MONASH MOTORSPORT

FINAL YEAR THESIS COLLECTION

DESIGN AND INTEGRATION OF AN ELECTRICAL SYSTEM FOR A COMBUSTION FORMULA-SAE RACE CAR

Thejana Abeykoon - 2019

DESIGN AND INTEGRATION OF AN ELECTRICAL SYSTEM FOR A COMBUSTION FORMULA-SAE RACE CAR

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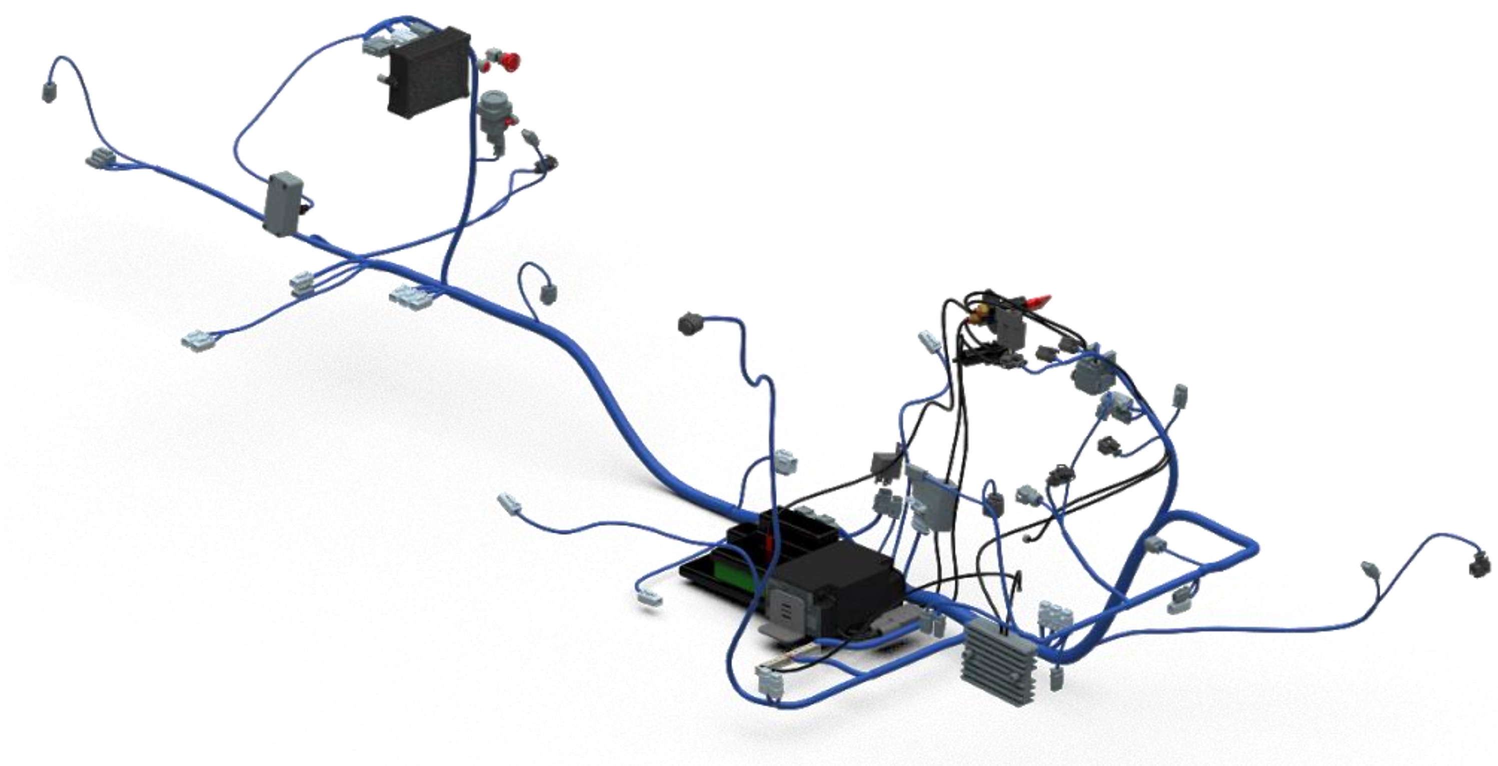


MONASH University
Engineering

SUMMARY

The objective of this project was to follow the design, integration and manufacture of the electrical systems that will be installed on Monash Motorsport's latest combustion racecar; M19-C. Over the course of semester 1, the groundwork was completed for the development of this system, in preparation for manufacture and installation onto the carbon fiber monocoque chassis.

A thorough LV Systems review and research period in early January saw the selection of the hardware and materials that will be installed onto the car. The selected MoTeC hardware includes the M150 ECU, PDM15 and D153 display – being selected for their superior functionality compared to competitors and ensuring consistency between M19-C and M19-E vehicles. The entirety of the system was then designed on a Computer Aided Design software (Siemens NX 12). This allowed for integration and careful packaging with the rest of the subsystems on the car. The process of designing the wiring harness on CAD also allowed for all wire lengths to the exported accurately, which greatly streamlined the manufacturing process.

Following the design phase, the manufacturing period commenced, which involved the manufacture of the wiring harness and power wiring, and installation onto the chassis. Upon successful installation, appropriate ECU, PDM and Display packages were produced and sent to the MoTeC hardware with all logic, sensor logging and engine tuning parameters set up. A proprietary MoTeC software called M1 Tune was used to start the car for the first time with a baseline tune, after which it progressed to on track testing for transient tuning of the engine for power and efficiency, and other vehicle dynamics parameter tuning. The testing phase ensured the car was reliable and the vehicle set-up was dialed, allowing for competitive performance at the FSAE-Australasia competition in December 2019.

This project highlighted the importance of meticulous care and attention to detail when designing and manufacturing such a critical system on a FSAE race car.

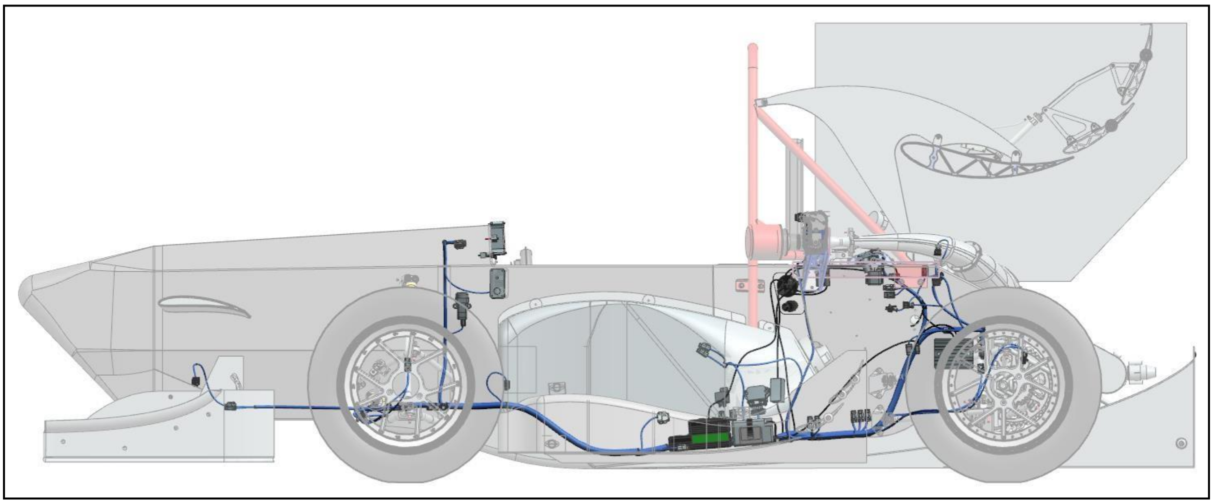


Figure i: CAD screenshot highlighting LV Systems on M19-C Master Model

TABLE OF CONTENTS

1. INTRODUCTION

Formula-SAE is an engineering design competition that involves universities from all over the world that design, manufacture and ultimately compete an open-wheel race car to determine which car outperforms the rest in a number of judging categories. There are a large number of parts on a Formula-SAE car that require a significant amount of design consideration in order to produce a car that will be competitive at an international level. These parts fall into the categories of Chassis, Suspension, Aerodynamics and Powertrain. This project will follow the design, integration and manufacture of the electrical system (also referred to as LV Systems) that will be installed on Monash Motorsport's latest combustion race car; M19-C.

Figure 1.1: M18-C Testing at Munich International Airport, MMS Europe Campaign 2018

The components that are involved in the electrical system include: the wiring harness, electronic control unit (ECU), display, power distribution module (PDM), battery, power wiring, shutdown circuit, steering wheel electronics and sensors. The LV systems on the car serves the purpose of interconnecting all relevant electronic components required to run the car. This involves communication between the wiring harness, control hardware, sensors, switches and buttons.

The wiring harness has two main uses;

1. Distribute power to all hardware and sensors, and
2. Transmit all sensor signals to a central location (ECU) where it can be logged and the inputs used for logic conditions.

The ECU takes inputs from sensors, switches and buttons to determine whether the car is in a safe state to run (e.g. all temperatures are within a suitable range and shutdown circuit is completely closed) and then through driver inputs of priming the car and actuating throttle pedal, turns the car on and sends signals to the starter motor, fuel pump, ignition and injector so that the car can drive.

By logging inputs from sensors in the ECU, the team is able to gain data that will allow data driven decisions to be made, such as suspension setup, and also allow diagnosis of issues as the exact state of the car prior to a shutdown will be known.

The shutdown circuit (mandated by rules) is also integrated into the wiring harness and acts as an additional layer of safety on the car. It consists of a series of switches (brake over travel, inertia, kill-switches and Brake System Plausibility Device) whereby any open circuit will result in the shutdown of the car.

The LV battery is required to power all the hardware, and must have sufficient capacity to last the maximum period of the time that a car will stay running (a competition-spec endurance including multiple restarts).

All the switches and buttons on the steering wheel and dash must communicate with the ECU and allow the driver to input different requests to the car (shifting, launch control, automatic upshift, ARB setting). The display also aids the driver by displaying critical information, so they can action any issues quickly and drive the car to its full potential given its current state.

A well-integrated wiring harness should not have to be taken off the car for servicing once it has been installed. If produced with good manufacturing techniques and outstanding build quality, the LV systems on the car should capable of powering and running the car for the entirety of the two- year design cycle (which includes all testing sessions and all competitions in both Australia and Europe).

The electrical system must be designed and manufactured to adhere to a number of rules stipulated by the competition organisers. These rules are in place to ensure the safety of drivers and spectators whilst the car is running, in addition to regulating the competition so no teams are disadvantaged.

Upon completion of this project, Monash Motorsport should have the documentation required to produce high quality wiring harnesses and associated electronics for Formula-SAE applications. This includes accurate power budgeting, hardware selection, wiring harness design, correct manufacturing techniques and training for juniors.

2. Aims

To design, integrate and manufacture an electrical system to be installed on Monash Motorsport's 2019 combustion vehicle; M19-C. In doing so, the following outcomes are to be met:

- Conduct research for hardware and material selection
- Construct pinout spreadsheets to document all wire routing
- Design the entirety of the electrical system on CAD, including harness, hardware and switches
- Manufacture, install and validate the functionality of the electrical system on M19-C
- Develop ECU, PDM and Display packages on MoTeC's proprietary software and calibrate using MoTeC M1 Tune
- Train and transfer knowledge to juniors on correct loom design and manufacturing techniques

3. Methodology and Project Timeline

3.1 LV Systems Review and Research: January

At the commencement of this project, a thorough literature review was conducted. This involved a critical analysis of previous years' electrical systems – what went well, what could have been improved, and reliability issues. In addition to this, new harness design and manufacturing techniques were investigated that will improve the overall build quality and reduce manufacturing time (Journal Papers, FSAE Forums, Motorsport Articles). The performance and assembly requirements of the M19-C electrical system were established, relating it closely to the FSAE and Formula Student rulesets to ensure the system will be rules compliant at every competition it is expected to compete in.

3.2 Design and Integration: January - March

Following the research period, preliminary design of the electrical system began. This included the selection of hardware, development of pinouts for all MoTeC hardware and routing of the harness. The entire system was designed on Siemens NX (CAD software) and was closely integrated with other subsystems in the M19-C Master Model to ensure all components requiring connections to the harness were considered. The design period also considered viability of different manufacturing methods, outsourced manufacturing and production of a budget for all components required for assembly. A power budget was also established at this stage to ensure M19-C will be able to run at a constant gain with the hardware that has been selected for this iteration of the vehicle.

A series of concepts were generated and presented to MMS Alumni at Preliminary Design Reviews – where the initial designs were critiqued and feedback provided from experienced team members. This allowed for any overlooked flaws or issues to be brought up and discussed. Feedback from this review was addressed and changes implemented into the final design which was locked in at the end of the design period, after which no further major design changes were to be made to the system.

3.3 Manufacture and Installation: March - July

This period began with outsourcing, whereby all items required for manufacture were purchased and any outsourced manufacturing sent off to relevant suppliers. Once these items had arrived, manufacture commenced. All preliminary manufacture was completed during semester 1– which included the power relay, mounts, battery leads and the display housing. Manufacturing of the wiring harness commenced towards the end of the semester and into the winter break – when a more representative monocoque was present in the workshop. Once the harness was built, all the components were installed onto the monocoque in preparation for testing and validation.

3.4 Testing and Validation: June - November

Once all the components had been installed onto M19-C, configuration package were pushed to the MoTeC M150 ECU and PDM to power up the system and test its functionality. All the sensors were calibrated and tested to ensure the wires routed to them are functional and outputting expected values. During this stage, the MoTeC D153 Display was also set up to show key information to the driver, including critical temperatures, gear position and engine RPM.

When all the electrical components were confirmed to be working as desired, the car was started for the first time using a preliminary fuel table from the dynamometer. Upon successful test-fire, the car proceeded to on track testing to validate the performance of the system whilst driving. Data logging was set up to log the various vehicle dynamics and powertrain sensors at different frequencies, which allowed for data driven decision to be made. Once the car proved to run reliably, on track tuning commenced where parameters such as fueling, ignition and shifting configurations were swept through to maximise efficiency, set up automatic upshift and tune launch control.

During the entire process listed above (January – November), there was a particular emphasis on getting multiple juniors involved so they can learn process of loom design, manufacture and testing – placing them in good stead going into a potential Europe campaign in 2020.

A detailed timeline can be found it Appendix 1.

4. Research and Design

4.1 MMS Electrical System Literature Review

M17's LV systems were designed and manufactured with vastly different techniques compared to previous years. 2017 was the first year that the wiring harnesses were routed on CAD before manufacture. This meant that the positioning of hardware was finalised early and wires were routed around the car to avoid areas likely to damage (where the driver gets in and out and sources of heat). Robust manufacturing techniques were used including concentric twisting, splicing using mechanical crimps, glue lined heat-shrink over mechanical crimps, and heat shrinking the entire loom. This concept has been validated over the 5 competitions that cars have driven in and proved to be largely reliable. The goals for this year were to build upon the techniques used previously in attempt to further improve reliability and functionality (via the new ECU, display and ETB).

An issue that appeared intermittently in 2018 was the short circuiting of the steering wheel shift LEDs during wet driving, which almost resulted in an DNF in the 2018 FSAE-Australasia Endurance. As such, waterproofing will be of paramount importance, and close collaboration is required with steering wheel part designers to ensure the steering wheel electronics are completely sealed. Additionally, the use of epoxy resin over heat shrink ends will be explored to add another layer of protection from water and other contaminants from entering the loom.

Careful consideration for the selection of wire gauges and types must be made to ensure the required reliability for the loom is attained. Power wiring can burn up and prevent proper power delivery to components if gauge is too small. Signal wire can induce noise and prevent accurate measurements if not properly shielded and the gauge is too small. By assessing required current of the different lines and capacity details given by manufacturer datasheets, the loom can be made to both minimise mass and ensure reliability.

Integration of the MoTeC E816 CAN Expander was also explored. It is a module that is designed to increase the I/O of MoTeC products. It integrates CAN connectivity and a number of configurable inputs and outputs, to provide greater flexibility to add sensors, customise channels and control more auxiliary functions. In our application, it would be used to simplify the harness in terms of the number of wires running from the front of the car to the rear. This would be done purely in the interest of simplifying wire routing and saving wire mass, whilst allowing for a large amount of suspension sensors to be integrated at the front of the car. Although the merits of the CAN Expander are very obvious, the final decision is to abstain from integrating it into the system this year. This is because the device itself weighs approximately 300g, which is insignificant compared to the mass in wires that would be used to run sensor wires from the front to the rear estimated to be no more than 100g). Furthermore, the strain on the power budget, packaging, and the additional resources required to implement a MoTeC hardware that the team has never used makes the concept less appealing. Alumni consultation also resulted in this consensus, but also got given recommendation that the CAN Expander is still worth keeping as an option for expandability of the current loom – if more sensors were required to run to gather data during testing sessions, then an external sensor loom may be connected via the expander.

4.2 Hardware Selection

The selected hardware for M19-C are the MoTeC M150 ECU, D153 Display, BR2 Beacon and Shorai LFX18A1-BS12. The primary reason for the selected MoTeC hardware is the team's current access to these items. The M150 was selected over the M400 (previously used on Monash Motorsport vehicles) for its ability to log (250mb of logging memory) - M400 could not. This meant that the Advanced Dash Logger (a previously used MoTeC Display) was no longer required, allowing the use of the D153 (a coloured display that is fully customizable). The M150 ECU has 3 individual CAN buses, meaning a reduced likelihood of overloading issues, and also has a large amount of inputs and powered outputs. It is also 50 grams lighter than M400 ECU.

Table 4.1: ECU Comparison

	M400	M150
		
Injector		
Peak & Hold Outputs	4	12
Ignition		
Low Side Ignition Outputs (max)	4	12
Auxiliary Outputs		
Low Side Output	8	6
Half Bridge Output	0	10
Inputs		
Universal Digital Input	0	12
Digital Input	4	4
Analogue Voltage Input	8	17
Analogue Temp Input	6	6
Lambda	1	2
Data		
CAN Bus/RS232/LIN	1/1/0	3/1/1
Logging Memory (MB)	0	250
Physical Size		
Dimensions, mm (LxWxH)	147x105x40	162x127x39
Weight (g)	500	450
No. of Connectors		
Superseal	2	4
Pins	60	120

For battery selection, Lead Acid and Lithium Ion ($LiFePO_4$) battery chemistries were considered. $LiFePO_4$ batteries contain no poisonous lead, no dangerous acid, and do not create explosive gasses during charging, as traditional Lead-Acid batteries do. Compared to lead-acid, lithium-ion batteries are also extremely light, have much lower self-discharge rate and do not sulfate (i.e. do not degrade while sitting unattended). They are also considerably more energy dense. These characteristics can be seen from Figure 4.1 and Table 4.2 below:

Table 4.2: Battery Comparison

Shorai LFX18A1-BS12 Chemistry: LiFePO4	Voltage (V)	12
	Capacity (Ah)	18
	Usable Cap. (Ah)	5.4
	CCA (A)	270
	Weight (g)	997
	Charge Rate (A)	18
	Dimensions (L/W/H)	148/66/105

Katana YTX9-BS Recommended by KTM Chemistry: Lead Acid	Voltage (V)	12
	Capacity (Ah)	8
	Usable Cap. (Ah)	8
	CCA (A)	135
	Weight (g)	4590
	Charge Rate (A)	0.8
	Dimensions (L/W/H)	150/87/105

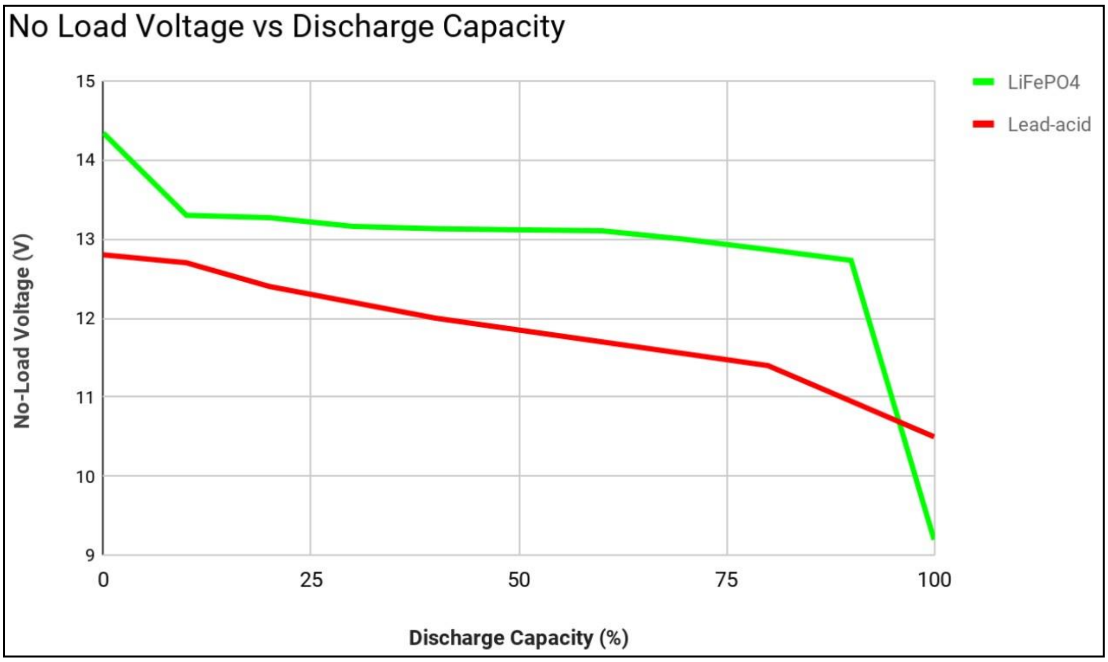


Figure 4.1: Battery Chemistry Discharge Characteristics

The Shorai 18Ah model was selected due to its high energy capacity. It was mentioned by alumni during the concept review that it is not worth downsizing the Shorai to the 14Ah model purely to save mass, as having more energy capacity is always a good fail safe, particularly if the car experiences any alternator or regulator rectifier issues. It was also mentioned that the 14Ah should only get selected if packaging was an issue. As such, the 18Ah Shorai was been selected and has been packaged for.

The ECU, PDM and Battery will all be positioned under the seat, behind the seat firewall. This is the most central location of the car and allows for the loom to be split to a front and rear loom. This position for the battery also means that an additional battery box will not be required, as it will already be behind a firewall. The selection concepts and criteria for hardware position can be seen below:

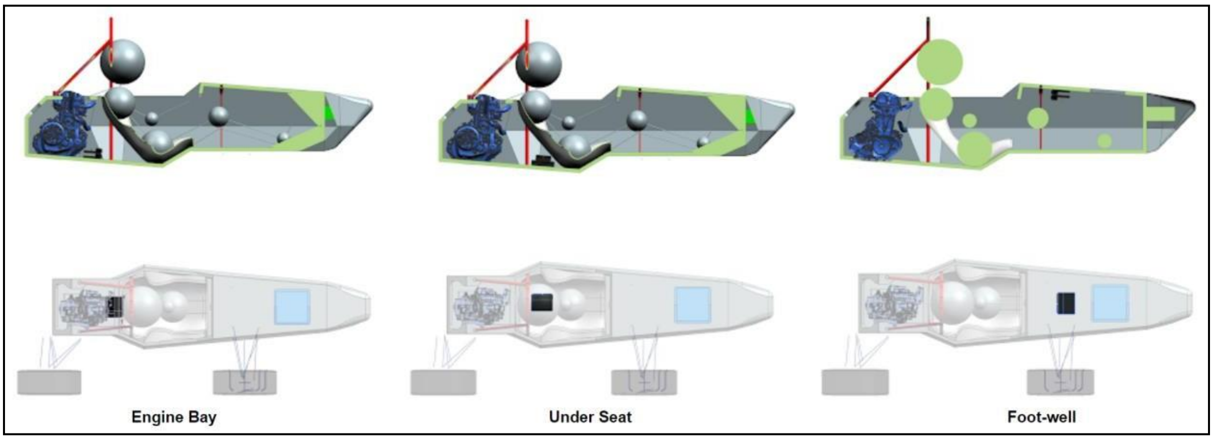


Figure 4.2: Hardware Position Concepts

Table 4.3: Hardware Position Analysis

Criteria	Under seat	Engine bay	Foot-well (M16 placement)
Pros	-Easy to package and mount -Minimised wire length -Easy to service -Protected from environment	-Lightest loom possible since its closest to the engine and rear loom	-Distanced from engine vibrations -Close to dash, steering wheel and front sensors
Cons	-Seat has to be removed to access -If battery is also there, then an additional battery box is required since it's in front of firewall	-Difficult to mount -Exposed to heat (potential of ECU shutdown due to overtemp) -Exposed to oil and coolant leaks	-Could be stepped on -Wire could get strained/ damaged when driver gets in and out
Composites (man hours)	Heat resistant wall/ box of sorts required for battery	No composites required	Heat resistant wall/ box of sorts required for battery
Reliability Concerns & Potential Testing time lost	-	Hazards from engine (heat and fluids)	Drivers damaging electrical componentry when getting in and out

4.3 Material Selection

Table 4.4: Wire Comparison

Property	Cambridge Tefzel Wire	Raychem Wire
Cost	~$0.50 per m (22AWG)	~$0.90 per m (22AWG)
Availability	Readily Available Quick shipping or on the day pickup	Buy from GR (but they are a seller so supply might be intermittent) Can pick up on same day
Pros	Cheap, reliable, used for entire loom on both cars currently, proved and validated.	Smaller insulation layer - lighter wire. Claimed to be of really high quality
Cons	Slightly heavier than Raychem	Expensive
Other Notes to Consider	Very helpful staff. MMS has a billing account with them.	Last year MMS had a small sponsorship wish-list from them - didn't eventuate into anything much. Potentially something that business can pursue.

Cambridge Tefzel Wire has been selected - A combination of 22AWG and 20AWG based on wire purpose (12V, 5V or Signal). Cambridge wire is cheap, reliable, used for entire loom on both M18-E and M18-C currently, proved and validated. Although it is slightly heavier than Raychem wire, its cost and reliability make it the preferred choice. They have very helpful staff and MMS already have a billing account set up with them.

Table 4.5: Heatshrink Comparison

Property	RS Pro Heatshrink	Raychem Heatshrink
Cost	~$8.28 per m (12.7mm)	~17.75 per m (12.7mm)
Availability	Readily available Fast shipping from RS. (Will arrive next day if ordered before COB and dispatched from VIC)	Again, from GR, re-seller so supply might be intermittent Potential to pick up same day pending stock
Pros	Cheap, reliable, used for entire loom on both cars currently, proved and validated.	Very high quality heatshrink. Incredible post shrink feel and quality of end product. Highly flexible
Cons	Stiff, sometimes un-preferred in sections of the loom that has tight radii	Double the price of RS heatshrink
Other Notes to Consider	Appropriate sizes need to be used to ensure a good wrap tight wrap around the wires and there's no airgap, hence no possibility of the heatshrink kinking.	If within the budget, entire loom would be wrapped in Raychem heatshrink. Raychem heatshrink is used for other high-end applications (IZZE sensors, MoTeC wiring)

A combination of RS Pro and Raychem heatshrink will be used. RS Pro heatshrink will be used for the core and central section of the loom (approximately 80% of the loom). This is due to it being cheap, reliable, proved and validated on both cars currently. Raychem heatshrink will be used for the branches that lead out to connectors. This is because those branches are what sees the most movement and get frequently connected/ disconnected. Although Raychem is more expensive than RS, its high flexibility makes it a suitable choice for splice branches.

