lines. This year it was an additional issue as the BOTS (Brake Over Travel Switch) was placed in very close proximity to the brake pedal. This meant that as the brakes became softer eventually when the driver would slam on the brakes it would trip the BOTS, open the IL and shutdown the car. Despite the name of the BOTS, it's designed to never trip unless almost all brake pressure has been lost. Initially efforts were done to push the BOTS further back, but the issue kept arising. The team needs to come up with a permanent solution to this. Perhaps the solution is to mount the BOTS further back, but it's likely to fix our brake lines, we seem to constantly need to bleed the brakes which is not an issue other teams face. Regardless of the solution, extra effort must be placed to fix this as it poses a vehicle reliability concern.

28 BMU Current Sensing

When attempting to precharge the vehicle, we failed multiple times due to incorrect current measurements read from the ADE7913. Eventually it was deduced where this originated from. Yet again, the schematic from the 2021 BMU was virtually copied over without much further analysis. The ADE7913 can only handle a maximum voltage difference between GND_ISO and VM/IM of 25mV. The issue is the accumulator's shunt is connected on the negative TSV side of the vehicle while HV_COM is connected to the positive TSV side of the vehicle as shown below.

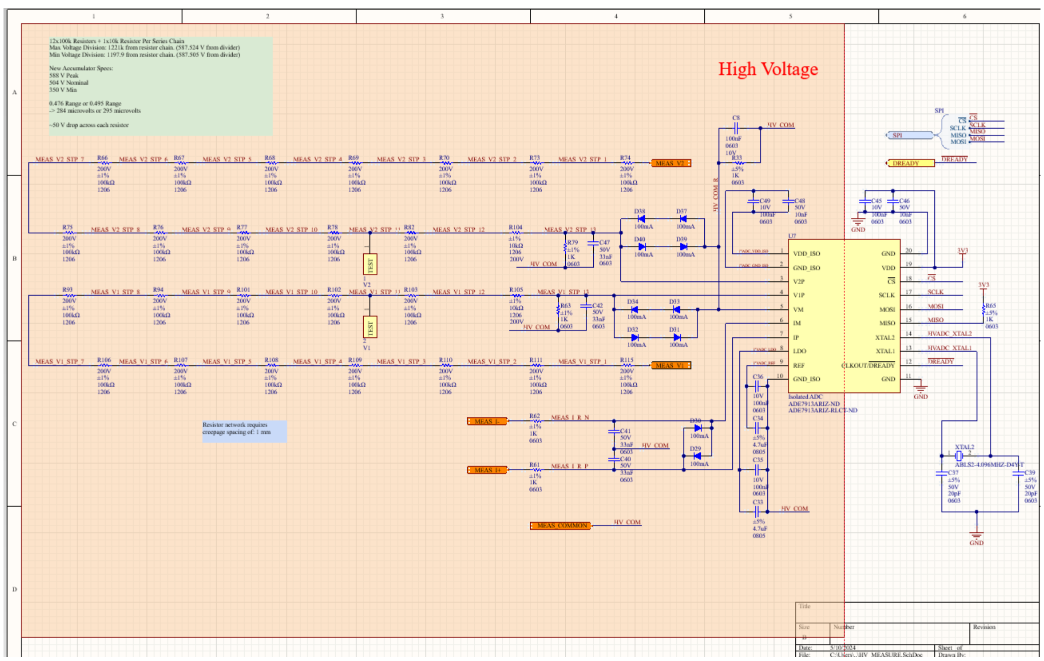

Figure 37: HV Measure Schematic for the 2024 BMU

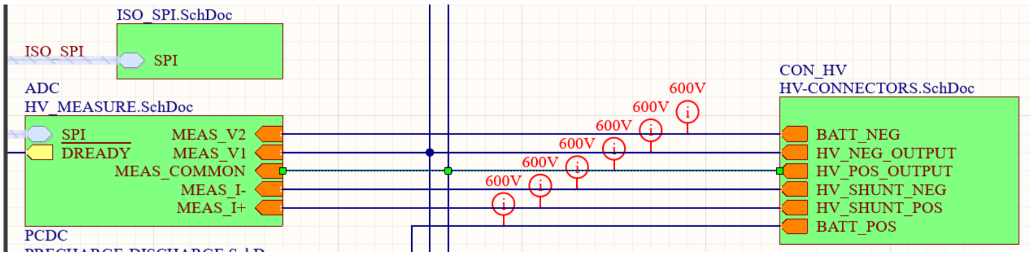

Figure 38: High Level Overview of 2024 BMU with the HV_MEASURE Schematic focused.

This topology is a relic of the 2020-2023 vehicle platform where the accumulator had a positive side shunt. However, the topology had to change for the 2024 vehicle as we are using FSAE Michigan's energy meter which has itself a shunt on the negative side of the accumulator. This means the voltage between IM and GND_ISO during normal operation would be on the order of 500V, well above the 25mV maximum. Prior to competition the shunt connections were removed to prevent any obstacles on this and the hall effect sensor was used. Integrating the hall effect sensor was a non-trivial task which took some time to develop and calibrate. The hall effect sensor is also quite noisy especially at low currents.

This is another example of the electrical team porting over a change without re-performing the analysis. The shunt change of location is documented extensively in the ESF-2. Going forward the team needs to perform more analysis on the things they do, and need to seriously descope work. The BMU took ~12 months and still is not complete, while it has some fairly significant issues which degrade functionality, not having a shunt seriously degrades the functionality of the BMU.

