Design and Implementation of Electronics in the DTU Ecocars "Dynamo" and "Innovator"

An "Electro" Handbook
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Content

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1 Introduction

Fulfilling the rules of the Shell Eco-Marathon, there are several aspects to the design of the car that involve electronical systems.[1] This document aims to provide an overview of the car's electrical system as well as its electronical components.

Note that all resources are kept in a Git based VCS on Bitbucket.

See Appendix A for glossary.

2 Mandatory Features

The Urban Concept car "Dynamo" must have the following features, as defined by the Shell Eco-Marathon 2017 Vehicle Design Rules Chapter 1.

2.1 Horn

Rules: See Article 31: HORN.

A loud battery powered horn is required. It is to be used by the driver every time she passes another vehicle. The horn is rated at 3 A and is powered by the main 12 V battery through a small relay. Due to the way the horn works, it can cause severe electrical noise at its terminals. A low pass filter on the positive terminal with a high capacitor value is used to reduce this effect.

In "Dynamo", the horn is activated when the driver presses the corresponding button on the steering wheel. This sends a signal through the communication bus and the Motor Board to the Front Light Board, which in return pulls the floating, negative terminal of the horn relay to GND. The relay connects the floating, negative terminal of the horn to GND, activating it.

[1] The rules of the competition are changed every year. It must be ensured that everything adheres to the rules by checking the current rules found on the Shell webpage.

In “Innovator”, the driver can operate a momentary push button, which connects the floating, negative terminal of the horn directly to GND, activating it.

2.2 Lighting

Rules: See Article 50: LIGHTING.

Products: See Appendix F.

In the front, two LED strips fulfill all the required light functions. Each strip can either light up with a standard white light, or blink to the side with a yellow animation. This is called a “sequential turn signal”. It is controlled with a 5 V control signal from the Front Light Board.

In the rear on the sides, there are two panels for the starter light and in the back, there are two multi-function strips. The strips can either be in normal mode or braking mode and can blink left or right. These are controlled from the Back Light Board.

A momentary push-button is attached to the brake pedal and its state is transmitted from the Front Light Board through the Motor Board. The starter light signal is sent directly from the Motor Board. Both light boards receive commands from the Motor Board, which in return polls the Steering Wheel for blinking and lighting commands.

2.3 Emergency Shut-Down

Rules: See Article 37: EMERGENCY SHUT-DOWN.

The car is fitted with two shut-down mechanisms for increased safety.

The external emergency shut-down mechanism cuts off power to the Mini Board, thus making further engine operation impossible. Operation of this mechanism is detected by the Motor Board, which sends a shut-down command to the RIO. The RIO immediately performs a soft shut-down and can only be restarted through a power cycle. In both cars, this is implemented as a red latching push-button with LED indicator.

The second, internal shut-down mechanism physically disconnects the negative terminal of the battery from the car’s electrical system. In “Dynamo”, this is accomplished with a special lever, capable of breaking the high current of the battery. In “Innovator”, the latching push-button shut-down mechanism opens a relay, thus interrupting the circuit.

2.4 Starter

Rules: See Article 64: STARTER.

The electric starter motor is the most power demanding component in the car. It is controlled by the RIO, through the Motor Board, which operates a large, high-current capable relay. This relay is connected through thick cables close to the battery and capable of handling the current without significant power loss. No datasheet exists for the DC motor, however, current

consumption is estimated to peak in the 50-90 A range. When the starter is operated, a voltage dip can be noticed on the entire car's 12 V supply, inversely proportional to the amount of charge left in the battery and the total capacity of the battery.

2.5 Cooling fan

Rules: See Article 23: DRIVER COMFORT (Cooling Fan).

A 140 mm fan is provided to ventilate the cabin and provide airflow for the driver, as well as reduce the likelihood of fog building up on the inside of the windshield. It is controlled from the Steering Wheel, through the Motor Board and the Front Light Board.

2.6 Windshield Wiper

Rules: See Article 46: VEHICLE BODY (Windshield Wiper).

The windshield wiper is enabled through the corresponding button on the steering wheel. This sends a bus command through the Motor Board to the Front Light Board, which send a signal to a windshield wiper motor. A special motor unit is used to ensure that the wiper always halts in the same zero position.

2.7 Steering Wheel

Rules: See Article 47: TURNING RADIUS AND STEERING.

The Steering Wheel contains 18 momentary push-buttons through which the driver can control the car's features. In its center, a 3.5" screen acts as the interface, showing relevant data to the driver, such as speed, gear, time and more. The 16 front facing buttons are illuminated by WS2812B RGB LEDs to provide feedback to the driver.