Table 4.6: Connector Comparison

Property	DTM	Autosport
Cost	~$8.00 (12 pin)	~$90.00 (12 pin)
Availability	Readily Available from RS Components Quick shipping or on the day pickup	Buy from GR (but they're a re-seller so supply might be intermittent) Can pick up on same day
Pros	Cheap, light, reliable, easy to use, used as the main connector type on both cars, proved and validated. Waterproof	Mil-spec quality. Built from robust materials, will not damage easily, Water proof, easy to use.
Cons	Bulky (especially 6 pins and higher)	Almost 10 times more expensive
Other Notes to Consider	Ran out of pins + sockets quickly with troubleshooting, sheared crimps, and other designers using crimps.	Large price tag means it will only get used where necessary (beacon, accumulator, maybe steering wheel)

DTM, Autosport, and various automotive connectors will be used. DTM connectors will be the primary connector type used throughout, as it is lightweight, cheap and reliable and waterproof. They are easy to source (from RS Components) and there is only a small learning curve to use them so teaching juniors will not be an issue. Autosport connectors will only be used where necessary (Beacon). Various OEM connectors will also be used where necessary (specific sensors, ignition module/ coils, etc.). The pinning process for each of these connectors is outlined later in this report.

4.4 Power Budget

Table 4.7: M19-C Final Power Budget

Component(s)	Power (W)	Av. Voltage (V)	Av. Current Draw (A)
M150 ECU (No loads)	7.176	13.8	0.52
PDM15 (No loads)	0.483	13.8	0.035
D153 Dash	5.244	13.8	0.38
Fuel Pump	62.1	13.8	4.5
Injector	3.036	13.8	0.22
Ignition Coil 1	8.418	13.8	0.61
Ignition Coil 2	8.418	13.8	0.61
Lambda Sensor	3.45	13.8	0.25
Fan Right	69	13.8	5
Fan Left	69	13.8	5
Suspension		5-12	0.471
Total Average Current Draw			17.596
690 Alternator Output	300	13.8	21.73913043
Current Surplus/ Deficit	4.143130435	A	
Average Auscomp Endurance Time	1681.3	s	
Battery Capacity Generated/ Used	1.934957	Ah	
Average Cracking Current	77	A	Calculating how much capacity (Ah) is used over a full endurance with 8 car restarts.
Time per crank	4	s	
Capacity used per crank	0.08555555556	Ah	
Cranks per endurance	8		
Total capacity used per endurance	0.6844444444	Ah	
Safety Factor	3		A battery of 2.05 Ah usable must be selected
Required Battery Capacity	2.053333333	Ah	

The power budget for M19-C has seen a number of refinements over the course of the design period. At the concept stage, there was an estimated total current draw of 13.305A. This was prior to confirmation of various electrical components such as the fuel system, fans and suspension sensors. At this stage, there was also ambiguity surrounding the actual output of the KTM 690 engine alternator. Once final designs had been confirmed, part designers have locked in their components resulting in a more accurate power budget. The main difference between the previous power budget and now is the PWM fuel system (drawing approximately 4.5 Amps) and the fans (drawings 5 Amps). Additionally, a current test was conducted on M18-C to determine the actual alternator output rather than relying on the technical manual and a utilisation factor (results and discussion can be found in section 4.6)

This final power budget shows that M19-C will run at a constant gain (with 4.14 Amps surplus), meaning that the current draw performance target for this car has been achieved. Running at constant gains means that the energy used by the car is less than the energy supplied by the alternator, ultimately meaning that the battery will always be charging as the car is driving. With the selected battery, the car will be capable of dry cranking for a total time of 252 seconds before the capacity of the battery depletes to unusable levels.

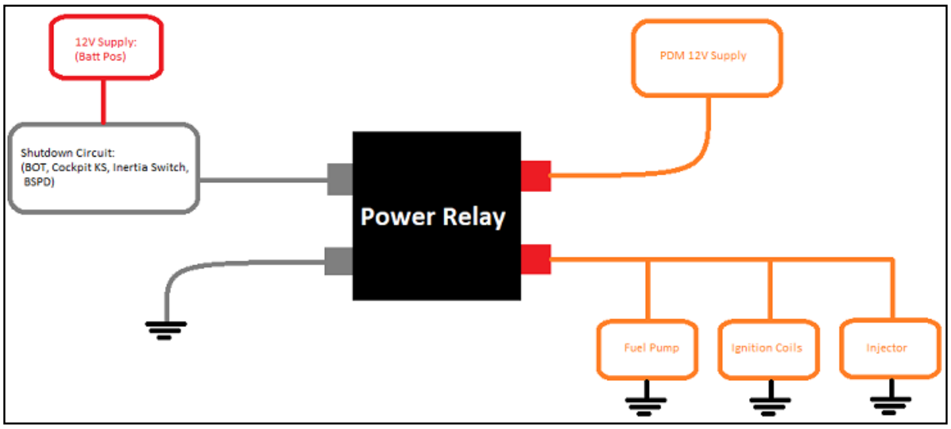
4.5 Shutdown Circuit

The shutdown circuit is mandated by rules, and is required to kill the car should it be in a state that is unsafe to drive. The shutdown circuit is loop of switched in series, whereby an open circuit will result in the loss of power to ignition and fueling, ultimately killing the car. The shutdown circuit for M19-C is as follows:

Figure 4.3: M19-C Shutdown Circuit Order

A mechanical relay is used for this purpose because rules state that shutdown circuit must be implemented with analogue components, and not using programmable logic controllers, engine control units, or similar functioning digital controllers. The original design for the shutdown circuit involved a relay which was in line with the battery and the PDM – whereby a trip in the circuit would kill power to the entire car since power to the PDM was cut. An FSG rule states that the cockpit kill switch must also be in line with the rest of the shutdown circuit. The implications of this for the original design is that whenever the cockpit kill switch is triggered, the entire car will turn off (including PDM and Display). This is far from desirable since cockpit kill switch is required to act as a switch between the prime on and prime off states. The solution for this was to rewire the shutdown circuit such that, if tripped, it doesn't cut power to the PDM - but only cut power to fuel pump, ignition and injector (which is acceptable by rules). A schematic of the new shutdown circuit is provided below:

Figure 4.4: M19-C Power Relay Schematic



There are a number of benefits this new power relay system has over the previous. Firstly, it will be much neater since the only wires that will connect to it are 20 and 22-gauge wire. Previously, there was 8-gauge wire in addition to 22-gauge wire which made for a very bulky component once all the terminals were sealed with plexus. The next benefit is that a trip of the brake over travel will only result in the pump, coils and injector being un-powered, as opposed to the entire car. This will make troubleshooting easier and the dash will remain on and display a trip in the shutdown circuit. The cockpit kill switch wiring will make use of the both the normally open and normally closed pins on the mushroom style push switch. The normally open pins will be used for the shutdown circuit, and the normally closed pins will be used as a switch input into the D153 display, so the car will know when the switch is closed and the car is in the "primed" state.

4.6 Current Draw Testing

During the design period, a current draw test was conducted to determine the actual output of the KTM 690 alternator, and starter motor current draw. The results are presented below:

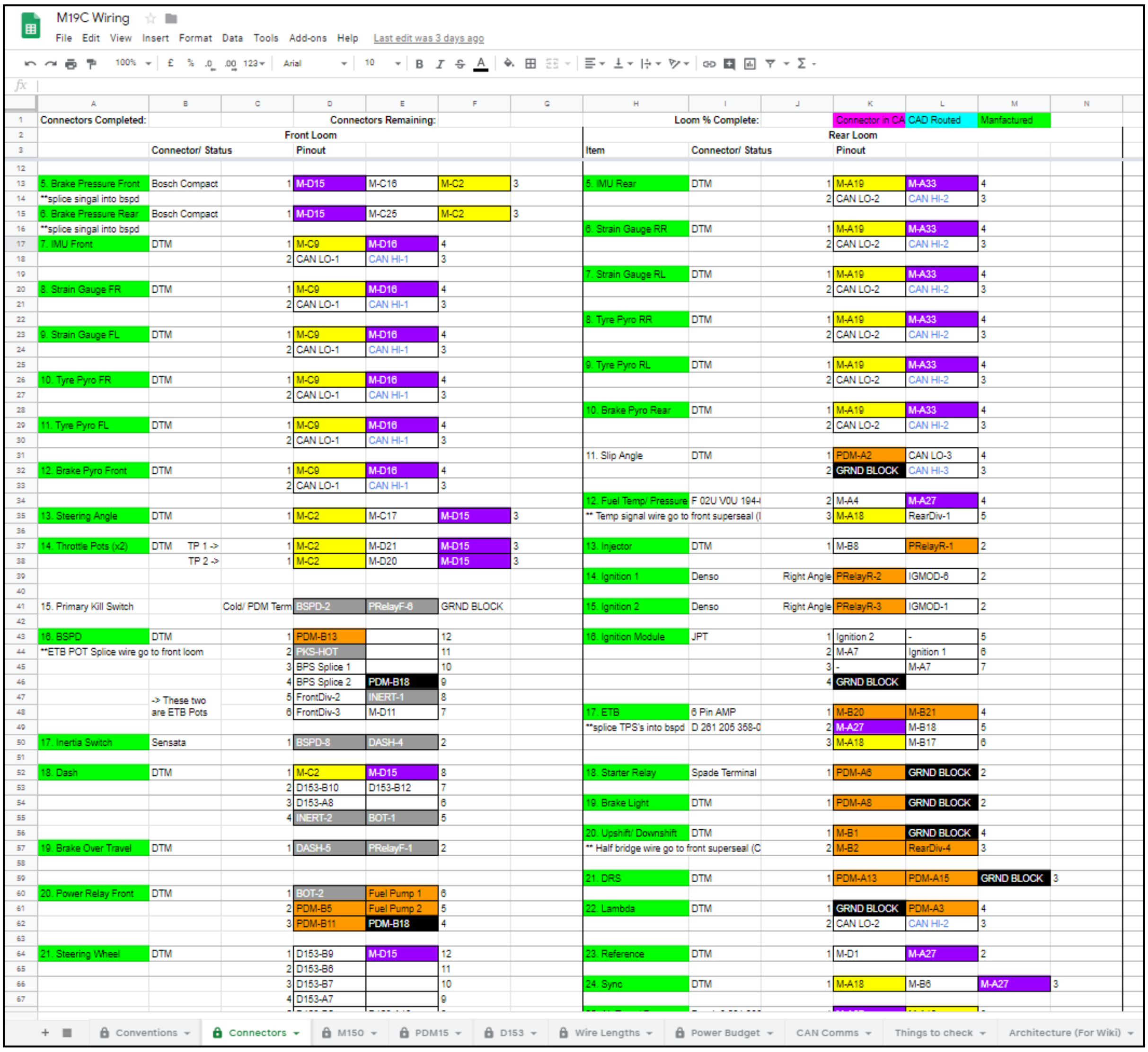
Table 4.8: Current Test Results

Purpose of Test	Variables Measured	Results
Starter Motor Draw	Current Draw	77 Amps
Alternator Output	Current Output	22 Amps

The preliminary power budget for M19-C relied on the starter motor current draw that was mentioned on the KTM manual, being 150 Amps. It was discovered that only 77 Amps were drawn by the starter motor upon cranking, making the power budget calculations extremely conservative. The result of this test influences the battery selection, since a lower starter motor current draw will mean a smaller battery capacity will be required for cranking. With the addition of this update into the power budget, only a 2.05Ah usable battery needs to be selected. This brings credibility to the downsizing of the Shorai, and makes the 14Ah Shorai a viable option. That being said, the 18Ah Shorai will still be selected battery, packaged for and saved for a rainy day, and the 14Ah will only be considered if packaging becomes an issue with the 18Ah Shorai.

The KTM 690 manual claims to have an alternator output of 300W. A conservative approach was taken for the preliminary power budget and an 80% utilisation factor was assumed for the alternator output. This resulted in an assumed average alternator output of 240W (0.8*300). This 240W was then used in calculating current output of the alternator by using the 13.8V average regulated voltage by the regulator rectifier - leading to a conservative current output of 17.39 Amps for the alternator. The results of the alternator output test indicated a current output of 22 Amps. This actual output is 5 Amps higher than the conservative estimate, and results in 303.4W output from the alternator. This ultimately confirms 100% alternator usage, since the calculated output (303.6W) agrees with what the manual claims (300W). This result favors the power budget considerably, since there is now 5 more amps to play with than anticipated, and allows for the PWM fuel system and servo-controlled ARBs to be a serious consideration as the car will still be able to run at constant gain.

4.7 *Wiring and Pinout Documentation*



	A	B	C	D	E	F	G
1	Connectors Completed:			Connectors Remaining:			
2			Front Loom				
3		Connector/ Status		Pinout			
12							
13	5. Brake Pressure Front	Bosch Compact	1	M-D15	M-C16	M-C2	3
14	**splice singal into bspd						
15	6. Brake Pressure Rear	Bosch Compact	1	M-D15	M-C25	M-C2	3
16	**splice singal into bspd						
17	7. IMU Front	DTM	1	M-C9	M-D16	4	
18			2	CAN LO-1	CAN HI-1	3	
19							
20	8. Strain Gauge FR	DTM	1	M-C9	M-D16	4	
21			2	CAN LO-1	CAN HI-1	3	
22							
23	9. Strain Gauge FL	DTM	1	M-C9	M-D16	4	
24			2	CAN LO-1	CAN HI-1	3	
25							
26	10. Tyre Pyro FR	DTM	1	M-C9	M-D16	4	
27			2	CAN LO-1	CAN HI-1	3	
28							
29	11. Tyre Pyro FL	DTM	1	M-C9	M-D16	4	
30			2	CAN LO-1	CAN HI-1	3	
31							
32	12. Brake Pyro Front	DTM	1	M-C9	M-D16	4	
33			2	CAN LO-1	CAN HI-1	3	
34							
35	13. Steering Angle	DTM	1	M-C2	M-C17	M-D15	3
36							
37	14. Throttle Pots (x2)	DTM TP 1 ->	1	M-C2	M-D21	M-D15	3
38		TP 2 ->	1	M-C2	M-D20	M-D15	3
39							
40							
41	15. Primary Kill Switch		Cold/ PDM Term	BSPD-2	PRelayF-6	GRND BLOCK	
42							
43	16. BSPD	DTM	1	PDM-B13		12	
44	**ETB POT Splice wire go to front loom		2	PKS-HOT		11	
45			3	BPS Splice 1		10	
46			4	BPS Splice 2	PDM-B18	9	
47		-> These two	5	FrontDiv-2	INERT-1	8	
48		are ETB Pots	6	FrontDiv-3	M-D11	7	
49							
50	17. Inertia Switch	Sensata	1	BSPD-8	DASH-4	2	
51							
52	18. Dash	DTM	1	M-C2	M-D15	8	
53			2	D153-B10	D153-B12	7	
54			3	D153-A8		6	
55			4	INERT-2	BOT-1	5	
56							
57	19. Brake Over Travel	DTM	1	DASH-5	PRelayF-1	2	
58							
59							
60	20. Power Relay Front	DTM	1	BOT-2	Fuel Pump 1	6	
61			2	PDM-B5	Fuel Pump 2	5	
62			3	PDM-B11	PDM-B18	4	
63							
64	21. Steering Wheel	DTM	1	D153-B9	M-D15	12	
65			2	D153-B6		11	
66			3	D153-B7		10	
67			4	D153-A7		9	

	H	I	J	K	L	M	N
1		Loom % Complete:		Connector in CA	CAD Routed	Manfactured	
2				Rear Loom			
3	Item	Connector/ Status		Pinout			
13	5. IMU Rear	DTM	1	M-A19	M-A33	4	
14			2	CAN LO-2	CAN HI-2	3	
16	6. Strain Gauge RR	DTM	1	M-A19	M-A33	4	
17			2	CAN LO-2	CAN HI-2	3	
19	7. Strain Gauge RL	DTM	1	M-A19	M-A33	4	
20			2	CAN LO-2	CAN HI-2	3	
22	8. Tyre Pyro RR	DTM	1	M-A19	M-A33	4	
23			2	CAN LO-2	CAN HI-2	3	
25	9. Tyre Pyro RL	DTM	1	M-A19	M-A33	4	
26			2	CAN LO-2	CAN HI-2	3	
28	10. Brake Pyro Rear	DTM	1	M-A19	M-A33	4	
29			2	CAN LO-2	CAN HI-2	3	
31	11. Slip Angle	DTM	1	PDM-A2	CAN LO-3	4	
32			2	GRND BLOCK	CAN HI-3	3	
34	12. Fuel Temp/ Pressure	F 02U V0U 194-(	2	M-A4	M-A27	4	
35	** Temp signal wire go to front superseal (I		3	M-A18	RearDiv-1	5	
37	13. Injector	DTM	1	M-B8	PRelayR-1	2	
39	14. Ignition 1	Denso	Right Angle	PRelayR-2	IGMOD-6	2	
41	15. Ignition 2	Denso	Right Angle	PRelayR-3	IGMOD-1	2	
43	16. Ignition Module	JPT	1	Ignition 2	-	5	
44			2	M-A7	Ignition 1	6	
45			3	-	M-A7	7	
46			4	GRND BLOCK			
48	17. ETB	6 Pin AMP	1	M-B20	M-B21	4	
49	**splice TPS's into bspd	D 261 205 358-0	2	M-A27	M-B18	5	
50			3	M-A18	M-B17	6	
52	18. Starter Relay	Spade Terminal	1	PDM-A6	GRND BLOCK	2	
54	19. Brake Light	DTM	1	PDM-A8	GRND BLOCK	2	
56	20. Upshift/ Downshift	DTM	1	M-B1	GRND BLOCK	4	
57	** Half bridge wire go to front superseal (C		2	M-B2	RearDiv-4	3	
59	21. DRS	DTM	1	PDM-A13	PDM-A15	GRND BLOCK	3
61	22. Lambda	DTM	1	GRND BLOCK	PDM-A3	4	
62			2	CAN LO-2	CAN HI-2	3	
64	23. Reference	DTM	1	M-D1	M-A27	2	
66	24. Sync	DTM	1	M-A18	M-B6	M-A27	3

Figure 4.5: M19-C Wiring Spreadsheet Screenshot

This spreadsheet is the holy grail of M19-C's electrical system. It contains a list of every single sensor, connector and piece of electrical hardware on the car alongside the pin out for each component. There are 4 primary tabs in this spreadsheet; Connectors, M150, D153 and PDM. The tabs for M150, D153 and PDM contains the pin outs for these MoTeC hardware with their use(s) assigned next to them. The Connectors tab shows where each individual wire originates from and goes to. Due to the intricate nature of this spreadsheet, it is very critical that it remains as up to date and as accurate as possible. As such, the spreadsheet will be locked and edit permission only given to responsible individuals directly involved with the system - this has been an issue in the past whereby people accessing this spreadsheet accidentally edit it making for very frustrating troubleshooting sessions. It can also be noted that a wire colour convention has been used (detailed in the Conventions tab). This is done so to improve the serviceability of the system, reduce manufacturing complexity and assist during troubleshooting.

4.8 Computer Aided Design

Following the development of detailed pinout spreadsheets, the entire system was designed and routed on Siemens NX 12.0 CAD software using the electrical wiring harness application. A detailed tutorial on how to use this harness application has been produced by an MMS alumnus (see reference list).

Figure 4.6 below shows the general locations for all hardware and sensors that were conceptualized during the early design period. As part designers began finalizing designs, and part locations were locked in, more accurate decisions on the positioning of hardware and sensor connectors were able to be made.

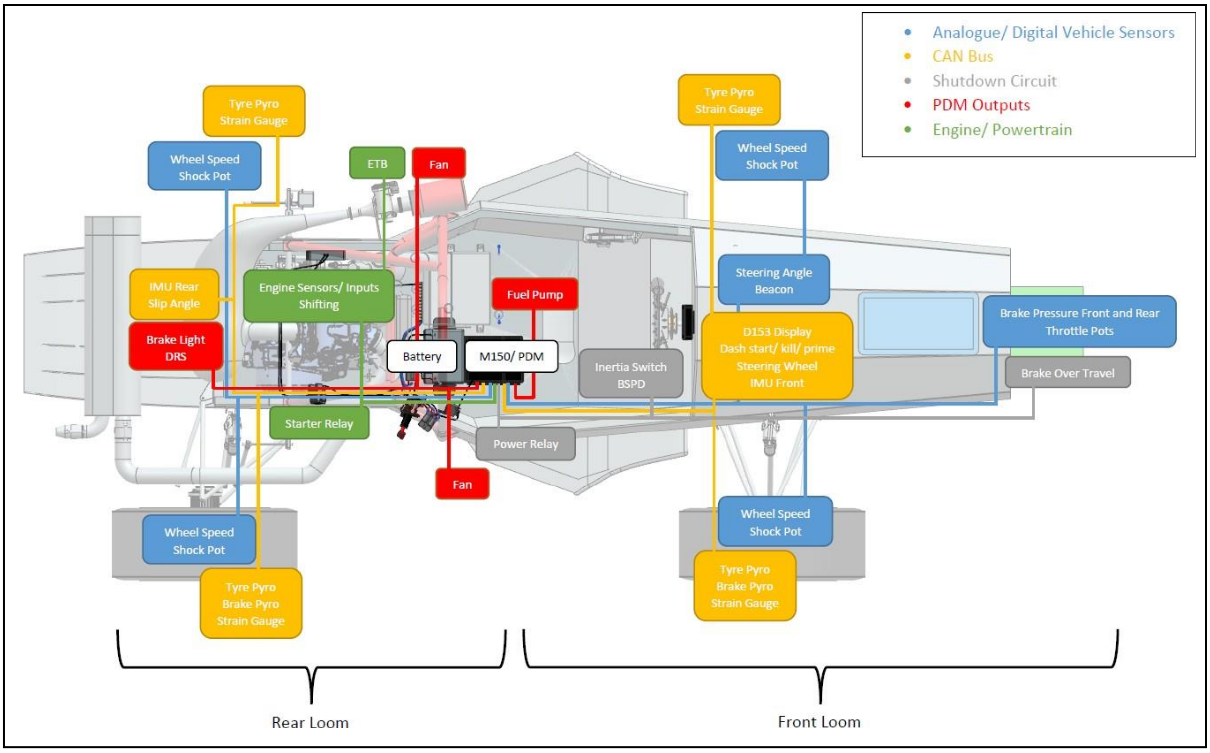


Figure 4.6: M19-C Electrical System Map

The CAD process was commenced by placing all the hardware in the finalized locations. These include battery, ECU, PDM, display, Beacon, switches and sensors. Following this, all the connectors were placed in their corresponding locations. A major goal for this loom was to have a front and rear loom split. This would be done as an attempt to increase manufacturability and serviceability, as both halves of the loom can get manufactured independent to one another. As such, the front loom was routed in CAD first, followed by the rear loom. Routing the system on CAD serves a number of benefits:

- Ability to route the harness away from areas of potential damage
  - Heat sources such as exhaust and engine
  - Drivers entering/ exiting vehicle (footwell and under seat)
  - Rotating objects such as driveline and wheels
- Ability to secure locations for hardware and minimise packaging and Interference issues
- Ability to export all wire lengths, ultimately streamlining the manufacturing process

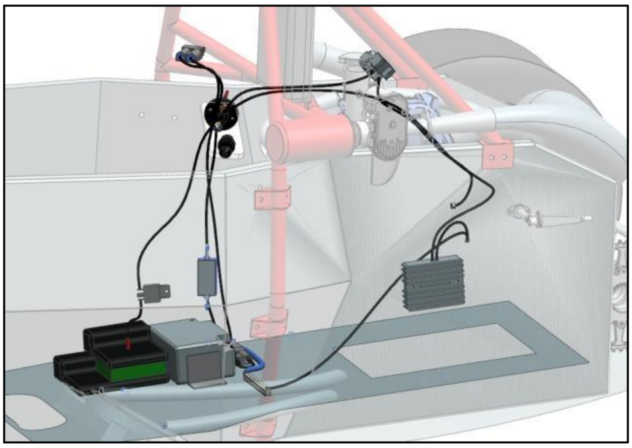


Figure 4.7: Hardware and Power Wiring

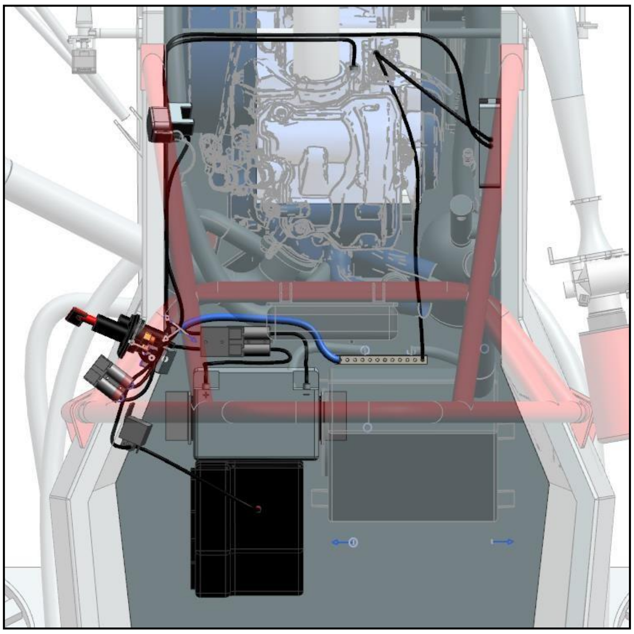


Figure 4.8: Hardware and Power Wiring Top View

The ECU, PDM and Battery will all be position under the seat, behind the seat firewall. This is the most central location of the car and allows for the loom to be split to a front and rear loom. This position for the battery also means that an additional battery box will not be required, as it will already be behind a firewall.

The goal for the power wiring was to have it as simple as possible, reducing 8-gauge power wire length and also increasing its serviceability.

The total length for the power wiring is 4.99 m. The structural body work of the monocoque allows for the mounting of components onto the walls of the car. The power relay, fuse and fuse holder and ignition module will all be mounted on the inner right wall of the monocoque, directly opposite the battery, ECU and PDM for wire length minimisation.

The grounding block is used so that all component grounding wires can be grounded via one central location. The grounding block will be located immediately behind the fuel tank.