29 Grounding Wires

EV8.1.4 in the Formula Hybrid 2024 rules states that all grounding wires must be a minimum of 16AWG stranded wire. This is to ensure a sufficient ground connection. The initial pass by the electrical team for grounding, all wire was 22AWG or thinner. This wasted a tremendous amount of time as the team had to revert everything to a thicker gauge wire. Luckily this was identified before competition so it was still feasible to fix this mistake. It's critical that all members read the rules, whenever someone is implementing a feature they should understand the rules around it. Section *EV8 Grounding* is a very short section, this should have been caught earlier, before the task had begun.

30 Issues Conclusion

There were still many more issues not discussed given this report is growing to an immense size. Hopefully the team can self-identify these and move forward with the lessons learned.

Part V

Future of UWFE

Figure 39: Will and Michael sitting on the dock

31 Short Term Plan

Currently the team is working on getting the car ready for FSAE Michigan. Justin and I will work on fixing the EMI issues to get a reliable vehicle. Justin is working extensively to get a proper DAQ (Data Acquisition)/Telemetry system working which will greatly improve debugging and data analysis. Extensive work must also be put into rules compliance and checking for FSAE Michigan, this is a competition we've never attended and we must ensure we are rules compliant to a T.

32 Suggested Future Goals

Given this last year has been a major platform and organizational overhaul for the Formula Electric team I would advise that the team run with this platform going forward. I know there is demand among members on the team to redo the accumulator, but this is a highly risky endeavor. The accumulator took much longer than expected this year, and to suggest it won't happen again is wishful thinking. Justin and I won't be here next year, which means system integration will be incredibly painful.

The team should work to refine the existing vehicle platform, improve robustness, rules compliance and increasing vehicle performance in more incremental areas. Right now the limiting factor is not likely the vehicle mass it's performance limited in other areas. Right now I suspect the sprocket ratio is not optimized for real driving situations, this should be investigated. Accumulator cooling is an understudied task and we have very little data on what's necessary.

Do not miss competition because you failed, the easiest way to kill the team is to have a bunch of 4th years work on a car, fail then

33 Team Structure

I was initially planning on posting the team structure here, but I will refrain from it until further consultations are made. Taras Rawlinson will be the technical lead for the team for the 2024/2025 season. His work will focus on vehicle design and team related final decisions. As discussed with Taras, I strongly suggest the team move towards the RE team structure where ownership is more specific and focused as I elaborated in my 2023 review report.

Part VI
Appendix

34 Competition Housing

Side note, competition housing was great this year. Fantastic location, hot tub was primo and definitely worth it.

Figure 40: Owen and Justin vibing in the tub

Figure 41: Owen Hot-tubing

35 A Reminder About What's Important About Formula Electric

This is somewhat tangential from the report but I thought it was important to document it for younger members and future generations. What is often unspoken about on the team is what is important. Very often we get wrapped up in racing the car and competition and such. When you've worked long enough on the team or in engineering in general is the problem you are facing in engineering is not the real problem "man" is facing. In the end whether the Formula Electric car even shows up at competition or not provides no material benefit to any other person in the world. What it does is it exposes the members to the realities of task execution.

The problems faced on the Formula Electric team are the exact same ones faced in the real world: Project Management, Labor Relations, Systems Design, Recruitment and Retention, Team Management. The technical issues we fix on the Formula Electric team are identical to ones I've done on co-ops in the workforce working at large tech companies. What we have is an incredible opportunity to have a huge impact on a small project, to be exposed to full systems level design. Whereas all your other peers go into the workforce and are given small tasks, on the Formula Electric team you are exposed to high level decision making and real engineering design, so when you face it in the workplace you are ready. There really is no better preparatory mechanism for engineering in the real world. Personal projects lack team dynamics, large budgets and system integration. There is almost no where else you can work on High Voltage Systems, Battery Assembly, distributed board design, suspension design, etc. I think Formula Electric is the ideal experience for engineers looking for systems design and we're really blessed to have this opportunity.

Even though, I just stated all that, in essence the engineering skills gained are really not even the point of the team. The stated goal of the team is to develop a fully electric Formula style race car, an experienced member will understand that as I stated the true latent purpose of the team is to develop engineering and team working skills. But even this is not a full understanding of the true latent purpose of the team.

The real purpose of the team is to develop character. On this team over the past 5 years I've worked on it, and the past 2/3 years I've been Technical Lead I've seen many members grow their engineering skills which is beautiful, but what is real awe-inspiring is seeing members develop their character. Formula Electric in it's true essence is a test of character, it's a test of resilience and struggle. You get out what you put into the team, if you strive to go far you can push your limits further than you possibly expected. I've seen quite a few members go further then they ever thought they could, and it's really an amazing thing to see.

In the past I've used the analogy of the Nickel Cadmium battery's memory effect. If you partially discharge a Ni-Cd battery and then try to recharge it, the battery suffers from the memory effect where it will no be able to perform a full discharge it will remember a smaller capacity as it was not taken down to it's limit. The same principle applies to people, if you don't push your limits you gradually soften over time and lack resilience.

Over the years I've seen many people crack under the pressure, they go "this is too difficult" and quit the team or coast or "grief" the team somehow. But with a few people I've seen them come out of the experience as better people overall and significantly better engineers. The engineering topics we learn are fairly temporary and constrained but the life lessons and the character we develop is permanent and broad. In university you are defining the person you are to be in the real world, and for a select few on the Formula Electric team they are setting themselves up to be truly legendary figures, able to withstand tremendous pressure, make good decisions and act in a moral and **honest** way.

I'll leave this report with a passage from Theodore Roosevelt's speech "Citizenship in a Republic", a passage I would often think about when under the immense pressure and something which I think is important to grasp and understand on the Formula Electric Team.

> It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better.
>
> The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs, who comes short again and again, because there is no effort without error and shortcoming;
>
> but who does actually strive to do the deeds; who knows great enthusiasms, the great devotions; who spends himself in a worthy

cause;

who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who neither know victory nor defeat.

Regards, Owen Brake