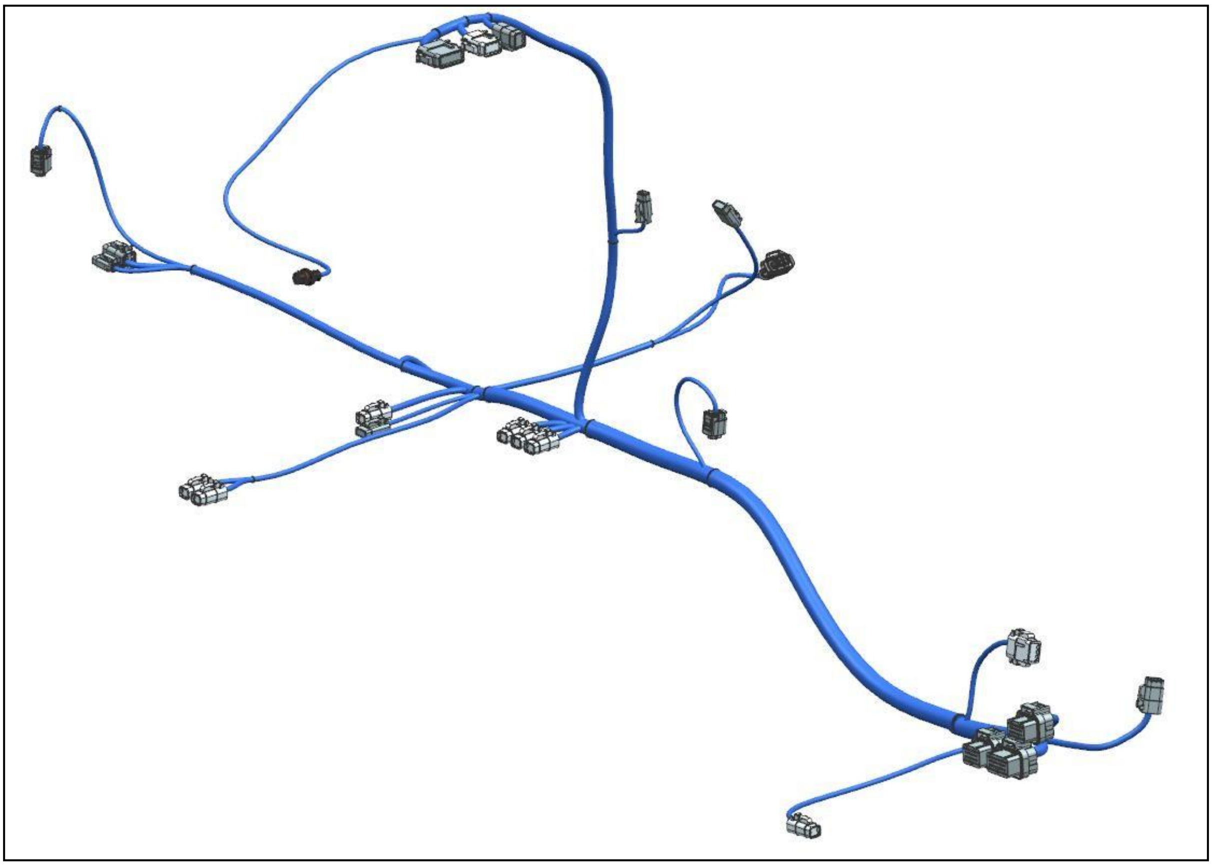


Figure 4.9: M19-C Front Loom Isometric View

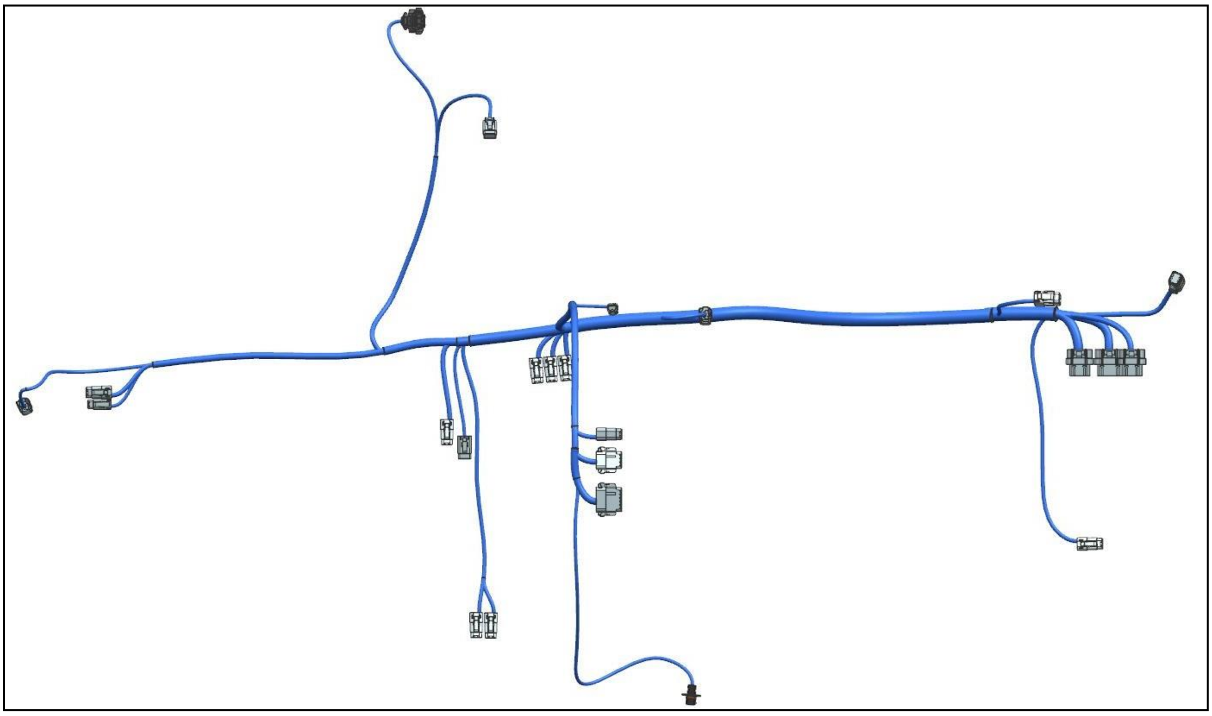


Figure 4.10: M19-C Front Loom Top View

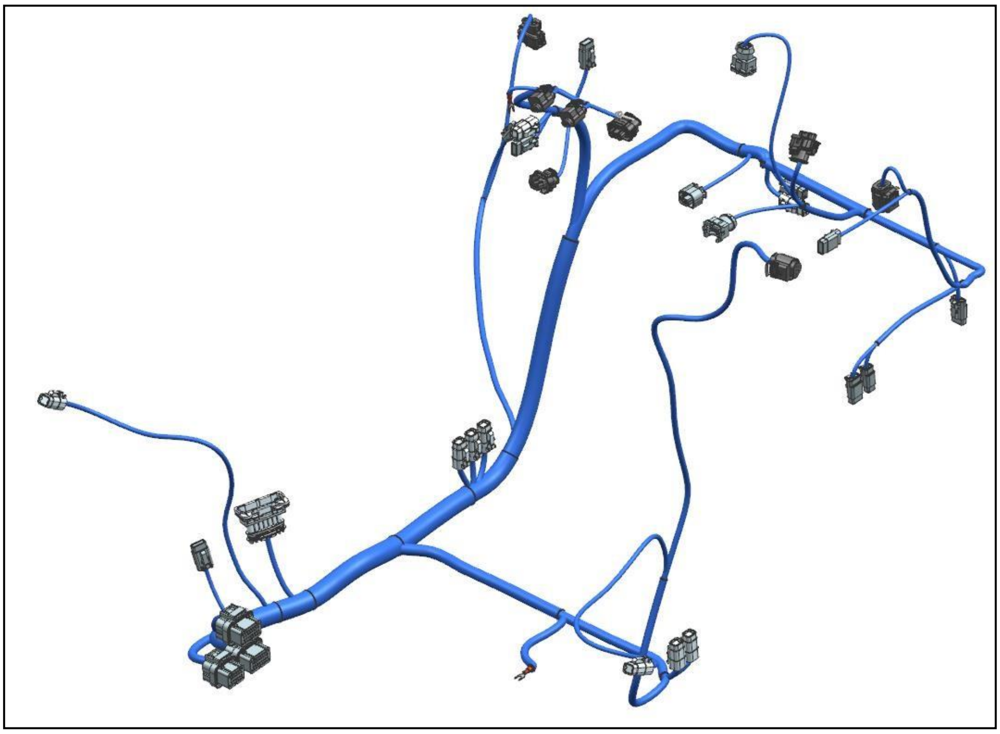


Figure 4.11: M19-C Rear Loom Isometric View

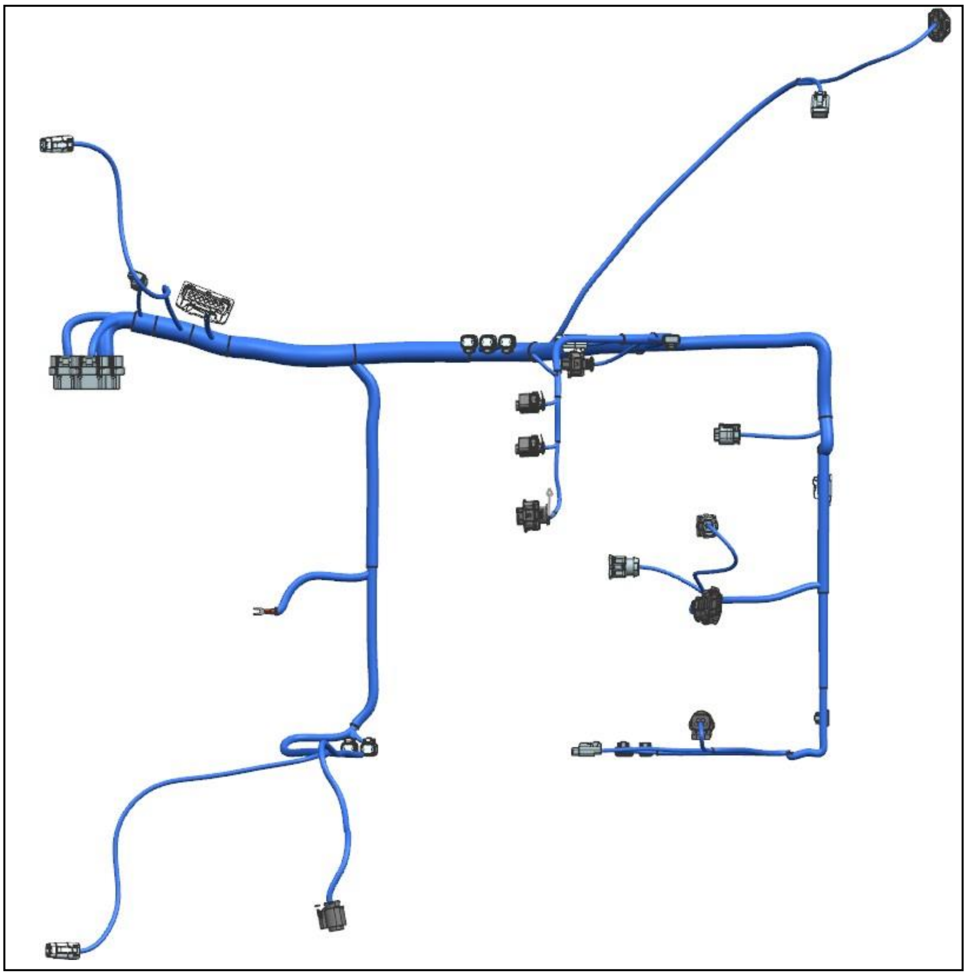


Figure 4.12: M19-C Rear Loom Top View

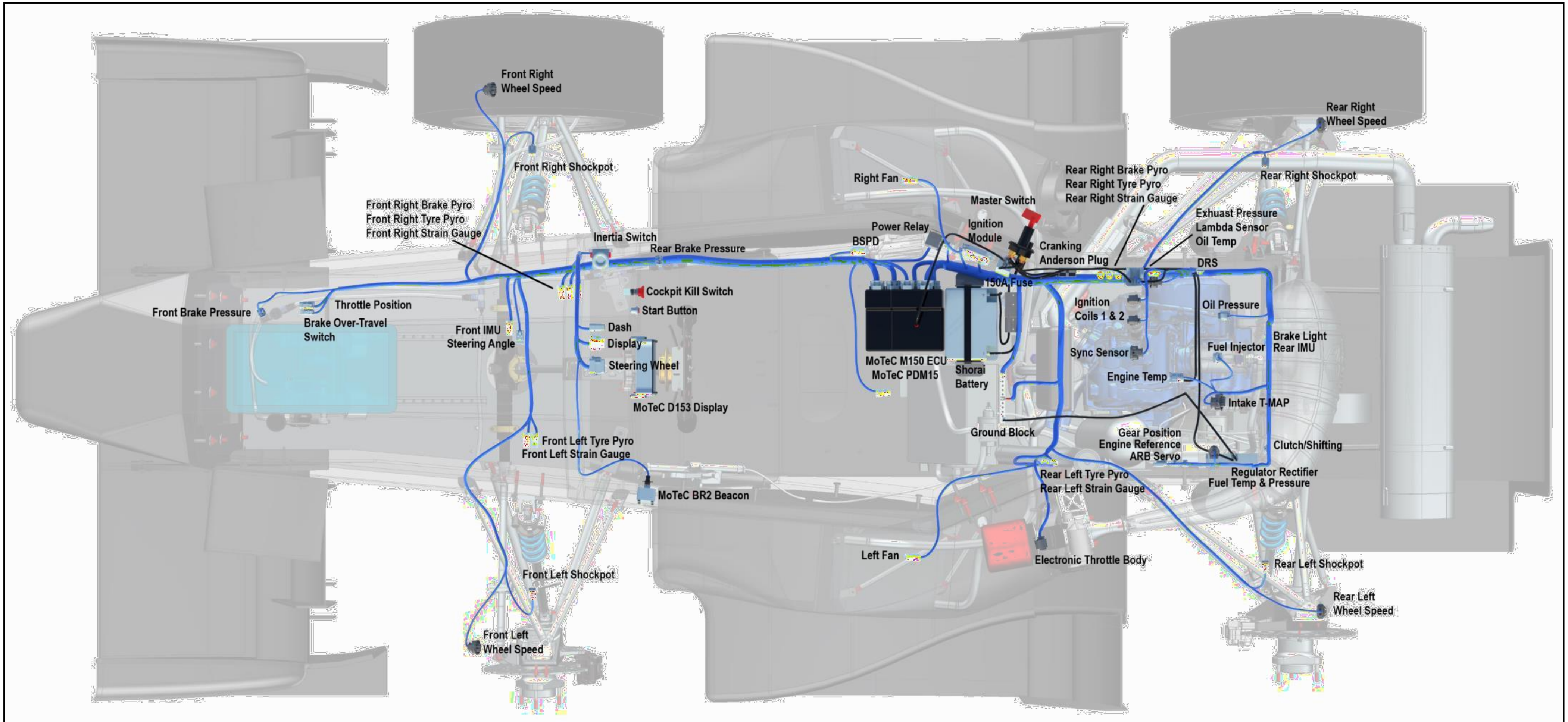


Figure 4.13: M19-C Full LV Systems on CAD Master Model

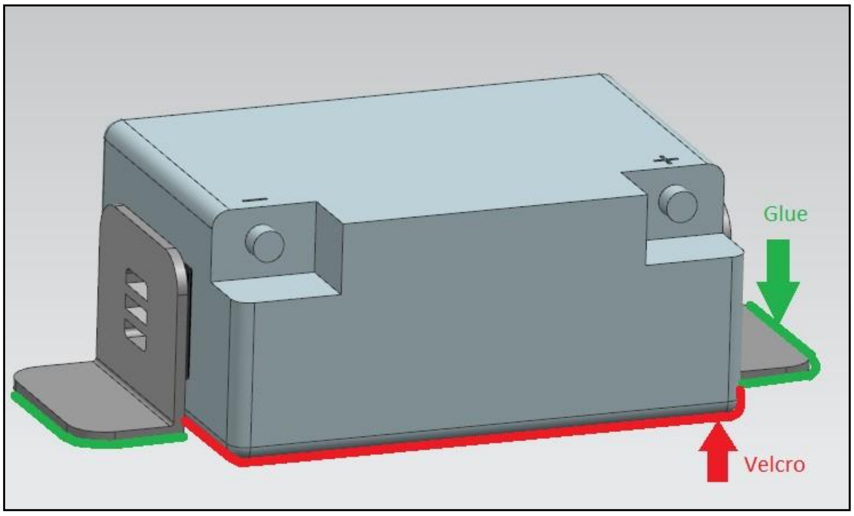


Figure 4.14: Battery Mounting

The entire bottom face of the battery will be lined with Velcro and attached to the monocoque floor. In addition to this, there will be 2 L brackets on either side of the battery with a buckle - where a strap will be weaved through to securely fasten the battery. This mounting method enables the battery to be easily removable for charging.

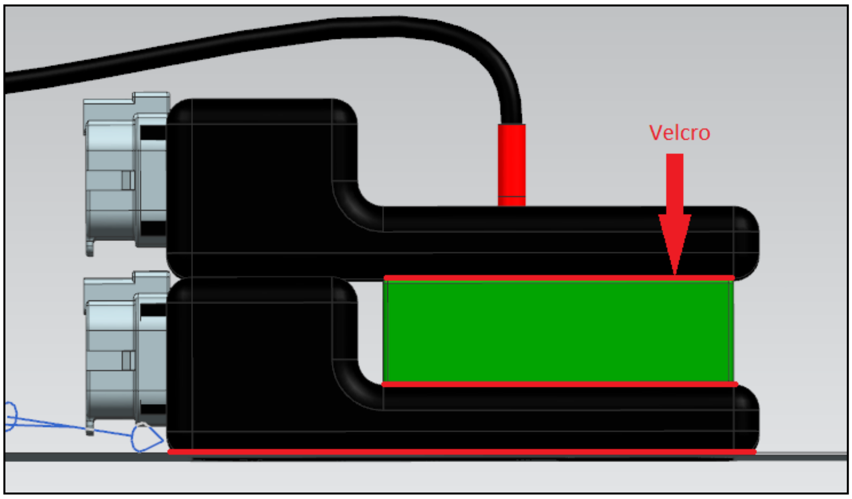


Figure 4.15: ECU/ PDM Shim and Mounting

The ECU and PDM will be stacked one on top of the other and mounted to the chassis with Velcro. This again ensure easy removability when swapping hardware between car and dyno. Additionally, a foam shim will be placed in between the two so that the PDM does not cantilever off the ECU. The position of the ECU and PDM was finalised to be under the seat. This is the most central location and allows for the implementation of a front and rear loom without the need for a dividing connector. The wiring pin outs have been done such that connector A and B on M150, and connector A on PDM are for the rear of the car, and connector C and D on M150, and connector B on PDM are for the front of the car. This largely simplifies manufacturing since the two halves of the loom can be manufactured independent of one another. This is also made possible through the use of the multiple CAN busses on the M150. There will be a single CAN bus for the front of the car, and single CAN bus for the rear, and a dedicated CAN bus for slip angle sensor and any other CAN sensors that the team decides to integrate in the future.

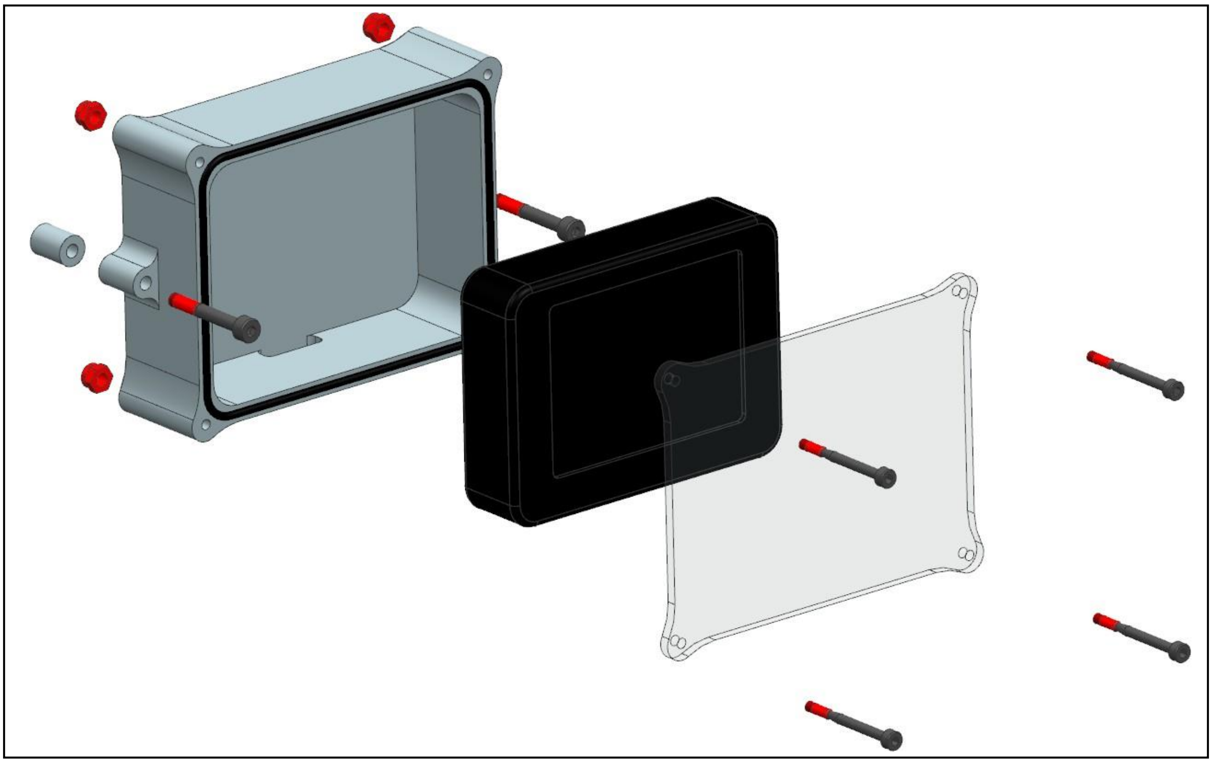


Figure 4.16: Display Casing Assembly Explosion

The display mounting went through a number of iterations over the design period. A water tight housing is required for the MoTeC D153 Display since it is not rated for use in rain. The display housing consists of two parts; the main body in which the display will sit, and a clear panel to view the display through. The main body will be 3D printed from 3D Systems (following successful geometry testing from the student workshop). The main body has 4 bolt holes in each corner that attach the clear panel to the main body via M3 bolts. The bolts fasten onto M3 nuts which will been recessed into the body. This is done so that the housing can sit flush against the dash panel. The body will attach onto the dash panel via 2x M4 bolts on either side of the body. The bolts will fasten onto threaded inserts which will be glued into the dash panel. The main body also has an O-ring groove for an O-ring to sit which will seal the housing. The clear panel will be made from 3mm laser cut acrylic.

There is a hole on the bottom of the main body for the display wires to exist from. This hole will be sealed with rubber edging. A cable gland was considered for this hole, however, this will not be feasible with the tight geometry inside the body, and the bend radius from the effective gauge of the wires exiting the display (around 8 gauge).

An off the shelf box was explored for housing the display also. This would be done with the intention of improving the quality of the final product and ensuring a perfect seal. The geometry of the D153 display proved to be difficult to match when searching for an off the shelf container with specific internal geometries. In addition to this, none of the housings found had a viable mounting method onto the dash, meaning that an additional 3D printed section would be required to mount the housing onto the dash. As such this idea was discarded, and the final solution will be to 3D print a housing - geometry tested in house, and then final design printed by 3D systems to a high standard.

5. Manufacture

5.1 Loom Manufacture

The manufacture of the looms for both M19-C and M19-E commenced at the end semester 1 exam period, 2019. This section of the report will focus primarily on the manufacture of M19-C's loom, as the lessons learned, skills used and techniques applied are universally applicable.

5.1.1 STEP 1: Inventory

It was absolutely imperative that all the materials and tools required for manufacture were consolidated, well organised and readily accessible in a known location. This minimised time wasted looking for tools, and allowed manufacturers to hit the ground running as soon as they arrived at the workshop in the morning. As such, the first step was to inventory and organise all required materials in a neat and orderly manner.

Figure 5.1: Electrical Drawer in Workshop

Figure 5.2: Heatshrink, Pins, Crimps

Figure 5.3: OEM Connectors

Figure 5.4: 20/22 AWG Single and Multi-Core Tefzel Wire

5.1.2 STEP 2: Junior Introduction

Since juniors were to be heavily involved in loom manufacture, it was important that they fully understood what it is they were making and the plan of attack. As such, prior to commencement, time was set aside to thoroughly walk all juniors involved through the structure of the loom. This was done first by walking them through the CAD of the loom - detailing what every connector is and its purpose, in addition to why the loom is routed the way it is. This helped them wrap their head around the wiring harness (as most of them have never even heard of nor seen one before), making the manufacturing process significantly more efficient. Following this, CAD screenshots of both halves of the loom were printed out so they could be referred to without having to go back and forth between the office and workstation every time there was a concern about routing.

5.1.3 STEP 3: Cutting Wires

The next step was the cut all the wire. This process was extremely streamlined due to having all the wire lengths exported, filtered and ready to go (detailed in section 4.5). Similar to the CAD screenshots, a large excel sheet was printed on A3 paper that had every length of wire that had to be cut, organised by colour, where the wire originates from and where the wire needs to go (refer to Figure 5.5). This further sped up the cutting process as juniors were able to tick each length off as they were going, and didn't run the risk of cutting the same length of wire twice. It can be seen from Figure 5.5 that there is a CAD length and a CUT length column. The CUT length is the CAD length with a 1.2 safety factor applied, which will account of concentric twisting. The excess length can then be cut down so the wire is the perfect length when fitted on the car. Once all the wire lengths were cut, they were labelled with masking tape and placed in zip-lock bags, separated by colour (Figure 5.9). When labelling with masking tape, it is beneficial to fold the tape over onto itself as opposed to wrapping the tape around the wire multiple times. This means that the tape can get easily ripped off when required, without having to need to find the edge of the tape and unwrap it from the wire.

Safety Factor 1.2

Signal

From	To	CAD Length	Cut Length
M150-C	SPFR	1426	1711.2
	SPFL	1760	2112
	BPF	1504	1804.8
	BPR	740	888
	Steering Angle	984	1180.8
	Fuel SS Relay	395	474
M150-D	WSFR	1390	1668
	WSFL	1714	2056.8
	TP1	1268	1521.6
	TP2	1268	1521.6
	TP3	1268	1521.6
	Beacon	1716	2059.2
	FrontDiv-1	239	286.8
	FrontDiv-5	239	286.8
	BSPD Trip	247	296.4
	Dash Prime/ Kill	1241	1489.2
	Map Switch	1241	1489.2
BSPD	BPF Splice	100	120
	BPR Splice	100	120
	FrontDiv-2	372	446.4
	FrontDiv-3	372	446.4
D153	Wheel-1	108	129.6
	Wheel-2	108	129.6
	Wheel-3	108	129.6
	Wheel-4	108	129.6
	Wheel-5	108	129.6
	Wheel-6	108	129.6
	Dash-2	100	120
	Dash-3	100	120

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
M150-A	FuelPressure	1532	1838.4
	IGMOD-2	243	291.6
	IGMOD-7	243	291.6
	AirTemp	1308	1569.6
	AirPressure	1308	1569.6
	OilPressure	1029	1234.8
	EngineTemp	889	1066.8
M150-B	WSRR	1099	1318.8
	WSRL	1426	1711.2
	SPRR	938	1125.6
	SPRL	1292	1550.4
	Injector	1352	1622.4
	ETBPot 1	1435	1722
	ETBPot 2	1435	1722
	Reference	1483	1779.6
	Sync	1151	1381.2
	ExhaustPress	929	1114.8
	GearPos	1499	1798.8
RearDiv	FuelTemp	1616	1939.2
	OilTemp	982	1178.4
	ETBSplice	150	180
	ETBSplice	150	180
IGMOD	Coil1	948	1137.6
	Coil2	990	1188

Sensor 5V

From	To	CAD Length	Cut Length
M150-C2	Splice 1	583	699.6
Splice 1	BPR	157	188.4
Splice 1	Splice 2	156	187.2
Splice 2	Dash	534	640.8
Splice 2	Splice 3	121	145.2
Splice 3	Steering Angle	246	295.2
Splice 3	Splice 4	104	124.8
Splice 4	Splice 5	140	168
Splice 5	WSFR	194	232.8
Splice 5	SPFR	196	235.2
Splice 4	BPF	540	648
Splice 3	Splice 6	693	831.6
Splice 6	WSFL	194	232.8
Splice 6	SPFL	207	248.4
M150-C9	Splice 7	739	886.8
Splice 7	SGFR	38	45.6
Splice 7	TPFR	46	55.2
Splice 7	BPyroF	59	70.8
Splice 7	Splice 8	121	145.2
Splice 8	IMUF	106	127.2
Splice 8	Splice 9	409	490.8
Splice 9	SGFL	44	52.8
Splice 9	TPFL	42	50.4
M150-D19	Splice 10	705	846
Splice 10	Throttle Pots	563	675.6
Splice 10	Beacon	1011	1213.2

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
M150-A10	Splice 1	272	326.4
Splice 1	Splice 2	552	662.4
Splice 2	WSRR	237	284.4
Splice 2	SPRR	77	92.4
Splice 1	Splice 3	868	1041.6
Splice 3	WSRL	249	298.8
Splice 3	SPRL	115	138
M150-A18	Splice 4	272	326.4
Splice 4	ETB	1125	1350
Splice 4	Splice 5	401	481.2
Splice 5	Splice 6	179	214.8
Splice 6	ExhaustPres	40	48
Splice 6	Sync	262	314.4
Splice 5	Splice 7	264	316.8
Splice 7	Oil Pressure	94	112.8
Splice 7	Splice 8	135	162
Splice 8	TMAP	202	242.4
Splice 8	Splice 9	185	222
Splice 9	Fuel	232	278.4
Splice 9	GearPos	170	204
M150-A19	Splice 10	272	326.4
Splice 10	Splice 11	349	418.8
Splice 11	SGRL	60	72
Splice 11	TPRL	60	72
Splice 10	Splice 12	108	129.6
Splice 12	SGRR	37	44.4
Splice 12	TPRR	41	49.2
Splice 12	BPyroR	52	62.4
Splice 12	IMUR	637	764.4

Sensor 0V

From	To	CAD Length	Cut Length
M150-D15	Splice 1	549	658.8
Splice 1	BPR	157	188.4
Splice 1	Splice 2	156	187.2
Splice 2	Dash	534	640.8
Dash	Beacon	537	644.4
Splice 2	Splice 3	121	145.2
Splice 3	Steering Angle	246	295.2
Splice 3	Splice 4	104	124.8
Splice 4	Splice 5	140	168
Splice 5	WSFR	194	232.8
Splice 5	SPFR	196	235.2
Splice 4	BPF	540	648
BPF	Throttle Pots	64	76.8
Splice 3	Splice 6	693	831.6
Splice 6	WSFL	194	232.8
Splice 6	SPFL	207	248.4
M150-D16	Splice 7	739	886.8
Splice 7	SGFR	38	45.6
Splice 7	TPFR	46	55.2
Splice 7	BPyroF	59	70.8
Splice 7	Splice 8	121	145.2
Splice 8	IMUF	106	127.2
Splice 8	Splice 9	409	490.8
Splice 9	SGFL	44	52.8
Splice 9	TPFL	42	50.4

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
M150-A26	Splice 1	272	326.4
Splice 1	Splice 2	552	662.4
Splice 2	WSRR	237	284.4
Splice 2	SPRR	77	92.4
Splice 1	Splice 3	868	1041.6
Splice 3	WSRL	249	298.8
Splice 3	SPRL	115	138
M150-A27	Splice 4	272	326.4
Splice 4	ETB	1125	1350
Splice 4	Splice 5	401	481.2
Splice 5	Splice 6	141	169.2
Splice 6	ExahaustPres	78	93.6
Splice 6	Oil Temp	76	91.2
Splice 6	Sync	300	360
Splice 5	Splice 7	264	316.8
Splice 7	Oil Pressure	94	112.8
Splice 7	Splice 8	135	162
Splice 8	Splice 9	128	153.6
Splice 9	TMAP	74	88.8
Splice 9	EngineTemp	80	96
Splice 8	Splice 10	185	222
Splice 10	Fuel	232	278.4
Splice 10	Splice 11	126	151.2
Splice 11	GearPos	44	52.8
Splice 11	Reference	28	33.6
M150-A33	Splice 12	272	326.4
Splice 12	Splice 13	349	418.8
Splice 13	SGRL	60	72
Splice 13	TPRL	60	72
Splice 12	Splice 14	108	129.6
Splice 14	SGRR	37	44.4
Splice 15	TPRR	41	49.2
Splice 16	BPyroR	52	62.4
Splice 17	IMUR	637	764.4

PDM Output/ Bat Pos/ HB

From	To	CAD Length	Cut Length
PDM-B	BSPD	313	375.6
	PRelayF-2	305	366
	PRelayF-3	304	364.8
	Display	1382	1658.4
	Fuel SS Relay	428	513.6
M150-C	FDivCon-4	273	327.6
	FDivCon-6	273	327.6
PRelayF-5	Fuel Pump 1	487	584.4
PRelayF-6	Fuel Pump 2	487	584.4

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
PDM-A	StarterRelay	1023	1227.6
	BrakeLight	1023	1227.6
	DRSON	897	1076.4
	DRSOFF	897	1076.4
	Lambda	909	1090.8
	ARBPower	1587	1904.4
	FanRight 1	750	900
	FanRight 2	750	900
	FanLeft 1	1536	1843.2
	FanLeft 2	1536	1843.2
M150-B	ETBMotor1	1435	1722
	ETBMotor2	1435	1722
	Upshift (HB)	1295	1554
	Downshift (HB)	1295	1554
RearDiv	ARB (HB)	1657	1988.4
	Clutch (HB)	1350	1620
PRelayR	Injector	1431	1717.2
	Coil1	1005	1206
	Coil2	1047	1256.4

TOTAL LENGTH	149454

Ground/ Bat Neg

From	To	CAD Length	Cut Length
PDM-B18	Splice 1	124	148.8
Splice 1	PRelayF	182	218.4
Splice 1	BSPD	190	228
Splice 1	Dash	1258	1509.6

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
GRD BLOCK	IGMOD	538	645.6
	StarterRelay	1052	1262.4
	BrakeLight	1052	1262.4
	Shifting	1309	1570.8
	DRS	927	1112.4
	Lambda	938	1125.6
	ARB	1617	1940.4
	FanRight 1	1140	1368
	FanRight 2	1140	1368
	FanLeft 1	1144	1372.8
	FanLeft 2	1144	1372.8

CAN Twisted Pair

From	To	CAD Length	Cut Length
M150-D17/18	Splice 1	705	846
Splice 1	SGFR	38	45.6
Splice 1	TPFR	46	55.2
Splice 1	BPyroF	59	70.8
Splice 1	UTC	505	606
UTC	Display	106	127.2
Splice 1	Splice 2	121	145.2
Splice 2	IMUF	120	144
Splice 2	Splice 3	287	344.4
Splice 3	SGFL	44	52.8
Splice 3	TPFL	42	50.4

Front Loom | Rear Loom

From	To	CAD Length	Cut Length
M150-A30/31	Splice 1	272	326.4
Splice 1	Splice 2	368	441.6
Splice 2	SGRL	52	62.4
Splice 2	TPRL	60	72
Splice 1	Splice 3	108	129.6
Splice 3	SGRR	37	44.4
Splice 3	TPRR	41	49.2
Splice 3	BPyroR	52	62.4
Splice 3	Splice 4	292	350.4
Splice 4	Lambda	213	255.6
Splice 4	IMUR	345	414

Shutdown Circuit

From	To	CAD Length	Cut Length
PDM Terminal	BSPD	413	495.6
BSPD	Inertia Switch	895	1074
Inertia Switch	Dash	414	496.8
Dash	BOT	1111	1333.2
BOT	PRelayF	1393	1671.6
PRelayF	PDM-B18 (Splice	182	218.4

Figure 5.5: Filtered Wire Lengths

Figure 5.6: Wire Rack and Lengths Spreadsheet

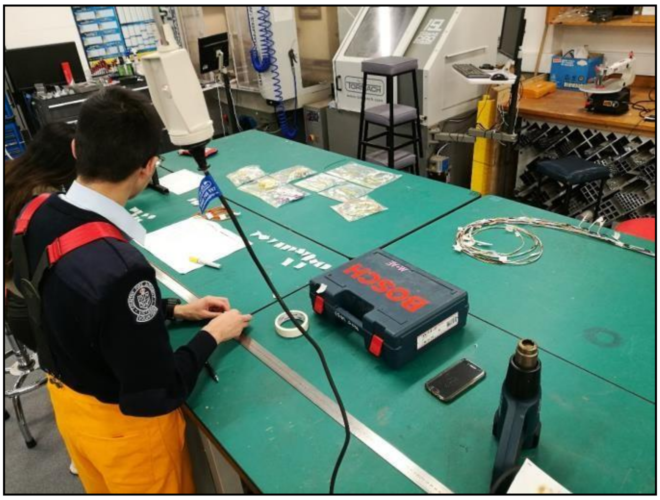


Figure 5.7: Juniors Measuring Lengths

Figure 5.8: Organising Wires into Zip-Lock Bags

Figure 5.9: Wires Cut, Labelled and Organised into Zip-Lock Bags

5.1.4 *STEP 4: Routing Wires*

Once all the wires had been cut, the routing process commenced. This process was started by running the first signal wire to the connector that was closest to the ECU. For M19-C, this was the rear brake pressure sensor connector. Once this length of wire was in place, there was a base to route all other wires around. Following this, sensor 5V and sensor 0V rails were spliced and branched off to their respective locations. Mechanical crimps were used (Figure 5.12) for all splices, with glue lined heat shrink over them. As each wire was added to the main branch, it was concentrically twisted to ensure all the wires were neatly organised, the loom was easy to work with, and to minimise noise - particularly important for the CAN bus. As the loom began to grow, and branches got added onto the loom, the loom was test fitted to the monocoque to ensure all the branches reached what they are supposed to. It was helpful to pin the Superseal connectors at the ECU and PDM as wires were being routed as it ensures a consistent origin to route all wires from. This entire process was repeated for the rear loom upon completion of front loom. There were some minor bottlenecks for the routing of the rear loom as the engine had to get mounted into the monocoque before the lengths of various connectors, including ignition coils, sync sensor, TMAP, fuel sensors and oil pressure could be finalised.

Figure 5.10: Front Loom Routed and Twisted

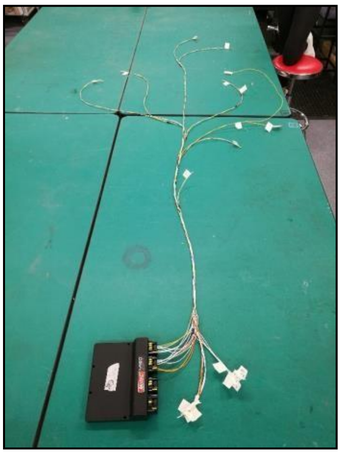
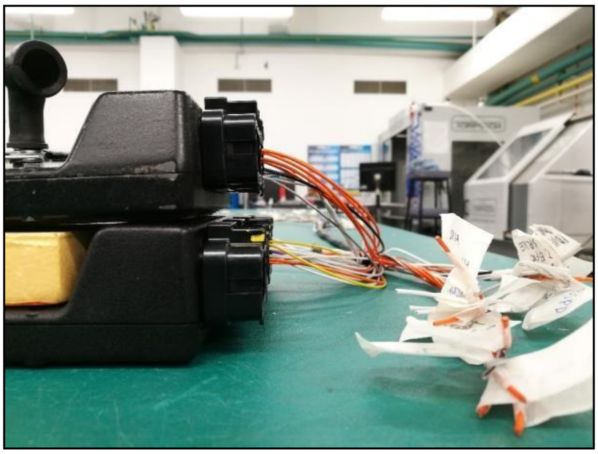


Figure 5.11: ECU/ PDM Stacked with



Connectors Pinned

Figure 5.12: Splicing using Mechanical Crimps

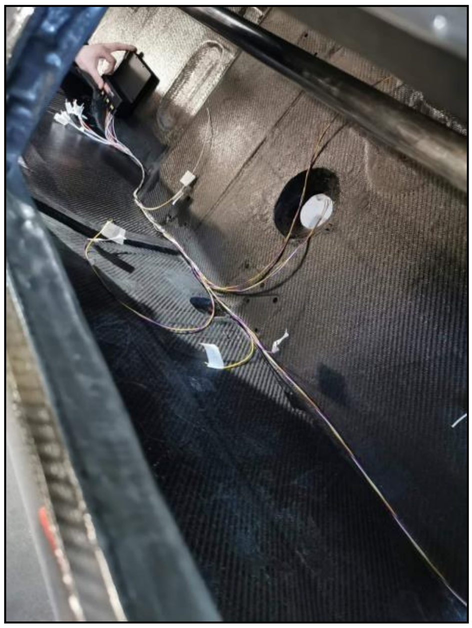


Figure 5.13: Testing Front Loom on Monocoque

Figure 5.14 (left) & Figure 5.15 (right): Concentric Twisting

5.1.5 STEP 5: Heatshrinking

Once all the wires were routed, crimped, concentrically twisted and splices branched off at correct angles, it came time to heatshrink the entire loom. Heatshrinking a harness serves a number of benefits, listed below:

- Strain relieves crimps
- Adds rigidity to overall harness, minimising chances of wire fatigue
- Keeps all concentrically twisted branches in one bundle, allowing for easy routing and mounting on monocoque
- Additional layer of protection from contaminants such as dust, water, fuel and oil
- Increases temperature resistance of harness

As finalised in the design phase, it decided to use two different types of heatshrink for this year's looms. RS Pro heatshrink was used for the majority of the loom (~80%) due to its low cost, and the fact that it significantly increases stiffness when heatshrunk over large cores of wire - particularly important as this is near the ECU/ PDM. Additionally, most RS Pro heatshrink sizes are available in a 3:1 shrink ratio, which significantly eases manufacturing as large diameter heatshrink can get sleeved over large bundles of wires which will shrink down and compress the wires nicely when heated. Raychem heatshrink was also used for outboard wires, steering wheel curly cord, and other portions of the loom that required constant movement, connection or disconnection. This is because Raychem heatshrink is very flexible once heated, unlike RS Pro, and is of a greater quality with higher temperature resistance than RS Pro. In future, it would be good to increase the ratio of Raychem to RS heatshrink used, but will require a lot of foresight to ensure that it can get sleeved over bundles of wires appropriately, as Raychem heatshrink is only available in 2:1 shrink ratio.

When using RS Pro heatshrink, it was effective to form bends into the loom while heatshrinking. This is so that the loom can route around the car with minimal strain on wires and crimps. These 'pre-bends' were done using metal billets, and heating the heatshrink around the billet (Figure 5.19) to form the radius that was desired. This position was held until cooled, after which the loom would hold that shape. This technique was highly effective, and allowed the navigation of sharp corners of the monocoque with minimal strain on wires.

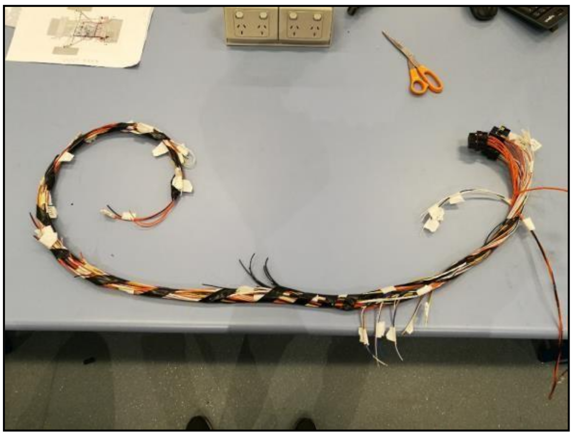


Figure 5.16: Electrical Tape Around Bundles

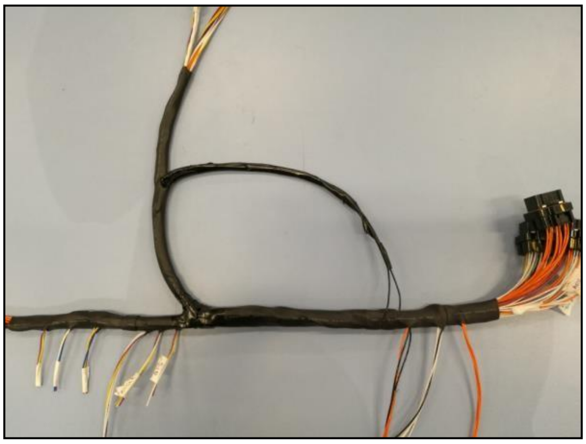


Figure 5.17: 90° Bend on Rear Loom

Figure 5.18: Heatshrink commenced on both halves

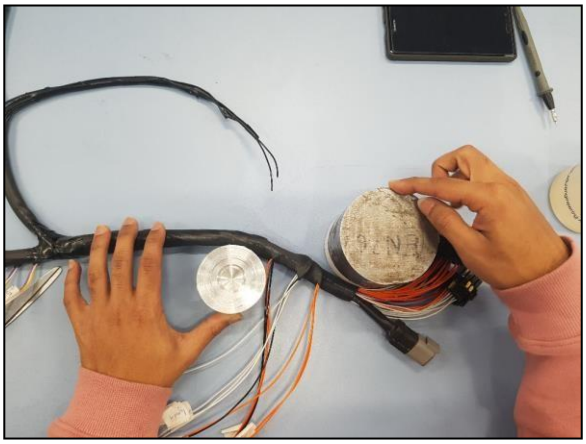


Figure 5.19: Forming Bends with Billets

Figure 5.20: Heatshrink Junction

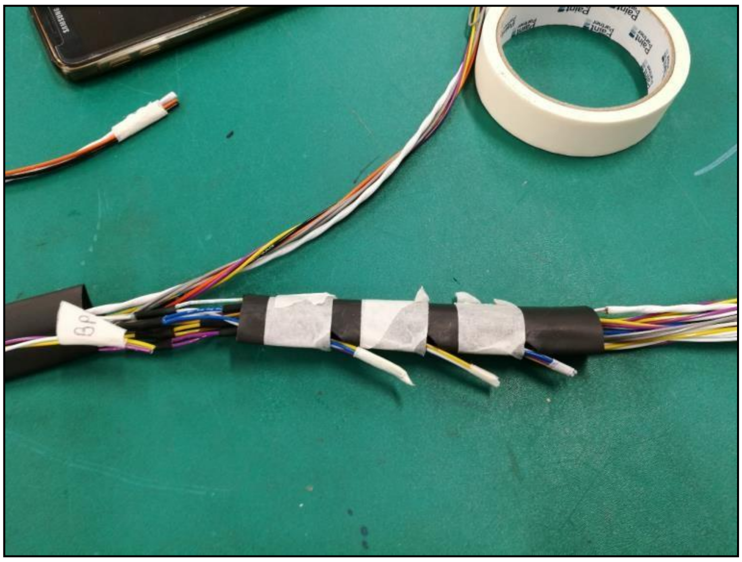


Figure 5.21: Feeding 3x CAN Breakouts Through Slits in Heatshrink

5.1.6 STEP 6: Pinning Connectors and Terminals

After the entirety of the loom had been heatshrunk, and all branches were cut down to the appropriate length (following test fitting on monocoque), pinning connectors and terminals commenced. The pinning process differs slightly between connectors however the sleeving technique remains consistent for all connectors. Around 35mm of wire should be exposed (outside of heatshrink) to allow for room to strip, crimp and insert the wire into the connectors. Care must be taken to ensure that another length of heatshrink is sleeved over the wires before they are pinned, so that the exposed wire can get heatshrunk over after pinning. The pinning process for the main connectors is shown below with pictures. Some connectors require the use of boots in place of heatshrink. These boots are sold by GR Motorsport Electrics in different pin number configurations. These boots also need to be sleeved over prior to pinning.

In future, it would be good to invest in the correct de-pinning tool for the compact connectors, as there is currently no legitimate way of unpinning them so they are essentially a one- use connector – which is largely inconvenient and costly.

This year, it was decided to further improve the serviceability of the loom by labelling all connectors. As such, once pinned, a label maker was used to print labels for all connectors. The adhesive on the label maker labels was insufficient for the conditions that the loom would see (wet, hot, dry) and so a layer of clear nail polish was applied over all the labels to essentially 'laminate' the label. This technique was extremely effective, and can be seen in Figure 5.30.

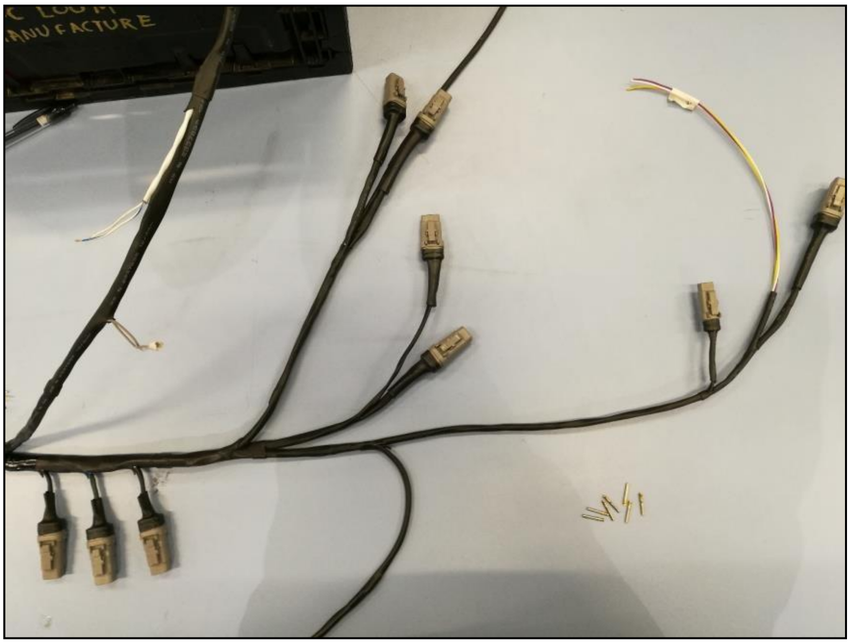


Figure 5.22: DTM Connector Pinning Process

1. Strip wire (Use inspection hole on DTM pin to ensure you've stripped enough)
2. Crimp pin (select correct wire gauge on DTM crimper)
3. Sleeve heatshrink length over exposed wire
4. Pin into connector (use red side of insertion/extraction tool)
5. Insert wedge lock into connector
6. Shrink heatshrink

Figure 5.23: Superseal Connector Pinning Process

1. Strip wire (test fit on Superseal pin to ensure you've stripped enough)
2. Crimp exposed wire onto rectangular teeth on Superseal pin (Use red handled Molex crimper on letter D)
3. Crimp insulation over triangular teeth on Superseal pin (Use red handled Molex crimper on letter B)
4. Unlock Superseal connector (push the white tab on connector up until you hear a click)
5. Install crimped wire into connector with fingers (No tool required, insert until you feel/ hear a gentle click)
6. Lock Superseal connector (push white tab on connector back down until it is flush)

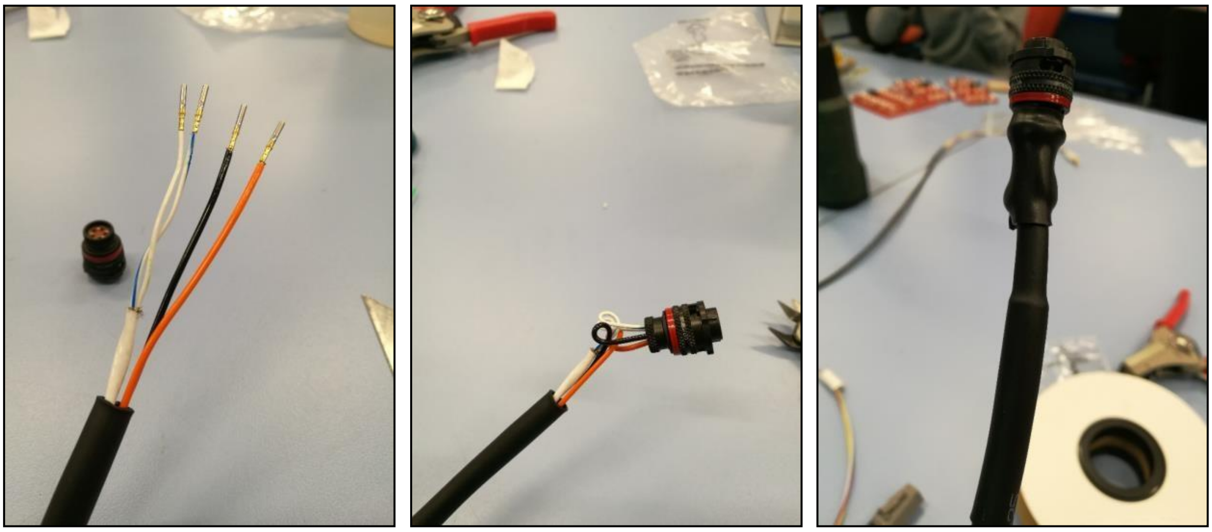


Figure 5.24: Autosport Connector Pinning Process

1. Strip wire (Use inspection hole on Autosport pin to ensure you've stripped enough)
2. **NOTE: Because Autosport pins are thinner/ smaller than DTM, you may need to cut individual wires from the core to make it fit inside the pin**
3. Crimp pin (select correct wire gauge on DTM crimper)
4. Sleeve heatshrink length over exposed wire
5. OPTIONAL: Create service loops (middle image) in wires for ease of insertion/ extraction. Useful if connector is likely to get de-pinned/ pinned frequently.
6. Pin into connector (use insertion side of white and green insertion/extraction tool)
7. Shrink heatshrink

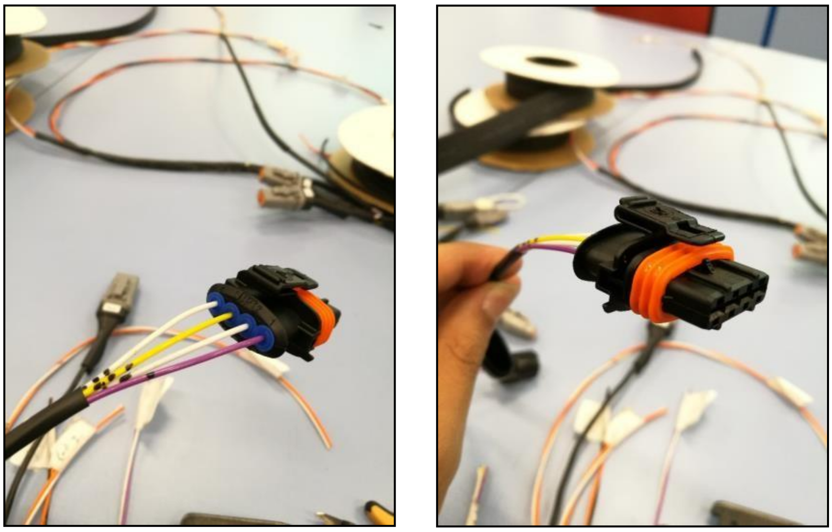


Figure 5.25: Connector Pinning Process

1. Strip wire (test fit on pin to ensure you've stripped enough)
2. Insert individual wire boots (blue in Figure 5.25, left image) onto each wire
3. Crimp exposed wire onto rectangular teeth on pin (Use red handled Molex crimper on letter D)
4. Crimp insulation over the longer teeth on pin (Use red handled Molex crimper on letter B, then go over it again in letter D)
5. Sleeve heatshrink length over exposed wire
6. Sleeve appropriately sized connector boot onto wires
7. Install crimped wire into connector with fingers (No tool required, insert until you feel/ hear a click)
8. Shrink heatshrink
9. Push individual wire boots into connector until they sit flush with connector
10. Sleeve boot over lip at the back of connector

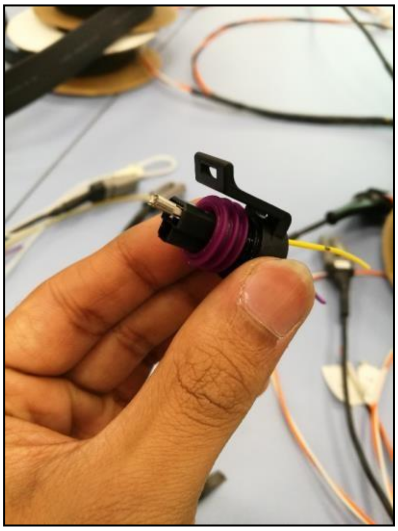


Figure 5.26: Metri Pack Connector Pinning Process

1. Feed wire through connector
2. Strip wire (test fit on pin to ensure you've stripped enough
3. Crimp pin using Molex crimping tool (similar process to Figure 5.25)
4. Pull pinned wire pack into connector until locked in place

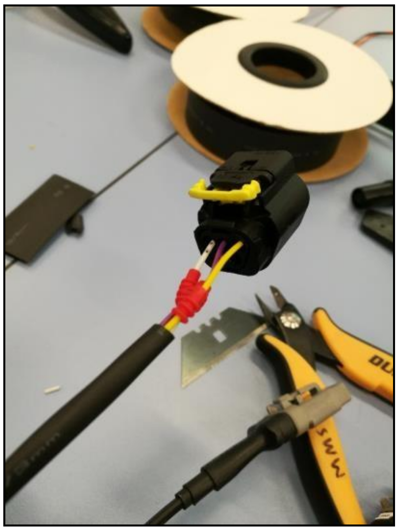


Figure 5.27: 5-pin mating Connector Pinning Process

1. Strip wire (test fit on pin to ensure you've stripped enough
2. Insert individual wire boots (blue in image above) onto each wire
3. Crimp pin using Molex crimping tool
4. Sleeve heatshrink length over exposed wire
5. Unlock connector by pushing blue tab to the left
6. Install crimped wire into connector with fingers
7. Lock connector by pushing blue tab to the right
8. Shrink heatshrink
9. Push individual wire boots into connector until they sit flush with connector

Figure 5.28: Grounding Ring Terminal

1. Strip wire
2. Sleeve glue-lined heatshrink over 3-4 wires bundled
3. Crimp 1x 6mm ring terminal over 3-4 wires bundled
4. Shrink heatshrink

Figure 5.29: Labelled Connectors

Figure 5.30: Clear Nail Polish

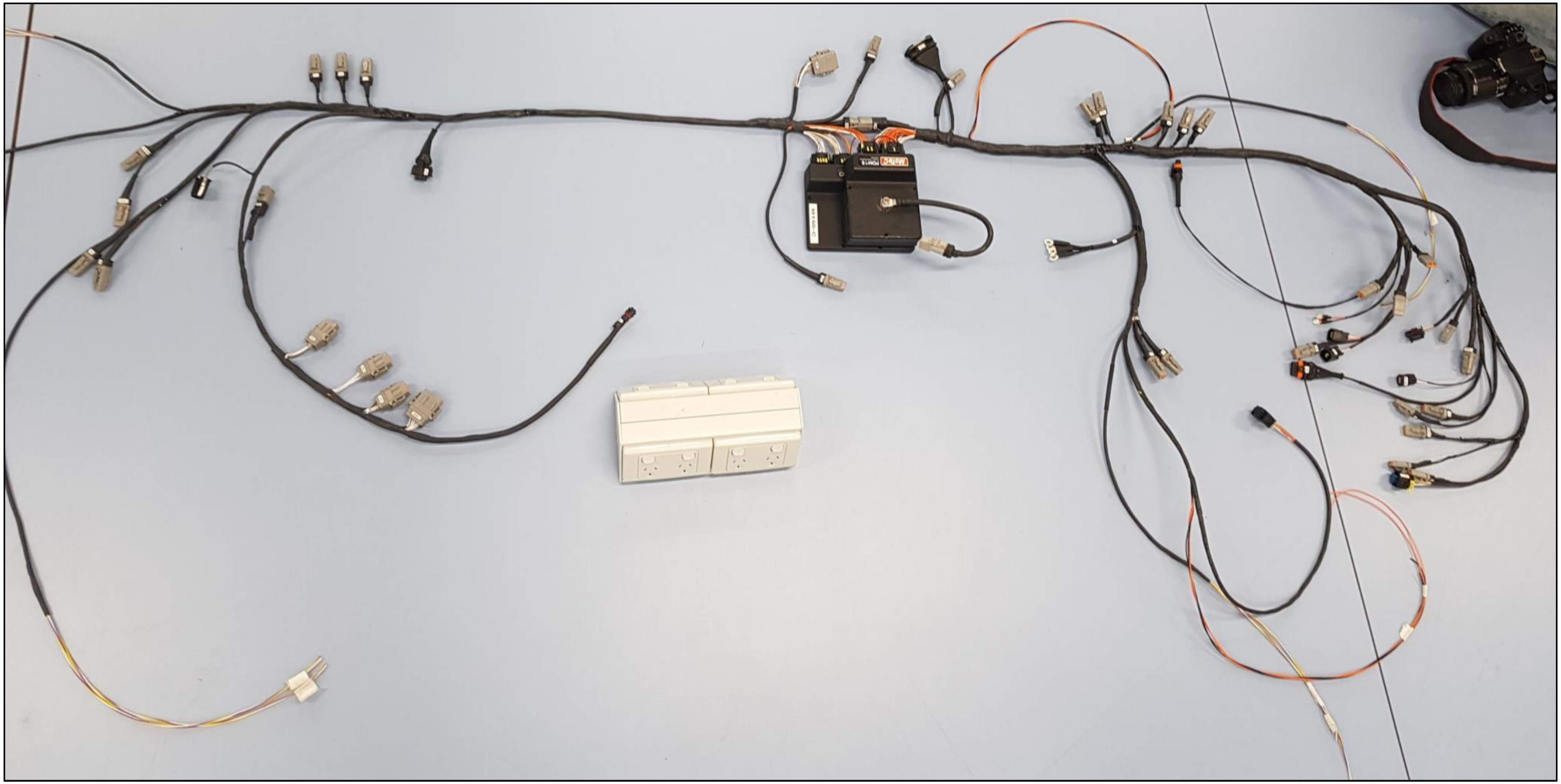


Figure 5.31: Full Loom (Both Halves) Heatshrunk, Connectors Pinned and Labelled, Ready for Final Installation on Car

Note that there are some exposed wires (un-heatshrunk) that have not been pinned (wheel speeds, shock potentiometers and fans). This is because these branches needed to get pinned on the car as the wires needed to get fed through small holes in the monocoque that the connectors would not fit through.

5.1.7 STEP 7: Installation

Installing the loom onto the chassis this year differed significantly to how it was previously done due to the monocoque. In previous years, the loom was mounted onto the chassis using cable ties around the chassis tubes. Due to the lack of tubes on the monocoque, a cable tie mounting solution was required. The benefit of this method was that there was no limitation by the geometry of the space frame for how the loom could route - instead cable tie mounts were glued where necessary, further assisting in reducing wire lengths.

The cable tie mounts used, in addition to other mounting studs, were supplied by a company called Click Bond. They develop a variety of extremely high quality and light weight adhesive bonded fasteners for military, automotive and aerospace applications. These mounts were glued onto the monocoque using DP-490 Epoxy. This epoxy has a cure time of around 30 hours, and is black in colour blending in with the monocoque nicely. All these mounts came with a plastic housing that applied pressure on the adhesive area - this meant that the mounts could get glued and left overnight to cure.

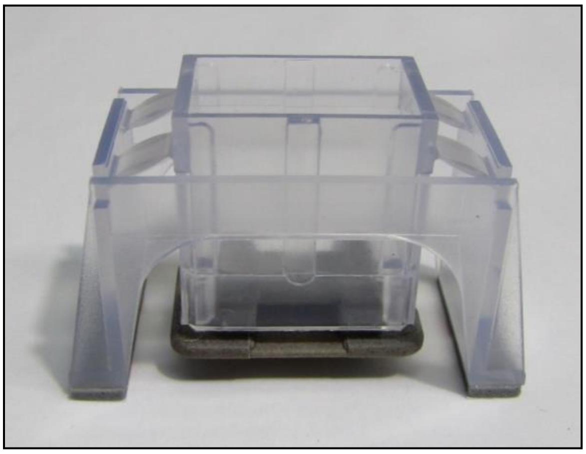


Figure 5.32: Click Bond Cable Tie Mount

Figure 5.33: Cable Tie Mounts Being Glued to Steering Wheels

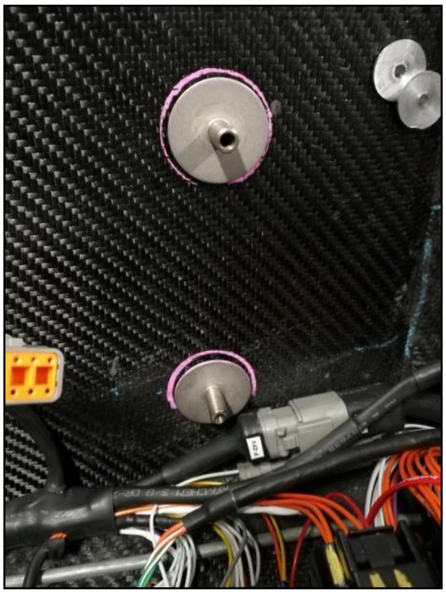


Figure 5.34: BSPD Mounting Studs

Figure 5.35: Inertia Switch Mounting Studs

The locations for the cable tie mounts were selected such that quantity used was minimised, but also allowed for secure fastening of the loom to the monocoque. The loom was placed on the monocoque for jigging, whereby a paint pen dot was placed at every location that required a cable tie mount. After this, the loom was taken off and all mounts were glued using DP-490 epoxy. Once the adhesive had fully cured, it came time to install the loom onto the monocoque for the final time. It was very tedious feeding and routing the branches of the rear loom around the engine bay and engine mounts, but once this step was completed, it does not need to be done again. Locations where the loom exited the monocoque (outboard wires for wheel speeds and shock pots) were reinforced with another layer of glue lined heatshrink to minimise damage to the loom from vibrations during driving. At the time of writing this, the M19-C has been driving for around 1.5 months and has not yet encountered a failure of these mounts, ultimately validating the epoxy adhesive used and the quality of these Click Bond mounts.

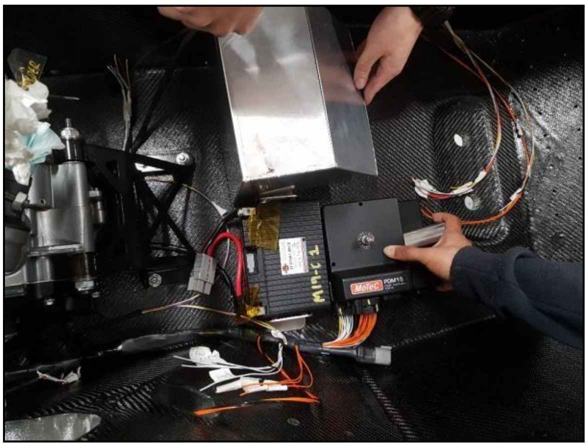


Figure 5.36: Jigging Hardware Next to Fuel Tank

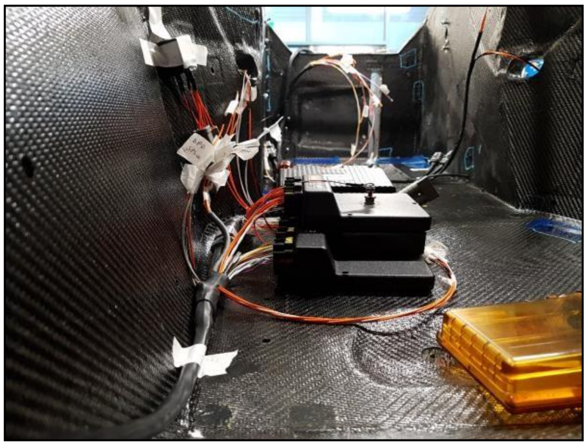


Figure 5.37: Loom Installed for Cable Tie Mount Positioning

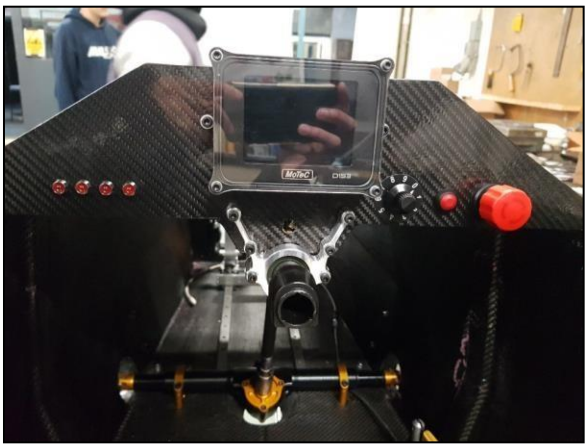


Figure 5.38: M19-E Dash Panel

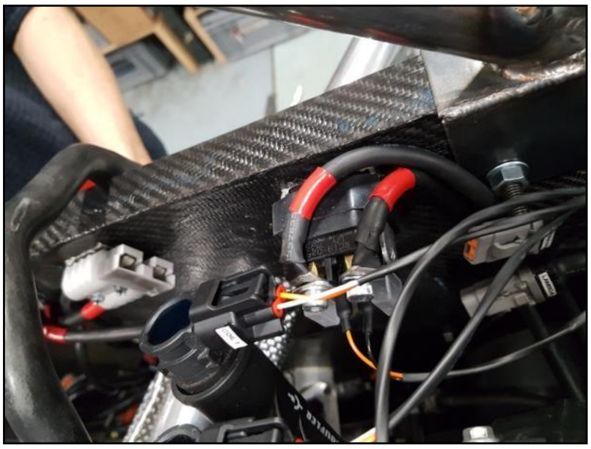


Figure 5.39: Cranking Anderson, Ignition Coils and Starter Relay Region

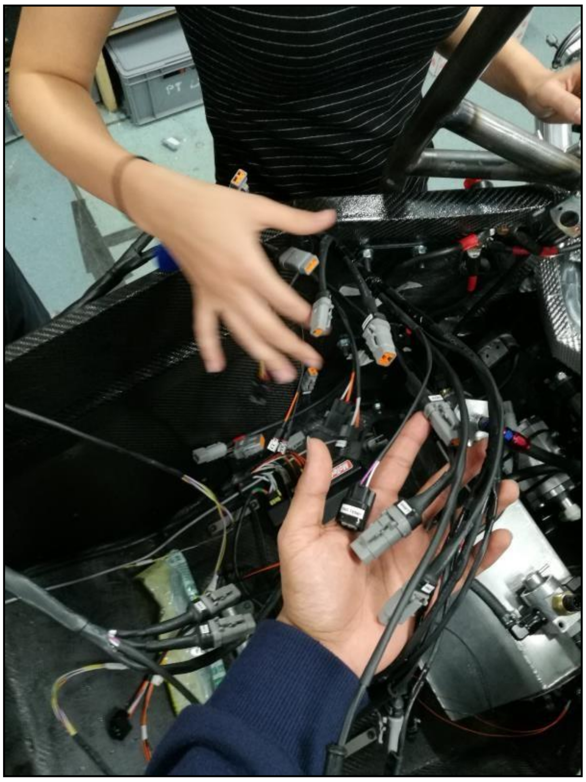


Figure 5.40 and Figure 5.41: Final Installation onto Monocoque

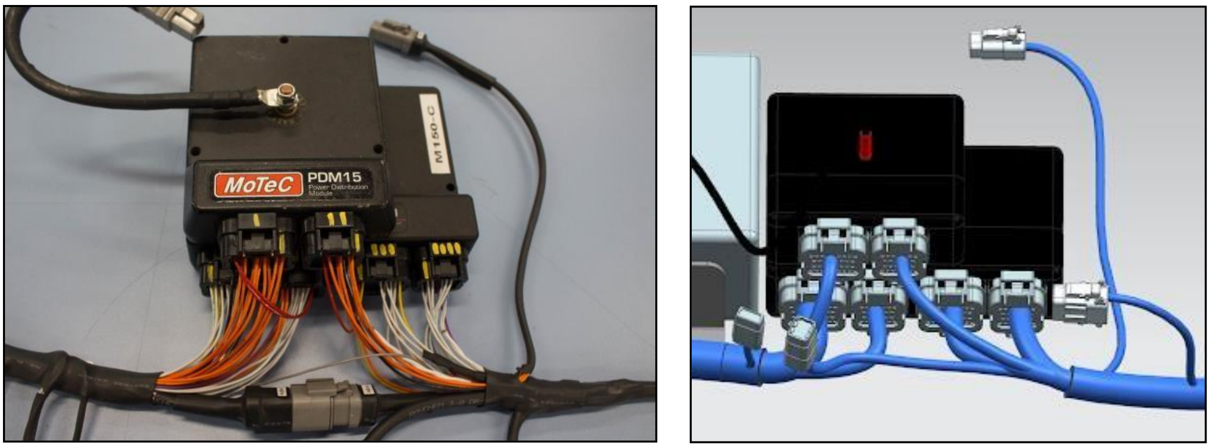


Figure 5.42: CAD vs. Real Life Comparison of ECU/ PDM Region

5.2 Display Housing

Following geometry testing, a number of issues in the original design were picked up and addressed.

- A 5mm service hole was added at the back of the housing so that the display could get pushed out from the back once it has been inserted. This hole will be sealed with rubber when the housing is installed onto the car.
- The exit hole for the wires (bottom of housing) was widened by 2mm to account for heatshrink over the MoTeC wire bundle A and B.
- The holes for the M3 bolt holes fastening the acrylic cover was slopped out to be 3.5mm in diameter to account for inaccuracy between the 3D printer and laser cutter - holes did not originally line up with 3mm holes. This slop is not an issue since the acrylic cover is fastened with clamping force.
- O-ring groove in the display housing was sized such that 3/4 of the O-ring sits inside the housing with 1/4 protruding out - this is sufficient for sealing the display.
- When the final 3D printed housings arrived from 3D Systems, it was noted that the display did not fit smoothly into the housing. This was a result of the internal geometry not being toleranced correctly in CAD. Consequently, the internal walls had to be sanded to ensure the display had a smooth fit into the housing and could slide in out and out without damaging the housing or the display. The service hole proved to be largely useful when ejecting the display from the housing, especially when the wires were installed.

It was decided to print another iteration of this housing, which had raised mounting holes to ensure that the display would sit below the top of the dash (this was done to meet MMS aesthetics standards, alongside giving the dash panel a well-integrated look). This iteration also had correctly toleranced interior geometry to ensure the display could slide in without the need to sand it back.

Figure 5.43: Geometry Testing Display Housing

5.3 Power Relay

The power relay for M19-C relied on the use of epoxy resin for waterproofing and strain relieving - as opposed to plexus used in previous years. All 4 spade terminals were crimped with the appropriate wires using the appropriate colour convention. Following this - electrical tape was wrapped around the perimeter of the relay to act as a barrier for the epoxy potting. The epoxy was the mixed and poured into the relay, ensuring all parts of the spade terminals were completely covered. This was left to set over night and once set, the electrical tape was removed. In future years, a less flexible tape/ barrier should be used since the electrical tape deformed slightly - which meant the final shape of the epoxy around the relay wasn't perfectly square. There was a little lip on the epoxy around the edges which was trimmed using a blade.

The manufacturing method used for this year's power relay provided a higher quality and lighter part than its M18 counter-part. The picture below compares M19-C's power relay (left) to M17-C's (right).

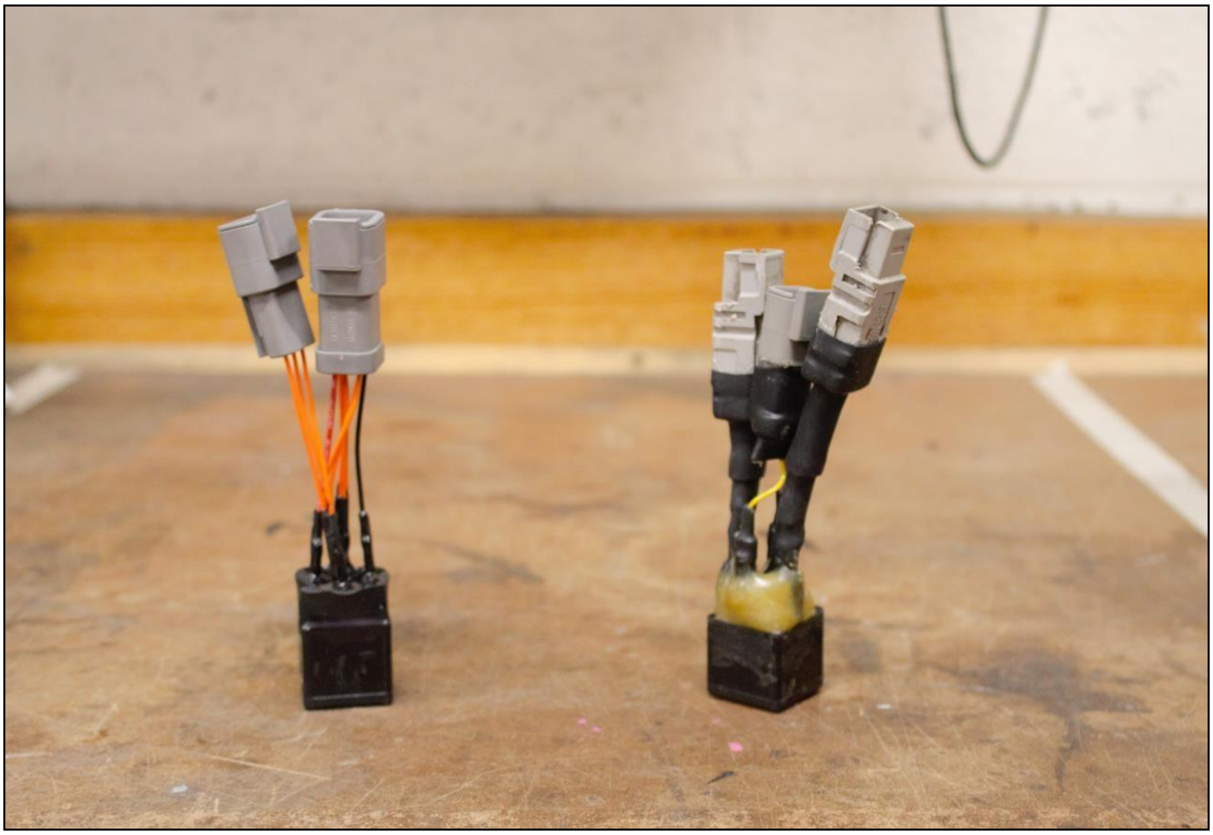


Figure 5.44: M19-C vs M18-C Power Relay Comparison

5.4 Battery

5.4.1 Leads

The leads for the Shorai batteries were manufactured very early on during semester 1 since it was a relatively quiet period with minimal intense manufacturing occurring due to waiting on outsourced parts to arrive. The leads were made with 8-gauge power wiring and 10-8mm lugs crimped onto them with the hydraulic crimpers. Due to the stiffness of 8AWG power wire, the wire was heated to preform a bend into it so that the lugs at both the battery terminals and the Anderson plug were strained relieved once installed onto car. In future, it would be beneficial to look into more flexible option for 8AWG wire - this will make routing a lot easier and minimise strain on crimps.

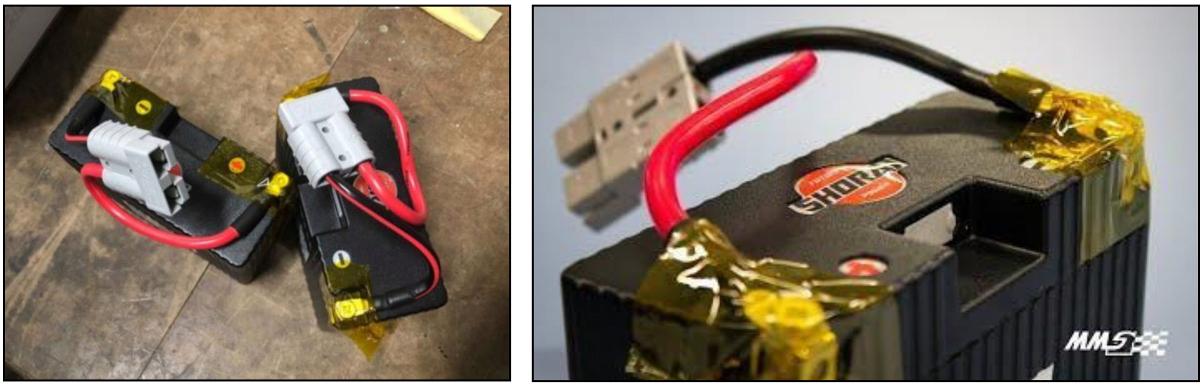


Figure 5.45: Shorai Battery Leads Manufactured and Installed

5.4.2 Mounting

The mounting method for the Shorai was decided to be two L-brackets on either side with a fiber buckle strap that secures the battery in place. The L-brackets were glued onto the monocoque floor with plexus. Velcro was also be applied on to the bottom face of the battery to give more support in the longitudinal direction. ISSUE: When the L-bracket were glued on to the monocoque, it was jigged with the fuel tank installed, however the thickness of the strap was neglected. This meant that the bracket was hugging the fuel tank wall a little bit more closely than what would be ideal. The solution for this was to apply battery foam on the left L-bracket face to ensure the aluminium from the bracket wasn't rubbing against the aluminium from the fuel tank. Overall, the mounting method was very simply, elegant and integrated and serves its purpose with minimal weight addition to the entire system (32 grams).

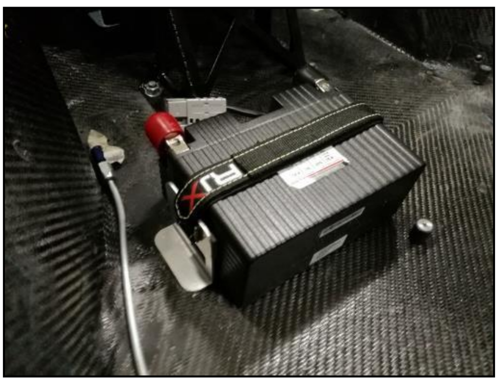


Figure 5.46: Battery Mounted in Final Position on Car

5.5 *Steering Wheel*

The steering wheel electronics required significant attention this year to ensure complete waterproofness and to avoid any unexpected shorting during wet driving conditions. Two steps were taken to achieve this. IP67 rated dome pushbuttons were selected, in addition to using electrical epoxy over the button terminals where it was soldered. This completely seals any exposed wire, and also strain relieves the crimps when the epoxy cures.

This year, it was decided to use Raychem wire and heatshrink for the curly cord. This is because the Raychem wire is considerably more flexible compared to Tefzel wire. Raychem heatshrink is also more flexible and durable compared to RS heatshrink, which is an attractive characteristic to have on a steering wheel curly cord - which gets rotated and moved very frequently.

The process for producing the curly chord is as follows:

1. Solder all wires to pushbutton terminals
2. Place electrical epoxy over solder terminals, and let it cure over night
3. Splice all the ground wires for each button into a single ground
4. Concentrically twist full length of wire
5. Sleeve Raychem heatshrink over twisted wire
6. Shrink heatshrink
7. Tightly twist shrunk heatshrink around a metal rod of approx. 20mm diameter
8. Go over the twisted heatshrink again with a heat gun
9. Hold in this position and let it cool to room temperature
10. Once cooled, remove rod and pin DTM (steps on how to pin a DTM are detailed in section 5.1.6)

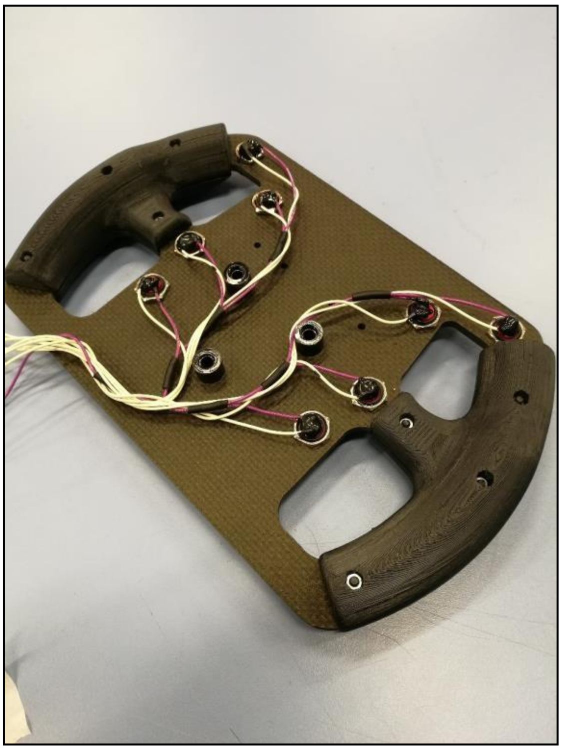


Figure 5.47: Epoxy on Buttons, Grounds Spliced, and Wires Routed

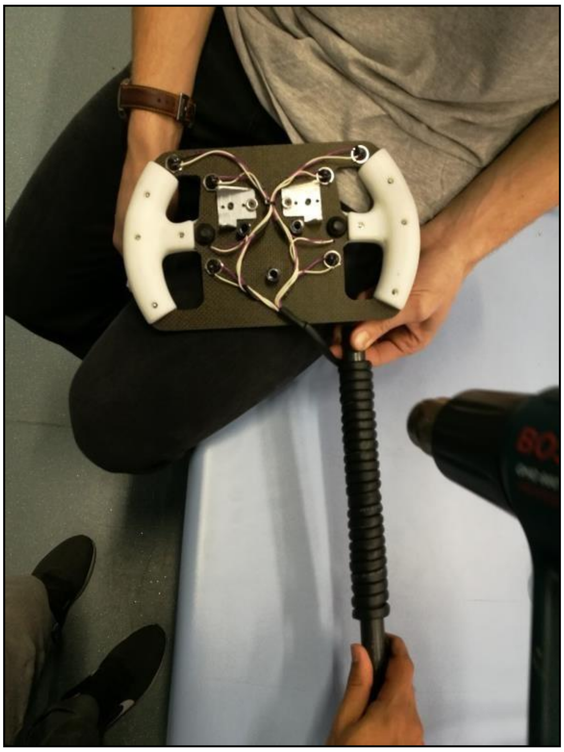


Figure 5.48: Tightly Twisting Around Metal Bar While Heating

5.6 CAN Bus

Each CAN bus requires the use of two terminating resistors on either end of the bus to ensure proper functionality. Terminating resistors serves the purpose of allowing a voltage drop to be produced along the bus (which is how the CAN bus transmits messages), and also prevents signal reflections between the HI and LOW rails - ultimately minimising noise. There are three CAN busses on M19-C this year, meaning that a total of 6 terminating resistors were required. MoTeC recommend using 100 Ohm resistors for their hardware. The diagram depicts how the terminating resistors were set up. Notice the 100 Ohm resistor on either end, giving the bus an effective resistance of 50 Ohms between the HI and LOW rails.

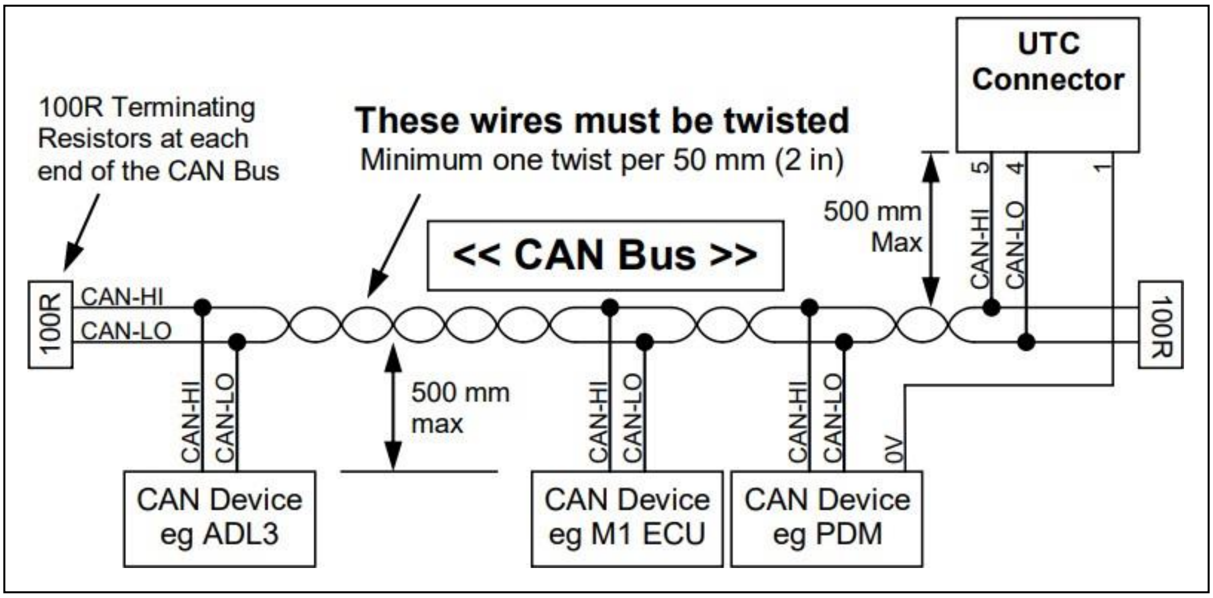


Figure 5.49: MoTeC Recommended CAN Bus Wiring Schematic

Table 5.1: M19-C Terminating Resistor Locations

	Front	Rear	
Bus 1	Beacon	M150	(Front CAN Bus)
Bus 2	M150	IMU Rear	(Rear CAN Bus)
Bus 3	M150	Slip Angle Sensor	(Slip Angle Sensor Bus)

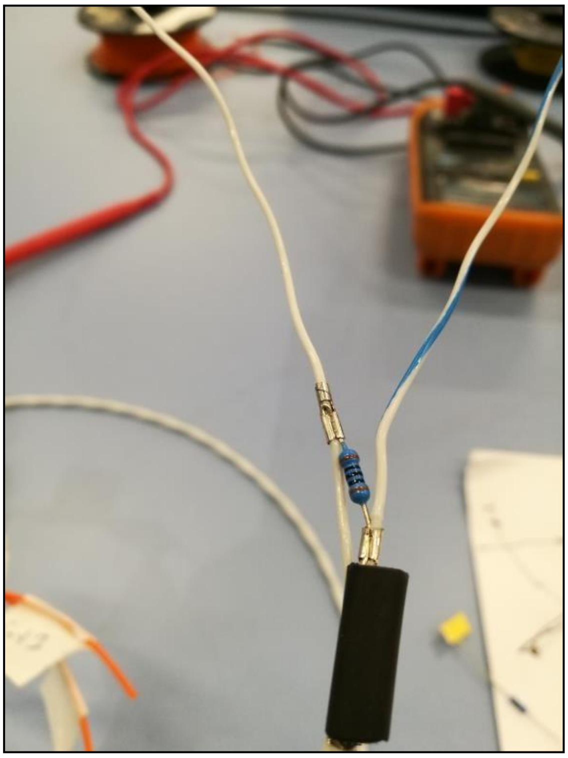


Figure 5.50: 100Ω Resistor Crimped Between HI and LOW

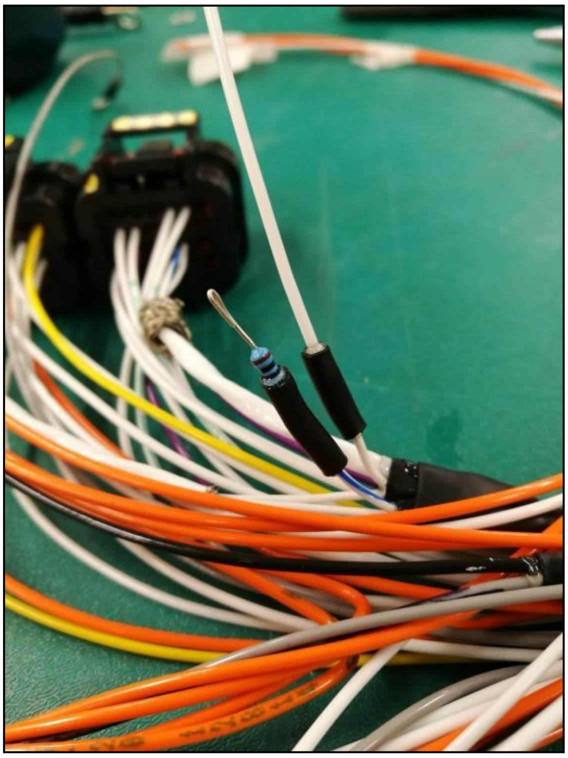


Figure 5.51: Glue Lined Heatshrink Over Mechanical Crimp

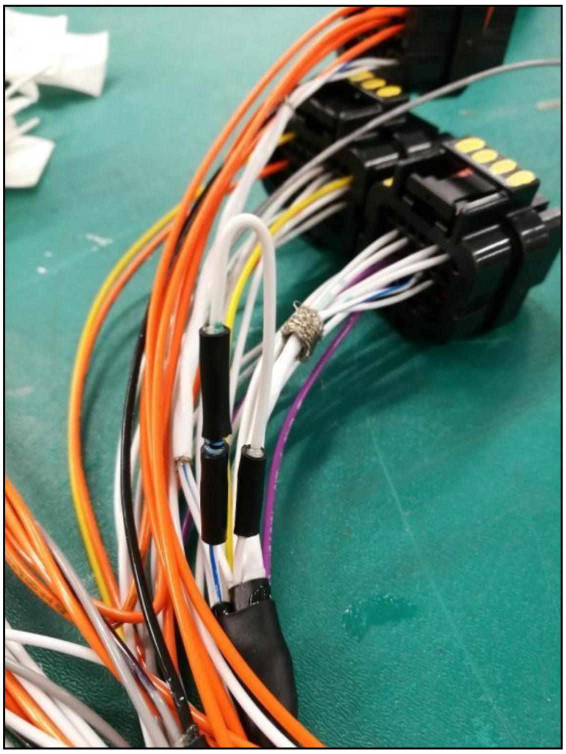


Figure 5.52: Glue Lined Heatshrink Over Both Mechanical Crimps

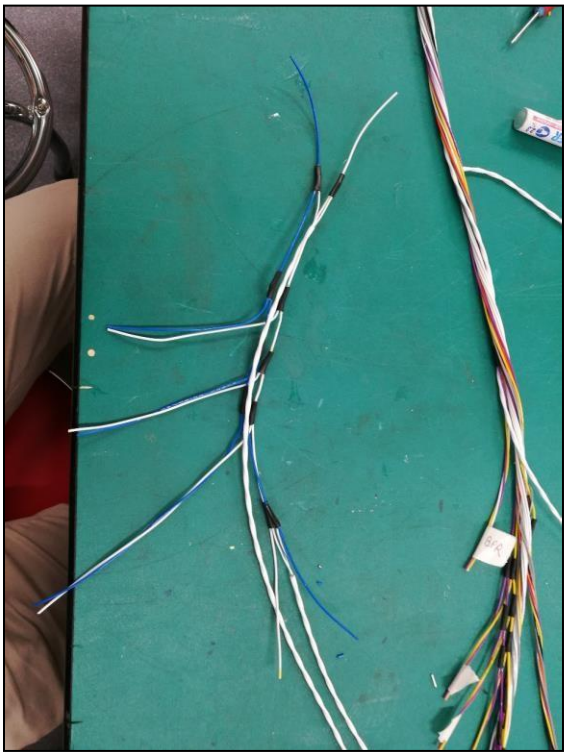


Figure 5.53: CAN Breakout for Pyros and Strain Gauges

6. System Overview

6.1 System Map

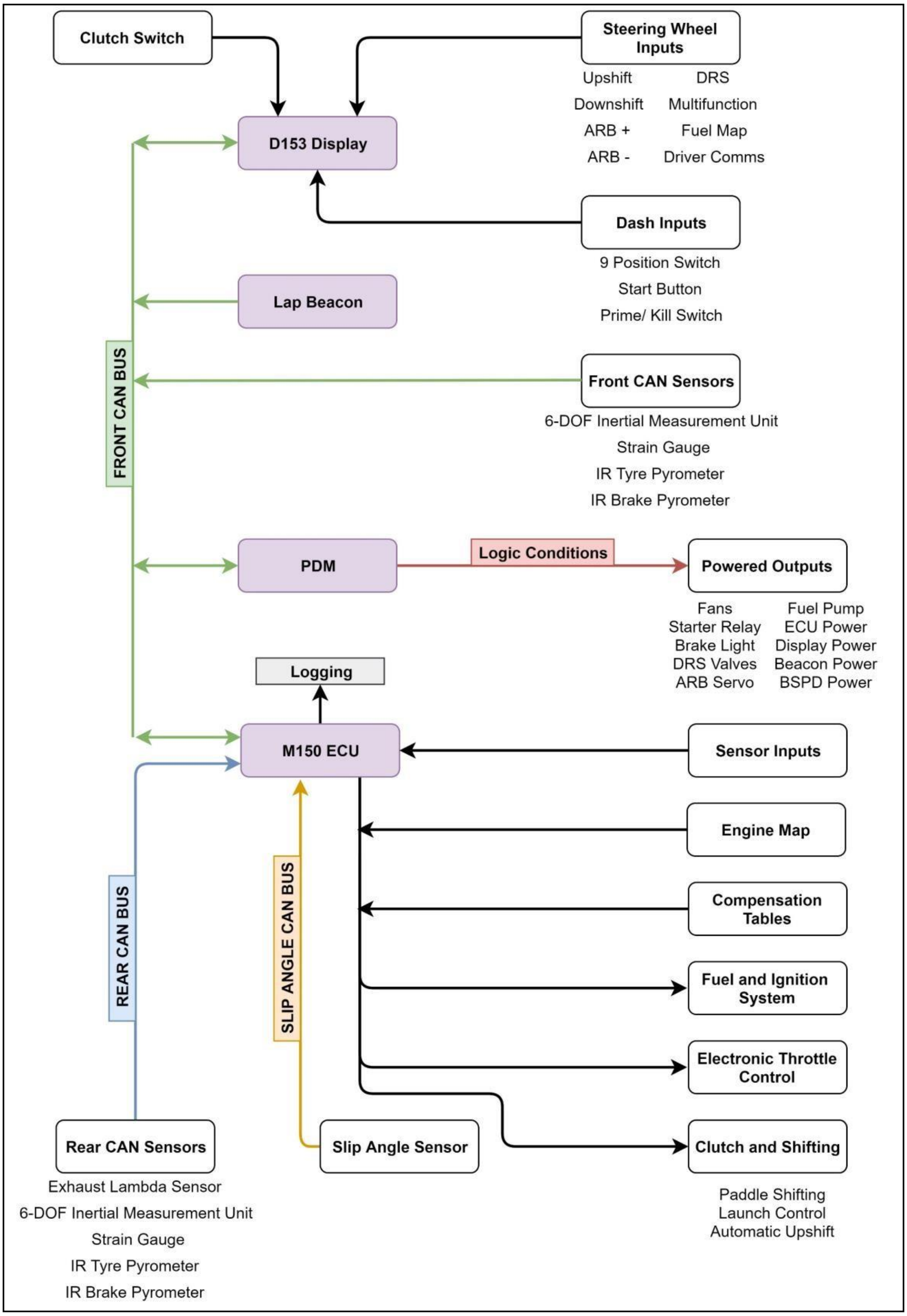


Figure 6.1: System Map Highlighting Hardware, CAN Bus Utilisation and System Inputs and Outputs

Front Loom	Input Type
Wheel Speed FR	Digital
Wheel Speed FL	Digital
Shock Pot FR	AV
Shock Pot FL	AV
Brake Pressure F	AV
IMU Front	CAN
Strain Gauge FR	CAN
Strain Gauge FL	CAN
Tyre Pyro FR	CAN
Tyre Pyro FL	CAN
Brake Pyro Front	CAN
Steering Angle	AV
Throttle Pots x3	AV
Brake Over Travel	Shutdown
Inertia Switch	Shutdwon
Power Relay	Shutdown
Primary Kill Switch	-
BPSD	Shutdwon
Dash	-
Steering Wheel	-
D153 Display	-
BR2 Beacon	-
Fuel Pump	-

Rear Loom	Input Type
Wheel Speed RR	Digital
Wheel Speed RL	Digital
Shock Pot RR	AV
Shock Pot RL	AV
IMU Rear	CAN
Strain Gauge RR	CAN
Strain Gauge RL	CAN
Tyre Pyro RR	CAN
Tyre Pyro RL	CAN
Brake Pyro Rear	CAN
Slip Angle	CAN
Fuel Temp/ Pressure	AT/ AV
Injector	Low Side Inj
Ignition 1	Low Side Ign
Ignition 2	Low Side Ign
Ignition Module	Low Side Ign
ETB	Half Bridge
Starter Relay	PDM
Brake Light	PDM
Upshift/ downshit	Half Bridge
DRS	PDM
Lambda	CAN
Reference	Digital
Sync	Digital
Air Temp/ Pressure	AT/ AV
Oil Temp/ Pressure	AT/ AV
Engine Temp	AT
ARB Servo	Half Bridge
Gear Position	AV
Fan Right	PDM
Ran Left	PDM
Groundig Block	-

CAN	PDM Outputs
M150	M150
D153	D153
PDM 15	Slip Angle
IMU Front	Lambda
Strain Gauge FR	Injector
Strain Gauge FL	Fan Right
Tyre Pyro FR	Fan Left
Tyre Pyro FL	Starter Relay
Brake Pyro Front	Ignition 1
IMU Rear	Ignition 2
Strain Gauge RR	Brake Light
Strain Gauge RL	DRS On
Tyre Pyro RR	DRS Off
Tyre Pyro RL	Fuel SS Relay
Brake Pyro Rear	Fuel Pump 1
Slip Angle	Fuel Pump 2

Figure 6.2: Sensor and Connector Architecture for Front and Rear Looms

Figure 6.1 illustrates the use of 3 independent CAN Buses on M19-C's electrical system. The first CAN bus is used for the front loom, which contains the front CAN sensors, Display and PDM. The second CAN Bus is used for the rear room which contains the rear CAN sensor and MoTeC Lambda to CAN (LTC). The third CAN Bus is dedicated for the Slip Angle Sensor, and any other high demand CAN sensors that the team wishes to use in the future. All three CAN Buses communicate simultaneously with the M150 ECU.

Figure 6.2 breaks down the type of sensor inputs used throughout the system. Analogue Voltage inputs (AV) are used for variable resistance sensors such as linear and rotary potentiometers. Analogue Temperature inputs (AT) are used for temperature coefficient-based temperature sensors, such as engine and oil temperature sensors. AT inputs similar to AV inputs, but have a 1000-ohm pullup resistor to the sensor 5V rail to allow for the ECU to detect changes in sensor resistance. Digital inputs are used for sensors that continually update their value and transmit it digitally, such as hall effect sensors for wheel speed and engine synchronization. PDM outputs are logic-controlled outputs from the PDM which switch battery voltage based on certain conditions.

There are 11 AV inputs, 4 AT inputs, 6 digital inputs, and 14 CAN inputs, resulting in a total of 35 sensors used for engine calibration and vehicle set-up tuning.

6.2 Power Budget Validation

A major consideration of the functionality of the LV systems is the power budget, and whether or not the system is capable of running at a constant gain.

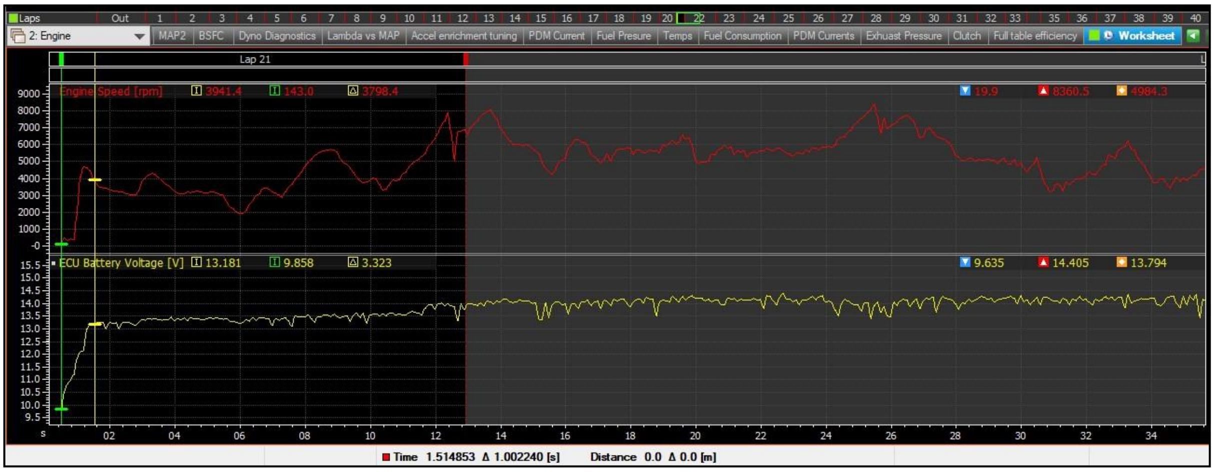


Figure 6.3: i2 Pro Screenshot Showing Battery Voltage and RPM Following an Endurance Driver Swap Car Restart

Figure 6.3 shows the battery capacity regeneration post cranking, with maximum loading on the electrical system (all control hardware, sensors, fuel pump and fans operating). This data is from a testing session at the Holden Proving Grounds in Lang Lang, where a 40-lap endurance was attempted. The shown segment of data is from when the car restarted following the driver swap. It can be seen that battery voltage climbs from around 9.6V to 13.2V within 1 second of the engine restarting. The battery voltage then climbs slightly and plateaus to a constant 14V for the remainder of the stint.

This is a critical piece of validation and clearly illustrates that the alternator of the 690 is capable of recharging the battery, and provide surplus energy to the electrical system. This phenomenon has been consistent throughout every testing session, whereby the car has been able to crank from the Shorai battery without issues, meaning the battery is always being charged to a satisfactory level during driving. This ultimately validates the power budget calculations made during the design period, seen in Table 7.

These results inspire a great amount of confidence in the power budget of M19-C, and prove that the car can restart after any unforeseen circumstances during a competition endurance, such as stalling or emergency situations which result in the car having to stop on track.

7. Failures and Solutions

7.1 Ignition Module Wiring

Due to the KTM 690 engine featuring twin spark ignition, it was required to have two ignition signals to power the two ignitions coils for effective combustion. An oversight/ assumption during design period resulted in each ignition coil being powered by a separate ignition output signal from the ECU. The issue here is that it is incredibly difficult and complex to set up twin spark in a single cylinder via the M150 Tune workspace. The M150 ECU is typically used for single spark engines, and so setting up twin spark would mean that ECU needs to be programmed such that the 690 is a 2- cylinder and tune its ignition timing accordingly. This is a very tedious and difficult process to get working correctly and reliably. The work around for this was to splice 1 ignition output into two, meaning that ECU think it is powering a single cylinder, single spark engine, but both ignition coils will fire simultaneously.

7.2 Software BSPD

Delays in the hardware BSPD meant that a software BSPD was required for the first few testing sessions. The software BSPD was coded in M1 Build to match that hardware BSPD functionality as closely as possible, whereby hard brake and throttle for > 500ms would kill power to ignition and fuel. The early iterations of the code for the software BSPD was very rudimentary, and resulted in unexpected BSPD trips which held up testing sessions. The issue was isolated to be the timer, which would not reset when the conditions for a BSPD trip were no longer present. When the timer code was revised to reset every time the trip condition was not met, the BSPD functioned as expected and the team has not had any unexpected software BSPD trips since.

7.3 Blowing of 150 Amp Fuse

Since manufacture, there have been two instances of the main 150A power fuse blowing on M19-C. The first case was due to an oversight by a junior forgetting to disconnect the battery Anderson plug when doing work on the primary kill switch cover. As a result, one of the power wires made contact with the monocoque (which was grounded) and shorted the battery. The take away from this was to ALWAYS disconnect the Shorai when working on/ detaching any of the power wiring. The second case was during a testing session. The cause of this blow is not 100% confirmed but is suspected to be the wiring on the right fan being munched during driving, which lead to power and ground wires to come into contact with each other and short. Once these exposed wires were repaired, and the fan wiring routed such that it wouldn't interfere with the fan blades, no such fuse blows have been encountered. These fuse blows are a good learning opportunity, and prove how effective the main fuse is in prolonging the life of the Shorai.

7.4 Fuel Tank and Battery Interference

After about 4 testing sessions, it was found that the left battery L-bracket was rubbing against the fuel tank causing a small leak in the tank. This is far from ideal, and the pre-emptive foam placed in between these two aluminium surfaces was insufficient against engine vibration. The final solution was to remove the L-Brackets entirely and shift them to the right around 10mm. This meant removing a mount that was plexused onto the monocoque. The technique to do this is the heat it up with a heat gun, and slowly chip away at the both of the mount with a chisel and hammer until the mounted detached. It is important to note that the monocoque will begin to de-laminate at around

120 degrees, and plexus loses its adhesive properties around 90 degrees. As such, aluminium tape was placed around the mount that was being heated to prevent damage to the monocoque. This technique was effective in removing a plexused mount from the monocoque.

8. MoTeC Hardware Configurations

Research into upgrading MoTeC hardware has been of a high priority in previous years for Monash Motorsport. There have been numerous team FYPs that laid the groundwork for this, and focused on the development and integration of these new hardware. As such, to avoid repetition, this section of the report will focus primarily on the key areas of these configurations that are applicable to M19-C.

8.1 D153 Display - Display Creator

The MoTeC D153 display is used as a visual aid to present key information to the driver, such as lap times, gear position, engine RPM, critical temperatures and pressures, to allow them to drive the car to its full potential given its current state. The software used to program the D153 is called ‘Display Creator’, supplied by MoTeC.

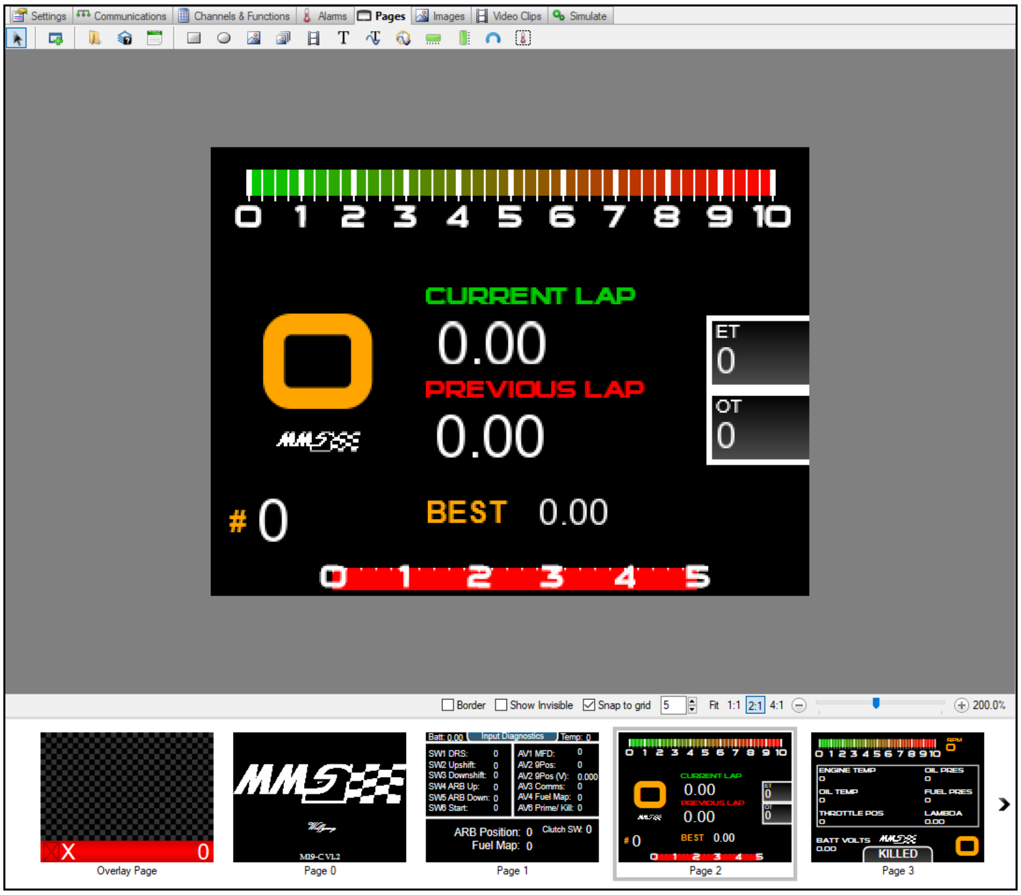


Figure 8.1: Page Layout on Display Creator

The D153 display is capable of having multiple pages, which can be cycled through with a driver input switch. Figure 8.1 shows the layout of these pages and how they are organised in Display Creator. Page 0 is the startup screen which displays for a set amount of time during power up. M19- C has 3 other pages. The main driving screen (shown above) display lap times, lap number, best lap, gear position, engine speed, as well as warnings for the driver when temperatures are getting too high or if any shutdown trips have occurred. The next page is the powertrain diagnostics page, which shows temperatures, pressures, throttle position, lambda and battery voltage – which is used for quickly diagnosing any issues on track. The last page is an input diagnostics page, used to determine if all the switch inputs going into the display are operating as expected.

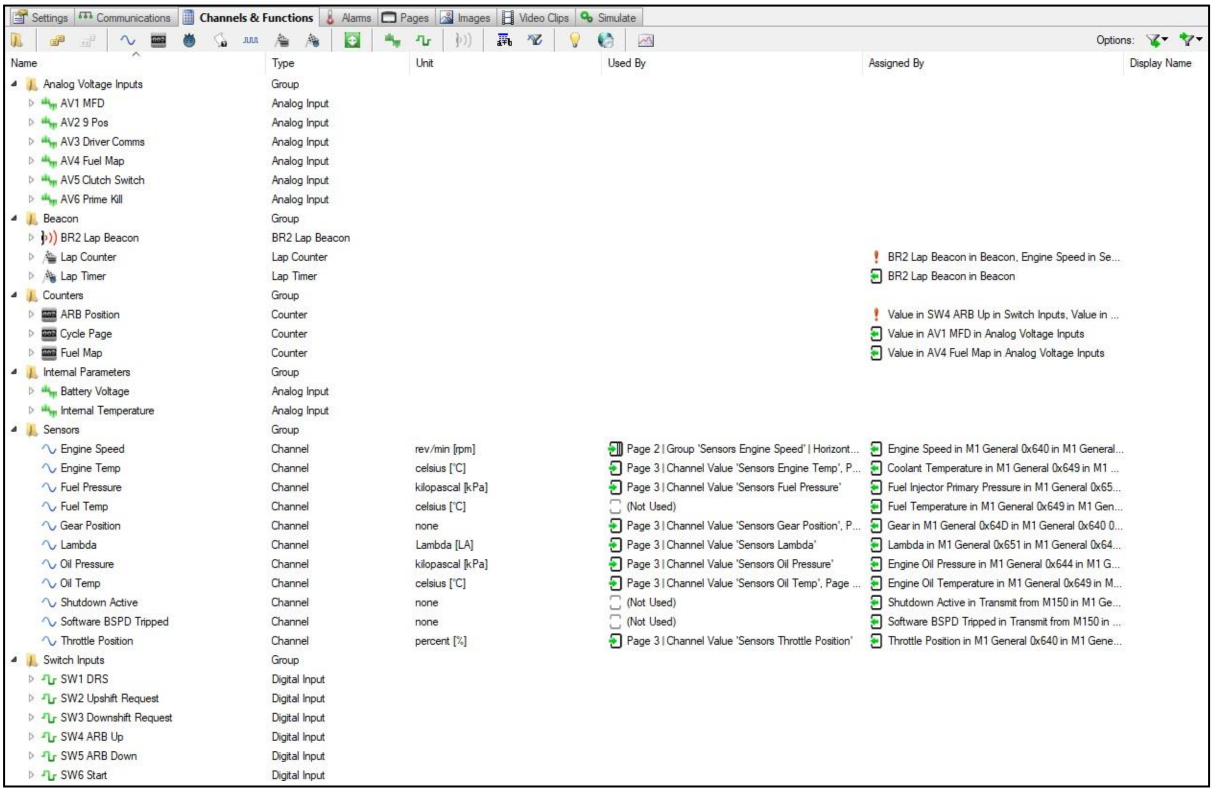


Figure 8.2: Channels and Functions on Display Creator

This tab is where all channels that are to be used by the display and defined and assigned. They can be assigned by either CAN inputs from the ECU (such as all the engine sensors), or inputs directly into the display, such as steering wheel/ dash switches and the lap beacon.

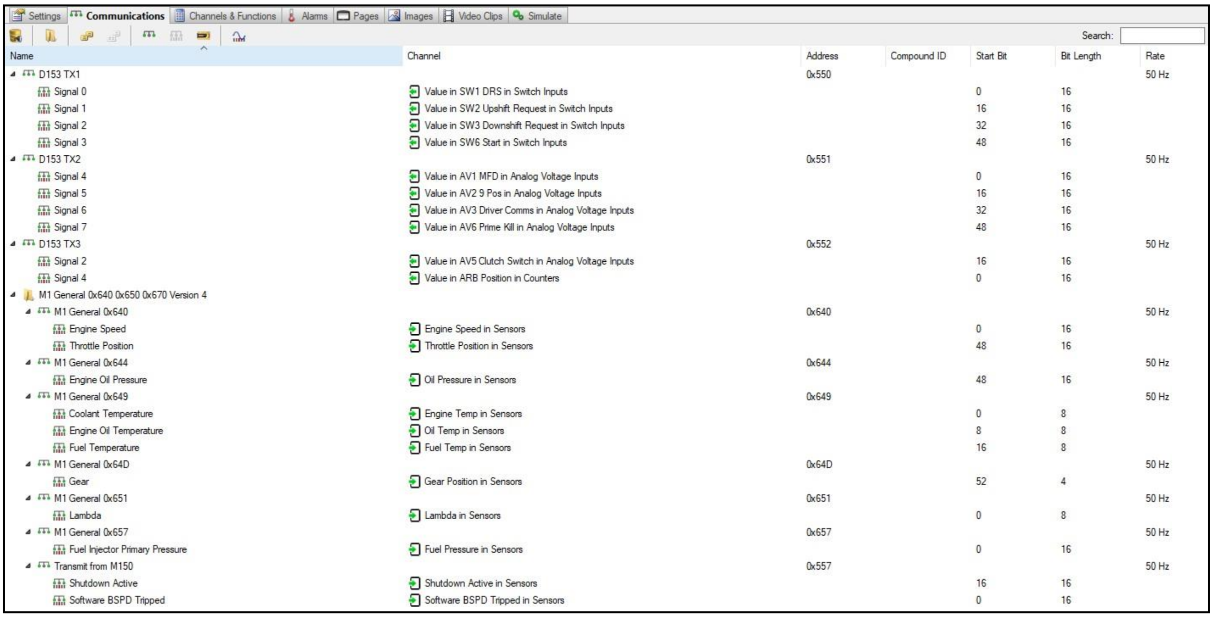


Figure 8.3: CAN Commutations on Display Creator

The communications tab is used to set up all the CAN communications that are being received and transmitted by the D153. Each individual group seen above is a different CAN address, with multiple individual signals being transmitted on each address. The CAN addresses, starting bit, bit length and transmission frequency are all assigned here.

8.2 PDM15 - PDM Manager

The MoTeC Power Distribution Module (PDM) is the device used to distribute battery power to components around the vehicle in a controlled, logical and protected manner. The PDM is capable of receiving and transmitting CAN messages, using logic to switch outputs, as well as have over current protection for all outputs. The software used to program the PDM is called 'PDM Manager', supplied by MoTeC.

Output	Pin	Rating	Channel	Max	Retry Delay	Retry Count	Master Shutdown	Stay Alive	Control
1	A_1/A_10	20A	ECU Power	15A	1.00s	Always Retry			MainKS_ON = true, true for 1.00s
2	A_3/A_12	20A	LTC Power	8A	1.00s	0			Prime
3	A_5/A_14	20A	Fan Right Power	19A	1.00s	Always Retry			(Coolant Temp > 80, true for 0.10s) and (Engine Speed > 1, true for 0.10s, false for 5.00s)
4	A_7/A_16	20A							
5	A_9/A_17	20A	Fan Left Power	19A	1.00s	Always Retry			(Coolant Temp > 80, true for 0.10s) and (Engine Speed > 1, true for 0.10s, false for 5.00s)
6	B_3/B_9	20A	Fuel SS Relay, ECU Power	15A	1.00s	Always Retry			MainKS_ON = true, true for 1.00s
7	B_5/B_11	20A	Pump, Injector, Ignition Power	19A	1.00s	3			(Prime = true, true for 0.10s, false for 2.00s) and (Shutdown active = false, true for 1.00s, false for 0.10s)
8	B_7/B_13	20A	Dash, Beacon, BSPD Power	10A	1.00s	Always Retry			MainKS_ON = true, true for 1.00s
9	A_2	8A							
10	A_4	8A							
11	A_6	8A	Starter Relay Power	8A	1.00s	0			Start
12	A_8	8A	Brake Light Power	5A	1.00s	0			BrakeLight = true, true for 0.10s, false for 0.10s
13	A_11	8A	ARB Servo Power	8A	1.00s	Always Retry			MainKS_ON = true, true for 1.00s, false for 1.00s
14	A_13	8A	DRS On Valve	5A	1.00s	Always Retry			DRS Switch = true
15	A_15	8A	DRS Off Valve	5A	1.00s	Always Retry			DRS Switch = true

Figure 8.4: Powered Outputs on PDM Manager

Figure 8.4 shows were all the powered outputs are set up in PDM manager. The PDM has two types of outputs: single pin outputs that have a maximum current rating of 8 Amps, and double pin outputs that have a maximum output of 20 Amps split across two output pins. It is also here where logic conditions are set up for each output, alongside maximum current limit for each output. These outputs can be switched using channel functions, which can be set up using the functions tab. An example of this is taking brake pressure signals (transmitted via CAN from the ECU) and setting the output for the brake light to turn on when brake pressure exceeds a certain threshold.

Channel	Data Size	CAN Address	Offset	Byte Order	Bit Mask	Divisor	Timeout Value
DRS Switch	16bit (unsigned)	550 hex	Byte 0	Normal	FFFF hex	1	0
Upshift Switch	16bit (unsigned)	550 hex	Byte 2	Normal	FFFF hex	1	0
Downshift Switch	16bit (unsigned)	550 hex	Byte 4	Normal	FFFF hex	1	0
Start Switch	16bit (unsigned)	550 hex	Byte 6	Normal	FFFF hex	1	0
MFD Switch	16bit (unsigned)	551 hex	Byte 0	Normal	FFFF hex	1	0
9 Pos Switch	16bit (unsigned)	551 hex	Byte 2	Normal	FFFF hex	1	0
Driver Comms Switch	16bit (unsigned)	551 hex	Byte 4	Normal	FFFF hex	1	0
Prime Kill Switch	16bit (unsigned)	551 hex	Byte 6	Normal	FFFF hex	1	1
Engine Speed	8bit	118 hex	Byte 0		FF hex		0
Coolant Temp	8bit	118 hex	Byte 3		FF hex		0
Shutdown active	16bit (unsigned)	557 hex	Byte 2	Normal	FFFF hex	1	0
Brake Pressure Front	8bit	655 hex	Byte 0		FF hex		
Brake Pressure Rear	8bit	655 hex	Byte 1		FF hex		
Run Switch	16bit (unsigned)	557 hex	Byte 0	Normal	FFFF hex	1	0

Figure 8.5: CAN Inputs on PDM Manager

The PDM can receive CAN messages from the ECU that contain channels which can then be used for logic in the PDM. An example of this is turning the fans on when coolant temperature exceeds a certain threshold. The PDM also outputs the current draw of each output on a preassigned CAN address, which can then be read and logged by the ECU for data acquisition purposes.

8.3 M150 ECU - M1 Build and M1 Tune

The MoTeC M150 ECU is the heart of the LV systems on M19-C, and is responsible for controlling the ignition, fueling, shifting, and logging sensor inputs. The ECU is completely open source, and the firmware for it can essentially be written from scratch to suit the needs of the team. That being said, MoTeC provide a general-purpose package (General Purpose Racing Paddleshift - GPRP) which is suitable for most internal combustion engine vehicles. This package contains all the core elements required to power an engine, in addition to vehicle dynamics sensors such as wheel speeds and brake pressures. M19-C uses this GPRP package, with modifications for the team's requirements, such as additional vehicle dynamics sensors and rules compliance plausibility measures. The firmware for the ECU is developed on 'M1 Build', and all the inputs and outputs are tuned and calibrated on 'M1 Tune'.

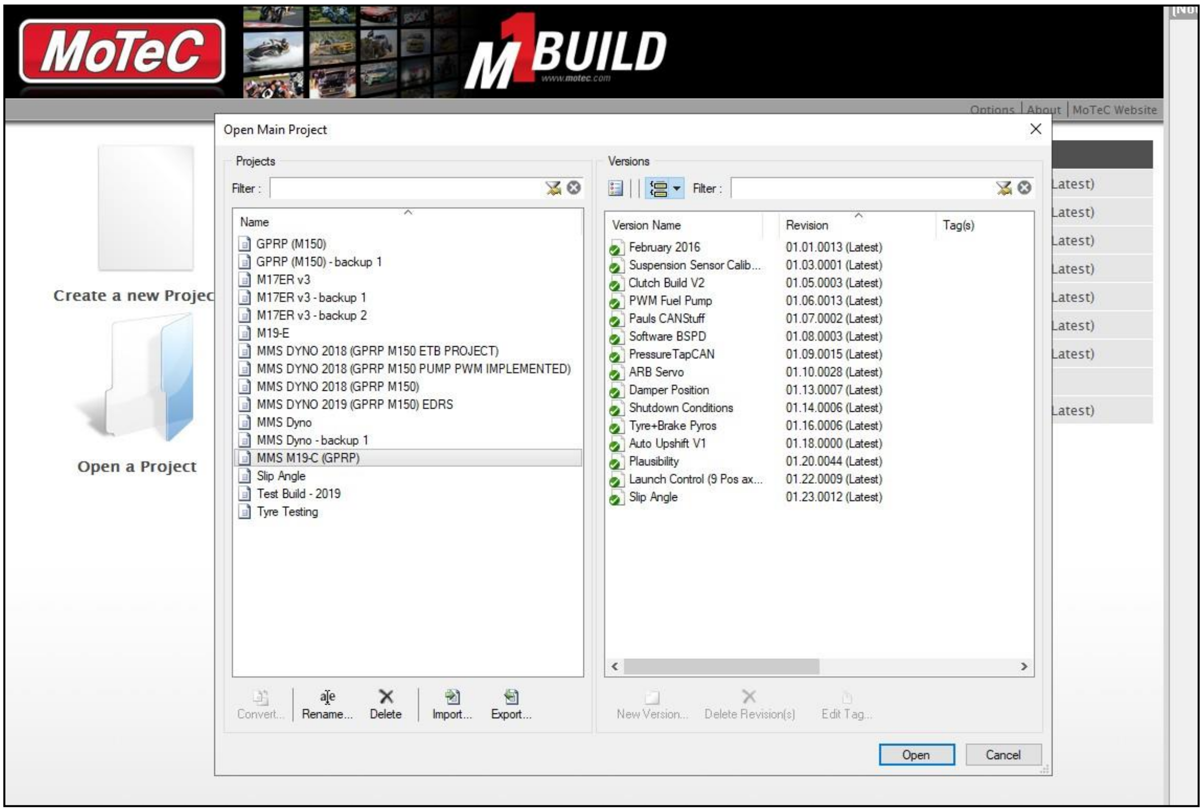


Figure 8.6: Firmware Version Control on M1 Build

M1 Build makes it easy to control all new version of firmware that are being created. Figure 8.6 shows how the GPRP package has evolved over the year to incorporate all the functionality that team requires. It started with the base GPRP package, after which new versions were created for suspension sensor calibration, clutch build, PWM fuel pump, Software BSPD, aerodynamics pressure tapping, ARB servos, damper position, shutdown conditions, tyre/ brake pyrometers, automatic upshift, plausibility conditions, launch control, and slip angle sensor. It is a good practice to create a new version every time a significant edit is being made to the build, to ensure there is a backup of a previously functioning firmware to revert to.

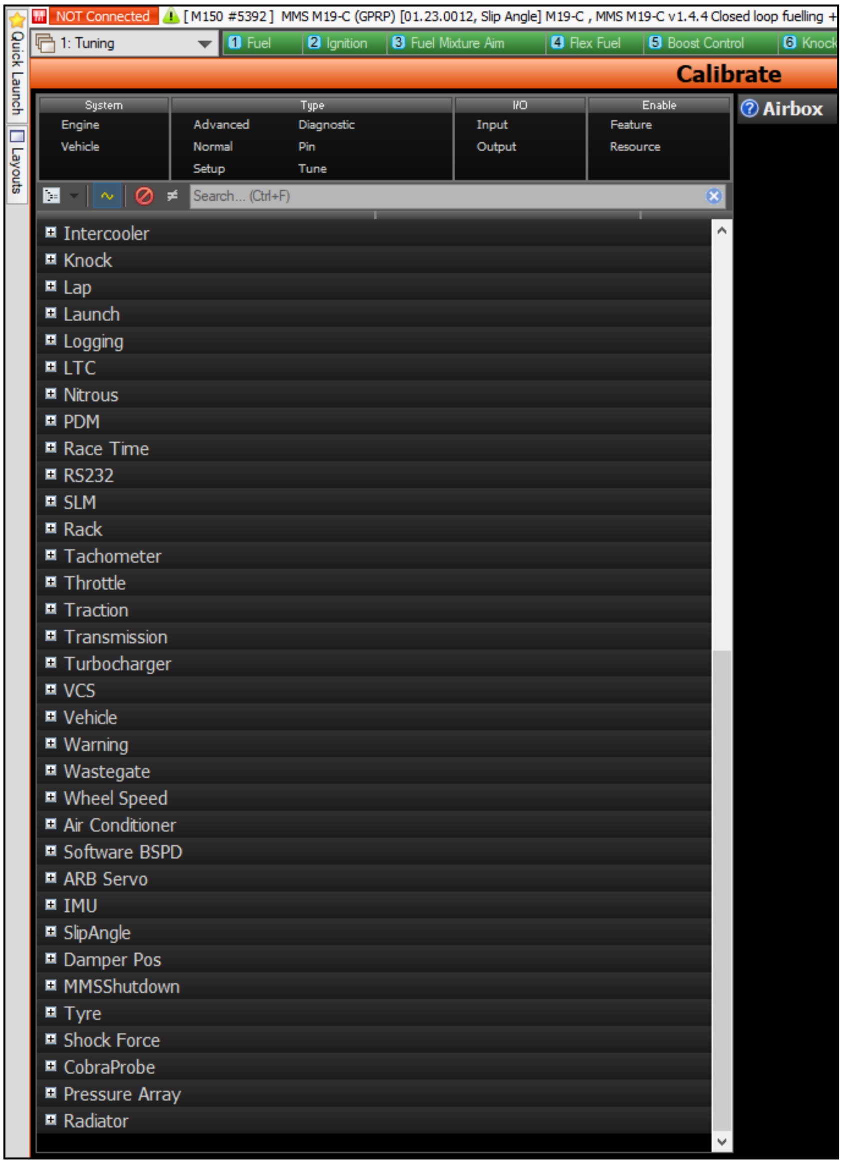


Figure 8.11: All Calibrate List with Groups Defined in M1 Build

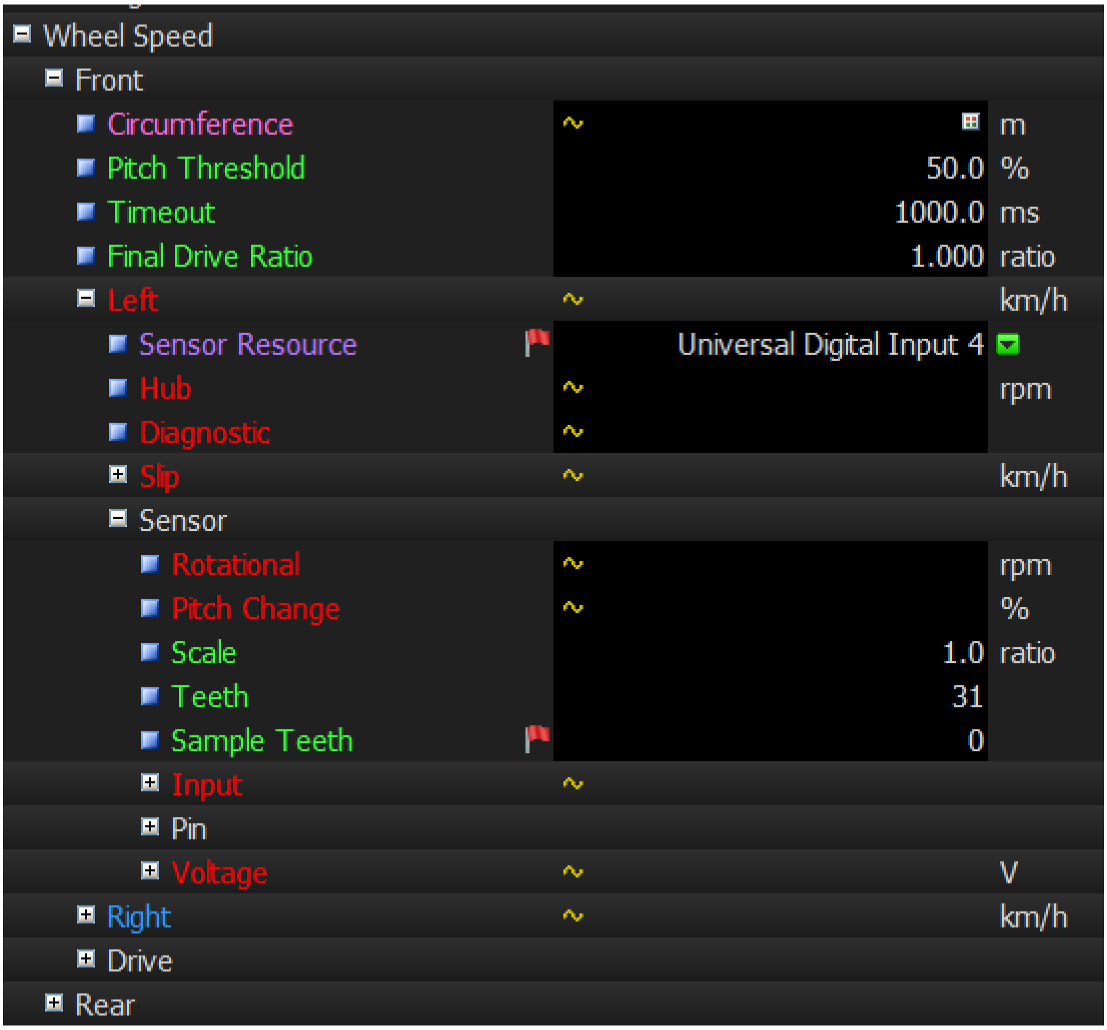


Figure 8.12: Calibration Example - Wheel Speed Sensor Calibration in M1 Tune

9. Conclusions

This project closely followed the design, integration and manufacture of the electrical system that was installed on M19-C; Monash Motorsport's latest combustion race car. The design period at the commencement of the year highlighted the importance of early concept generation and positioning of hardware, which allowed for packaging components around the car in such a way that allowed for seamless integration with other sub systems on the vehicle. Routing the wiring harness in CAD proved to be incredibly useful, as it allowed wires to be routed in areas away from potential damage, in addition to allowing for the exportation of all wire lengths which greatly streamlined the manufacturing process. The development of a power budget during the design period resulted in testing to confirm the capabilities of the KTM 690's alternator, ultimately allowing for an electrical system that ran at constant gain. Developing and documenting accurate pinouts for all connectors and hardware proved to be highly beneficial for manufacturing and troubleshooting during testing sessions.

Heavy emphasis was placed on build quality during the manufacturing period in order to significantly improve the reliability of the system. A number of measures were taken when manufacturing to waterproof the electrical system. For the harness itself, glue lined heatshrink over crimps and regular heatshrink over the core provided sufficient protection from fluid entering the loom. Additionally, all the connectors that were used (DTM, Autosport, Superseal and OEM connectors) had rubber grommets where the wire enters the connectors so that the crimp and terminal were completely sealed. Any other exposed wire that could not be sheathed in heatshrink or grommets was wrapped with electrical tape and epoxy potting compound.

The system was capable of firing the car in the workshop with minimal issues, which was a result of constant bench testing during manufacture to ensure all wire and connections were functional. Following this, on track testing showed the system to be incredibly reliable, meeting its functional requirements of powering the car, logging sensors and running at constant gain. A few issues were encountered during the testing period, such as the ignition module wiring, blowing main fuses, software BSPD trips and hardware integration issues – all of which were rectified, documented and used as a learning opportunity to further improve the system.

A well-integrated loom should not have to be taken off the car for servicing once it has been installed. If produced with good manufacturing techniques and outstanding build quality, the LV Systems on the car should capable of powering and running the car for the entirety of the two-year design cycle (which includes all testing sessions and competitions in both Australia and Europe). From the driving that M19-C has done so far, it is clear to see that the LV Systems is bullet proof and reliable, and is well on its way to achieving this goal. This is a testament to the meticulous care taken by all those involved during the manufacture, and this should be the standard for all looms and associated electronics that Monash Motorsport will produce in the future.

It should be noted that a copious amount of work has been completed this year for design of the LV Systems. This report is not exhaustive of, nor documents every piece of work that has completed. Detailed schematics, wiring pinouts, CAD files, configuration files and tutorials can all be found on the MMS server, Google Drive, and Wiki. I hope this report adds to the wealth of knowledge of the team, so future part designers can learn from and build upon this system to push our cars to peak performance and ensure Monash Motorsport is the *Most Respected FSAE Team in The World.*

10. ACKNOWLEDGEMENTS

I would like to acknowledge the Monash Motorsport team for giving me the opportunity to design a part from the ground up for a world class car. The team has continually supported this project, providing the resources for me to succeed and contribute greatly to the evolution into *1 Team 3 Cars.*

I would like to recognize all the juniors that were involved in manufacturing, assembly and installation onto the car; Anthony Ta, Joshua Taylor, Zara de Jersey, Jessica Lee and Rashmidha Kanagarajah. Their assistance has been of immeasurable value, and their commitment to quality has resulted in a finished product of high caliber - one that I will be proud to present to the world stage in Europe next year.

I would also like to also recognize the team's academic advisor, and my project supervisor, Dr. Scott Wordley for his mentorship throughout this project. His contributions to Monash Motorsport are invaluable in its continued evolution and success.

11. References

MoTeC. (2017). *M1 ECU Hardware.*
Retried from:
https://www.motec.com.au/filedownload.php/M1%20ECU%20Hardware.pdf?docid=4487.

MoTeC. (2013). *PDM Power Distribution Module.*
Retried from:
https://www.motec.com.au/filedownload.php/PDM%20User%20Manual.pdf?docid=2434.

MoTeC. (2015). *D153 - Colour Mini Display.*
Retried from: https://www.motec.com.au/filedownload.php/18027_d153_datasheet.pdf?docid=4259.

Gibson, J. (2017). *Professional Mil-Spec Motorsport ECU Wiring Harness Construction*.
Retrieved from: https://www.rbracing-rsr.com/wiring_ecu.html

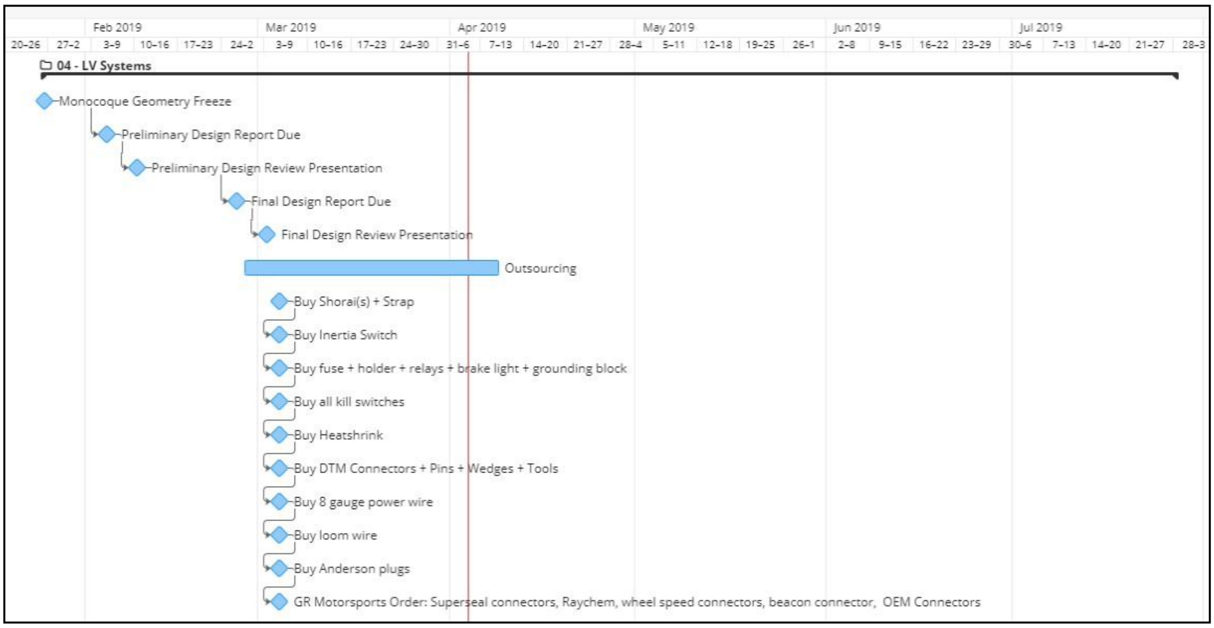
Lund Instrument Engineering. (2018). *Wire Gauge and Current Limits Including Skin Depth and Strength*.
Retrieved from: https://www.powerstream.com/Wire_Size.htm

Dawkins, P. (2016). *NX 10 Routing Electrical and Harness Tutorial.*
Retrieved from: MMS Server; MMS -> 2019 -> 03-Powertrain -> 04-LV Systems -> Manuals

SAE International. (2018). *Formula SAE Rules 2019.*
Retrieved from:
https://www.fsaeonline.com/cdsweb/gen/DownloadDocument.aspx?DocumentID=64b861c2-980a-40fc-aa88-6a80c43a8540

12. Appendices

12.1 Appendix 1: Timeline



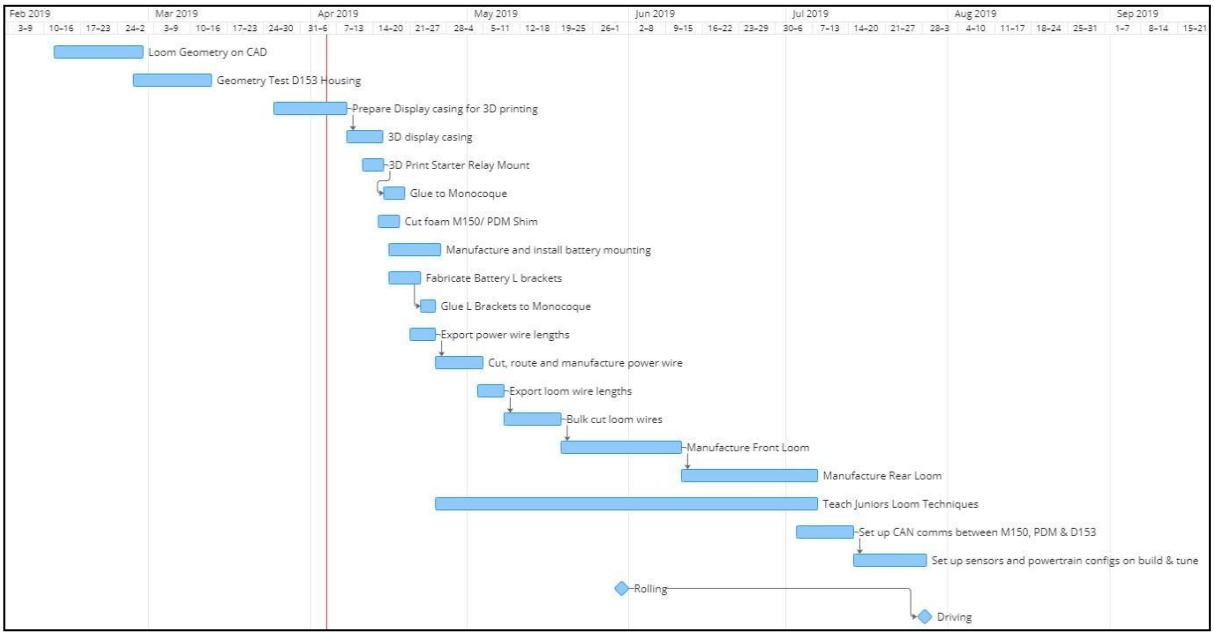


Figure 12.1: Detailed Wrike Timeline

12.2 Appendix 2: Mass Breakdown

Table 12.1: Mass Breakdown

Part	Mass (kg)
Front Loom	0.815
Rear Loom	1.059
Power Wiring	0.406
MoTeC M150 (ECU)	0.445
MoTeC PDM15	0.26
MoTeC D153 Display + Housing	0.365
Shorai Battery + Leads + Mounting	1.159
Grounding Block	0.091
Master Switch	0.126
Inertia Switch	0.04
Cranking Anderson Plug	0.018
Starter Relay + Mount	0.019
Regulator Rectifier	0.386
Cockpit Killswitch	0.033
Start Button	0.006
9 Position Switch	0.029
MoTeC BR2 Lap Beacon	0.095
Ignition Module	0.071
Total	5.423

12.3 *Appendix 3: Failure Mode Effect Analysis*

Table 12.2: FMEA

Function	Failure Mode	Effects	S	Cause(s)	O	Current Control	D	RPN	Recommended Action	Recommended Documentation
Crimps	Wire detaches from plug/socket	Lack of power, lack of signal, short circuit, electrocution, sparks, fire	6	Half-pressed crimps/Excessive force applied	8	Pre-manufacturing practice/Visual check	3	144	Ensure crimping technique is perfected, Test with expected force	Visual and/or physical checks added to checklist
Splices	Wire detaches from wire	Lack of power, lack of signal, short circuit, electrocution, sparks, fire	6	Half-crimped splices/Excessive force applied	8	Pre-manufacturing practice/Visual check	6	288	Ensure splicing technique is perfected, Test with expected force, double check continuity post-manufacturing	Visual and/or physical checks added to checklist
Power Transmission	Wire burn-out	Lack of power, short circuit, electrocution, sparks, fire	8	Incorrect choice of wire gauge/Excessive current	5	Pre-design calculations, post-manufacturing current checks	2	80	Following wiring sizing standard with design calculations, check post-manufacturing using current clamp	Visual checks added to checklist
Signal Transmission	Signal induces too much noise	lack of signal	3	Wire with no shield selected	4	Twisted sheathed pair for CAN network, peformance checks	8	96	Twisted sheathed pair for CAN network, asses for induced noise post-manufacturing	Visual checks added to checklist
Waterproofing	Water shorts electrical current	Lack of power, lack of signal, short circuit, electrocution, sparks, fire	7	Improper heat-shrinking/Plug pinning	6	Pre-manufacturing practice/Visual check	6	252	Ensure heats-shrinking and pinning technique is perfected	Visual checks added to checklist
Thermal Proofing	Heat melts insulation	Lack of power, lack of signal, short circuit, electrocution, sparks, fire	8	Insufficient thermal protection around hot spots of the car	5	Pre-manufacturing practice/Visual check	2	80	Ensure heats-shrinking and pinning technique is perfected, Thermal braid wrap extreme points	Visual checks added to checklist
Stress Loading	Wires fray/snap	Lack of power, lack of signal, short circuit, electrocution, sparks, fire	7	Insufficient slack allowed between wiring points	7	Pre-design calculations	2	98	Ensure sufficient slack is allowed between wiring points	Visual checks added to checklist
Shutdown	Car fails to shutdown	Lack of car control, Unsafe state of car	10	Improper wiring of the shutdown system	2	Design checks/Post-manufacturing test	4	80	Confirm correct operation prior to testing	System test added to checklist
Shutdown	Car shutdowns unexpectedly	Lack of car control	5	Improper wiring of the shutdown system/Short-circuit within system	4	Design checks/Post-manufacturing test	4	80	Confirm correct operation prior to testing	System test added to checklist

12.4 Appendix 4: Outsourcing Breakdown

Table 12.3: Detailed Outsourcing Breakdown

Material/Part	Material/Part to be bought (inc. size and part number)	Supplier	Cost
Wire	22 AWG Yellow Wire M22759/16-22-4 22 AWG Violet Wire M22759/16-22-7 22 AWG White Wire M22759/16-22-9 22 AWG Grey Wire M22759/16-22-8 22 AWG Green Wire M22759/16-22-5 20 AWG Red Wire M22759/16-20-2 20 AWG Black Wire M22759/16-20-0 20 AWG Orange Wire M22759/16-20-3 Bundled Shielded Wire (CAN) M27500-22-TG-2-T14	Cambridge Technologies	$371
DTM	2 Pin Male 2 Pin Female 3 Pin Male 3 Pin Female 4 Pin Male 4 Pin Female 6 Pin Male 6 Pin Female 8 Pin Male 8 Pin Female 12 Pin Male 12 Pin Female Male Wedges Female Wedges Sockets Pins	RS Components	$1,624.73
Power Hardware	30mm Kill Switch 40mm Kill Switch 100 Amp Fuse Power Relay Fuse Holder	RS Components	$133.79
Heatshrink	RS Pro Various Sizes RayChem Various Sizes	RS Components GR Motorsport	$500
Connectors	Superseal 34 Pin A Superseal 26 Pin B Superseal 34 Pin C Superseal 26 Pin D Wheel Speed Sensor Connector Beacon Connector Injector Connector Engine Temp Connector	GR Motorsport	$556.11
C Car Battery	Shorai LFX18A1-BS12	Shorai Power Litema	$570
E Car Battery	Bioenno BLF-1212A	Bioenno Power	$450
Power Hardware	Terminals (Spades, lugs, blades, rings) Anderson Plugs 8 Gauge Power Wire Push button switches Hook and Loop Tape Primary Master Kill Switch	Jaycar	$481.65
Inertia Switch	Sensata Inertia Switch 8-14G	EV Works	$111.20
OEM Connectors	Brake Pressure Sensor Connector ETB Connector TMAP Connector Fuel Temp/ Pressure Connector	Bosch Motorsport	$283.10
Ignition Module	2 Channel Ignition Module	Bosch Motorsport	$401.72
MoTeC Cables	D153 Display Cable A and B Ethernet to Autorsport Cable	MoTeC	$170
Battery Strap	Fiber Non-Slip Aluminium Alloy Buckle Battery Strap	Bang Good	$36
Ignition Module Connector	7 Pin JPT Connector	Streamline Automotive	$76
Ignition Coil Connector	Nippon Denso 2 Pole Connector	Carmo Electronics	$25
O-Ring	Display sealing O-ring (108mm OD)	Seal Innovations	$50
Brake Light	Red LED Strip	Scorptec	$34

12.5 *Appendix 5: M150 Pinouts*

M150 A	Use 1	Use 2	Notes	MoTeC Designation
1	Engine Temp		1K Pull up to Ser	AT5
2	Air Temp		1K Pull up to Ser	AT6
3	Air Pressure			AV15
4	Fuel Pressure			AV16
5	Oil Pressure			AV17
6				Low Side Ignition 9
7	IGMOD-7 & IGMOD-2			Low Side Ignition 10
8				Low Side Ignition 11
9				Low Side Ignition 12
10	Sensor 5V		Rear Sensors	Sensor 5V C1
11				Lambda Narrow input 1
12				Lambda Narrow input 2
13	Knock Sensor			Knock input 3
14				Knock input 4
15				Digital input 2
16				Digital input 3
17				Digital input 4
18	Sensor 5V		Engine Sensors	Sensor 5V C2
19	Sensor 5V		Rear CAN senso	Sensor 5V B2
20				LIN Bus
21	GPS			RS232 Receive
22				RS232 Transmit
23				Digital Input 1
24	GRND BLOCK		ECU Ground	BAT NEG3
25	GRND BLOCK		ECU Ground	BAT NEG4
26	Sensor 0V		Rear Sensors	Sensor 0V C1
27	Sensor 0V		Engine Sensors	Sensor 0V C2
28	CAN HI-3			CAN Bus 3 HI
29	CAN LO-3			CAN Bus 3 LO
	CAN HI-2			CAN Bus 2 HI
31	CAN LO-2			CAN Bus 2 LO
32				BAT NEG 5
33	Sensor 0V		Rear CAN senso	Sensor 0V B1
34			Temporary coolir	Sensor 0V A1
		Rear		

M150 B	Use 1	Use 2	Notes	MoTeC Designation
1	Upshift			Half Bridge Output 9
2	Downshift			Half Bridge Output 10
3	WS RR			Universal Digital Input 8
4	WS RL			Universal Digital Input 9
5				Universal Digital Input 10
6	Sync			Universal Digital Input 11
7				Universal Digital Input 12
8	Injector			Low Side Injector 5
9				Low Side Injector 3
10	SP RR			AV9
11	SP RL			AV10
12	Exahust Pressur			AV11
13	12V Power		PWR from PDM	BAT POS
14				Low Side Injector 6
15				Low Side Injector 4
16	Gear Position			AV12
17	ETB Pot 1			AV13
18	ETB Pot 2			AV14
19	12V Power		PWR from PDM	BAT POS
20	ETB Motor -			Half Bridge Output 7
21	ETB Motor +			Half Bridge Output 8
22				Peak Hold Injector 9
23				Peak Hold Injector 10
24				Peak Hold Injector 11
25				Peak Hold Injector 12
26				Sensor 5V A
		Rear		

M150 C	Use 1	Use 2	Notes	MoTeC Designation
1				Half Bridge Output 2
2	Sensor 5V		Front Sensors	Sensor 5V A
3				Low Side Ignition 1
4				Low Side Ignition 2
5				Low Side Ignition 3
6				Low Side Ignition 4
7				Low Side Ignition 5
8				Low Side Ignition 6
9	Sensor 5V		Front CAN Sens	Sensor 5V B
10				BAT NEG
11				BAT NEG
12				Low Side Ignition 7
13				Low Side Ignition 8
14	SP FR			AV1
15	SP FL			AV2
16	BP F			AV3
17	STEER			AV4
18	ARB Servo			Half Bridge Output 1
19				Peak Hold Injector 1
20				Peak Hold Injector 2
21				Peak Hold Injector 3
22				Peak Hold Injector 4
23	SS Relay Switch		For fuel pump P\	Low Side Injector 1
24				Low Side Injector 2
25	BP R			AV5
26	12V Power		PWR from PDM	BAT POS
27				Peak Hold Injector 5
28				Peak Hold Injector 6
29				Peak Hold Injector 7
30				Peak Hold Injector 8
31	Clutch			Half Bridge Output 3
32				Half Bridge Output 4
33				Half Bridge Output 5
34				Half Bridge Output 6
		Front		

M150 D	Use 1	Use 2	Notes	MoTeC Designation
1	Reference			Universal Digital Input 1
2				Universal Digital Input 2
3		Cooling sensor 1	1K Pull up to Ser	AT1
4		Cooling sensor 2	1K Pull up to Ser	AT2
5	Oil Temp		1K Pull up to Ser	AT3
6	Fuel Temp		1K Pull up to Ser	AT4
7				Knock Input 1
8	WS FR			Universal Digital Input 3
9	WS FL			Universal Digital Input 4
10				Universal Digital Input 5
11	BSPD Trip			Universal Digital Input 6
12				Battery Backup
13				Knock Input 2
14				Universal Digital Input 7
15	Sensor 0V		Front Sensors	Sensor 0V A
16	Sensor 0V		Front CAN Sens	Sensor 0V B
17	CAN HI-1			CAN Bus 1 HI
18	CAN LO-1			CAN Bus 1 LO
19				Sensor 6.3V
20	TP1			AV6
21	TP2			AV7
22	~~TP3~~			AV8
23	Don't forget			Ethernet Transmit +
24				Ethernet Transmit -
25				Ethernet Receive +
26				Ethernet Receive -
		Front		

Figure 12.2: M150 Pinout Spreadsheet

12.6 Appendix 6: PDM Pinouts

PDM A	Use 1	Use 2	Notes	MoTeC Designation	PDM B	Use 1	Use 2	Notes	MoTeC Designation
1	M150 Power		M-B13	Output 1 -20A (with A10)	1				Not Used
2	Slip Angle			Output 9 - 8A	2				Not Used
3	Lambda			Output 2 - 20A (with A12)	3	Fuel SS Relay			Output 6 - 20A (with B09)
4				Output 10 - 8A	4				Not Used
5	Fan Right 1			Output 3 - 20A (with A14)	5	Power Relay		Pump, Inj, Ign	Output 7 - 20A (with B11)
6	Starter Relay			Output 11 - 8A	6				Not Used
7				Output 4 - 20A (with A16)	7	D153 Dash	Beacon		Output 8 - 20A (with B13)
8	Brake Light			Output 12 - 8A	8				Not Used
9	Fan Left 1			Output 5 - 20A (with A17)	9	M150 Power			Output 6 - 20A (with B03)
10	M150 Power		M-B19	Output 1 - 20A (with A01)	10				Not Used
11	ARB Servo			Output 13 - 8A	11	Power Relay		Pump, Inj, Ign	Output 7 - 20A (with B05)
12	-			Output 2 - 20A (with A03)	12				Not Used
13	DRS On			Output 14 - 8A	13	BSPD			Output 8 - 20A (with B07)
14	Fan Right 2			Output 3 - 20A (with A05)	14				Not Used
15	DRS Off			Output 15 - 8A	15				Digital/ Switch Input 13
16				Output 4 - 20A (with A07)	16				Not Used
17	Fan Left 2			Output 5 - 20A (with A09)	17				Digital/ Switch Input 15
18				Not Used	18	Dash Ground	BSPD Ground	Interlock Ground	Battery Negative
19				Digital/ Switch Input 2	19				Not Used
20				Not Used	20				Digital/ Switch Input 11
21				Digital/ Switch Input 4	21				Digital/ Switch Input 12
22				Not Used	22				0V
23				Digital/ Switch Input 7	23				Digital/ Switch Input 14
24				Not Used	24				Digital/ Switch Input 16
25				Not Used	25	CAN LO-1			CAN Low
26	GRND BLOCK			Battery Negative	26	CAN HI-1			CAN High
27				Digital/ Switch Input 1					
28				0V					
29				Digital/ Switch Input 3					
30				Digital/ Switch Input 5					
31				Digital/ Switch Input 6					
32				Digital/ Switch Input 8					
33				Digital/ Switch Input 9					
34				Digital/ Switch Input 10					
		Rear					Front		

Figure 12.3: PDM Pinout Spreadsheet

12.7 Appendix 7: D153 Pinouts

D153 A	Use 1	Use 2	Notes	MoTeC Designation	D153 B	Use 1	Use 2	Notes	MoTeC Designation
A1 - Black	D153 DTM-4		A female DTM that connects to the loomside male D153 DTM	Battery Negative	B5 - Green	Wheel-1		DRS	Switch Input 1
A2 - Red	D153 DTM-1			Battery Positive	B6 - Blue	Wheel-2		Upshift req	Switch Input 2
A3 - Green	D153 DTM-2			CAN Low	B7 - Violet	Wheel-3		Downshift req	Switch Input 3
A4 - White	D153-DTM-3			CAN Hi	B8 - Grey	Wheel-4		ARB Up	Switch Input 4
A7 - Brown	Wheel-6		Mulitifunction	Analog Input 1	B9 - Orange	Wheel-5		ARB Down	Switch Input 5
A8 - Orange	Dash-3		9-Pos 1	Analog Input 2	B10 - Yellow	Dash-2		Start	Switch Input 6
A9 - Yellow	Wheel-7		Driver Coms	Analog Input 3	B12 - White	Dash-7		Prime/ Kill Dash	Analog Input 6
A10 - Blue	Wheel-8		Map Switch	Analog Input 4	B13 - Brown				Analog Input 7
A11 - Violet	Clutch Switch			Analog Input 5	B14 - Red				Analog Input 8
A18 - Grey	Clutch Switch Ground			Sensor 0V					

Figure 12.4: D153 Pinout Spreadsheet

12.8 Appendix 8: Display Case Drawing

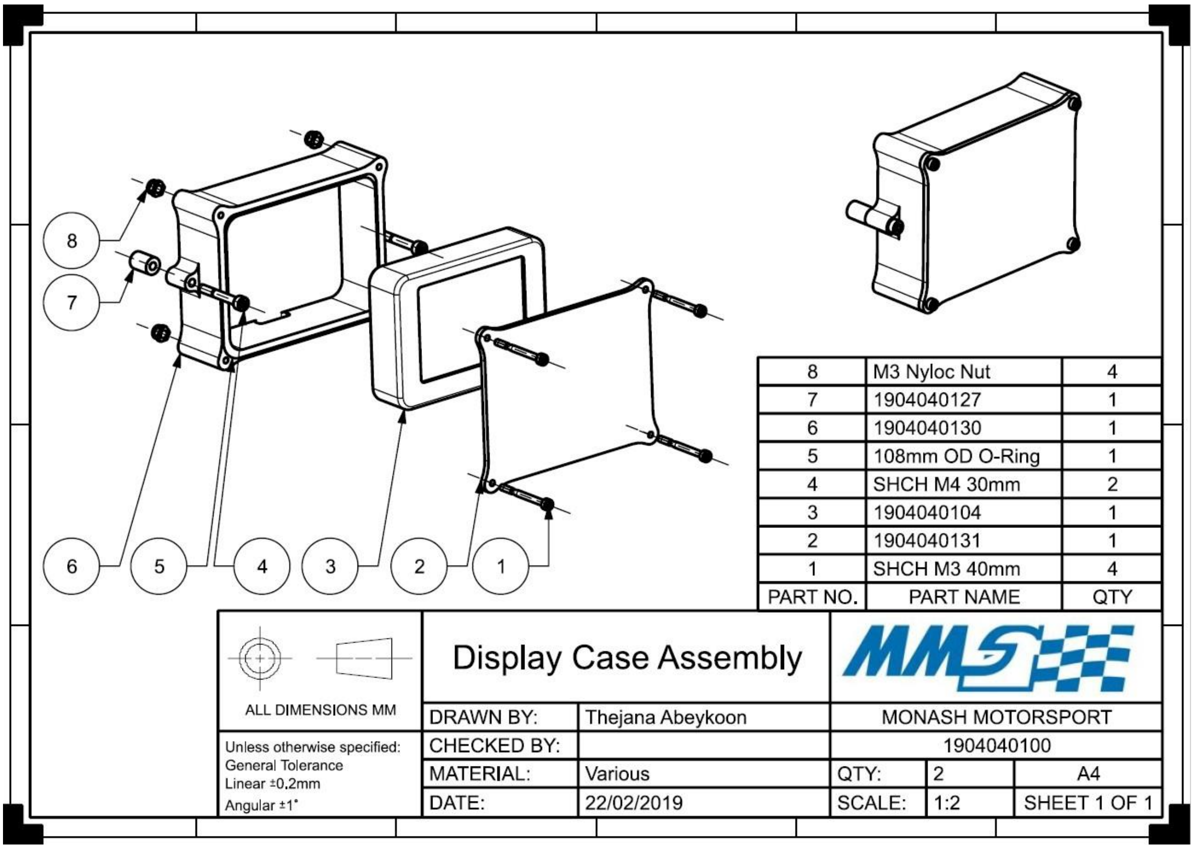
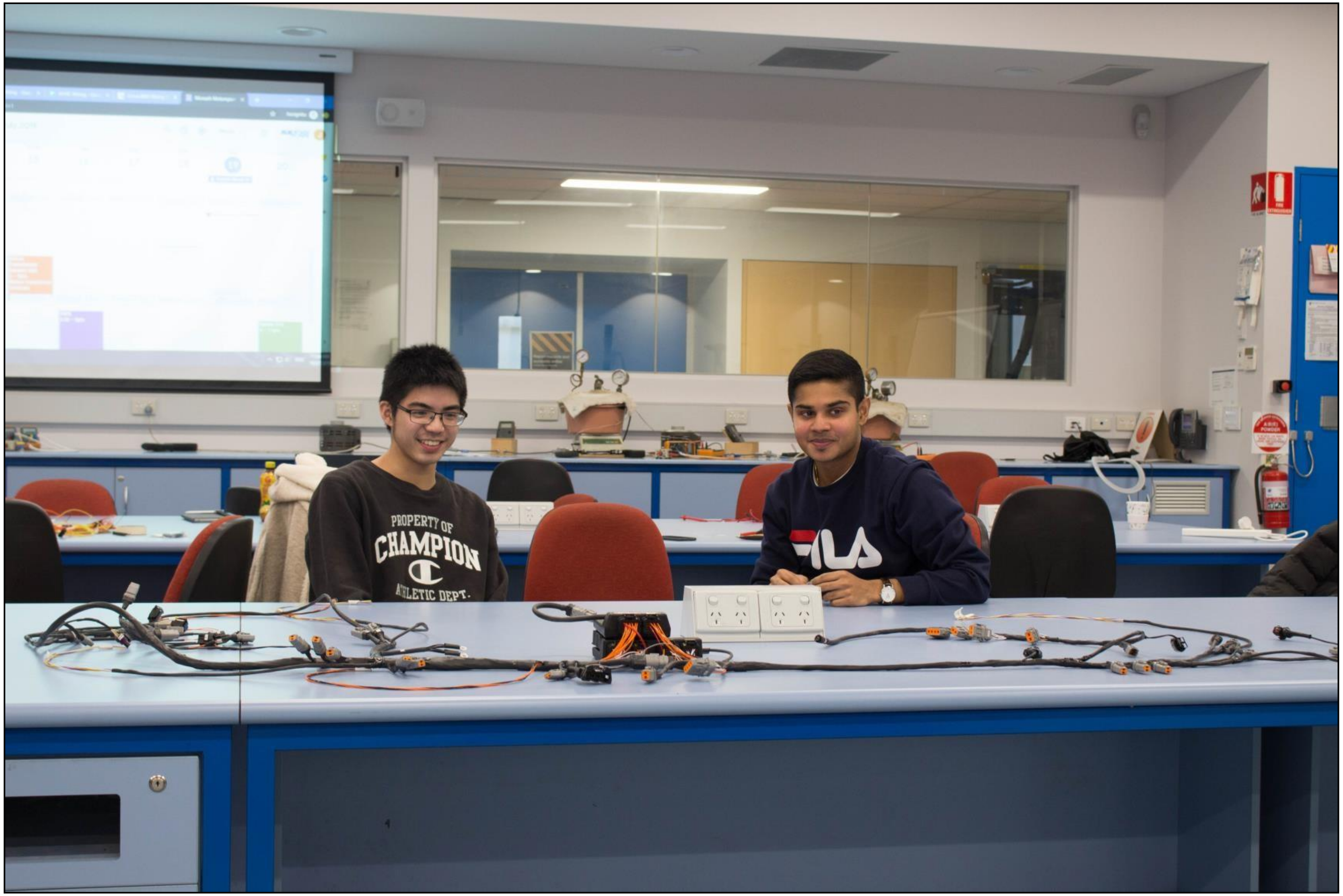


Figure 12.5: Display Case Assembly Drawing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