The physical wheel was developed by Brian in 2013 and 3D printed.

2.8 Vehicle Electrical Systems

Rules: See Article 57: VEHICLE ELECTRICAL SYSTEMS.

2.8.1 Fuses

The electrical system is secured in several locations. There is a main fuse, through which the entire car's current runs. It is selected to be rated at 100 A. With the exception of the starter motor, all power is further fused through the Fuse Box, where the different subsystems share fuses rated in the span 2-20 A. Furthermore, every Board is individually fused with a fast-acting SMD fuse in the range of 1-4 A. The Boards also have a diode, which will blow the fuse in the unlikely event that someone connects the battery with inverted poles.

2.8.2 Battery

Only one battery is used in the car. The nominal operating voltage of the electrical system is 12 V. However, the voltage of the battery can vary depending on charge and load. For example, when running on a 12 Ah Lithium battery, the design voltage range should be 9-15 V. A battery capacity of 12 Ah (Pb Lead) has shown to be the minimum safety threshold for sustaining the car over the course of its competition run. For the competition, it is important to use high quality battery brands (e.g. Exide, Panasonic, Yuasa), since generic brands often do not meet their specifications. The most power demanding part of the car is the starter motor, which requires somewhere between 50 A and 90 A. When running tests, lower quality batteries with a higher capacity are often used, since weight is not a concern in that case.

In an attempt to reduce weight, Shorai Lithium batteries have been used in the past. Their actual capacity is 1/3 of the indicated. Successful runs were accomplished with brand new "24 Ah" and "36 Ah" batteries. However, these batteries seem to have a very low lifetime, since an attempt to use a 1 year old battery failed, due to energy shortage. Because of this, the extra price of the Lithium batteries ($300) compared to Lead batteries ($50), and the weight difference of 2 kg, it was decided to switch back to using Lead batteries.

To ease the battery changing procedure, Anderson SB50 connectors are used for the battery connection.

2.8.3 Dead Man's Switch

The dead man's switch is the car's replacement for a throttle. It ensures that the propulsion system is only active, when the driver is pushing and holding the "BURN" button. This sends a bus command from the steering wheel through the Motor Board to the RIO. When the button is released, the engine should shut off immediately.

2.8.4 Other notes

The requirement for transparent enclosures, as stated in the rules, is not strictly enforced. One should however be prepared to remove the top of the enclosures during inspection to provide insight into the electronics.

Good cable management has been added to the rules in 2017.

For 2017, a Joulemeter (see 3.2 Power Measurement) and a DC-DC converter are to be installed.

2.9 Technical Documentation

Rules: See Article 58: TECHNICAL DOCUMENTATION.

This handbook is not to be used as a replacement for the requirement for technical documentation. The required documents can be found in the Documentation folder. Specifically, the

overview diagram of the electrical connections is the most important document. PCB schematics have not been requested in the past, but it is always good to have them ready for inspection.

3 Additional Features

3.1 Boards

For best practices and tips for schematic and board design in EAGLE, refer to Appendix E and Appendix F in the Learning folder. The NI CompactRIO acts as the car's Engine Control Unit.

The Atmel MCUs (ATMEGA328P, ATMEGA1284P and ATMEGA2560) are based on the AVR architecture. They are very similar and can be programmed through the AVR Dragon or USB ISP connection. We have used Atmel Studio and the C programming language for these chips.

The code can be found in the Code folder.

3.1.1 Motor

The Motor Board (also known as Main Board or Master Board) is the main hub for the car's electrical system. It interfaces to the CompactRIO through RS-232. The driver's steering wheel commands (e.g. the Burn command) are relayed through the Motor Board to the RIO. In return, the RIO sends data (e.g. desired gear position) to the Motor Board.

The Motor Board interfaces with the following sensors and devices:

- NI CompactRIO (RS-232)
- Communication Bus (RS-485)
- Gear Servo (5V PWM)
- Emergency Stop Button Detection (ADC)
- Starter Relay (Digital Out)
- Lambda Sensor (ADC)
- Smartphone (Bluetooth / USB / FSK[2])

Furthermore, it is capable of interfacing with several other sensors and devices, should the need arise.

3.1.1.1 RS-232 Protocol (as of 2016)

From Motor Board to RIO	From RIO to Motor Board
RIO_TX_BURN, // "RIO_START"	RIO_RX_ALIVE,
RIO_TX_IDLE,	RIO_RX_WATER_TEMP,
RIO_TX_CLOSED_LOOP,	RIO_RX_OIL_TEMP,
RIO_TX_AUTOGEAR,	RIO_RX_RPM_L,
RIO_TX_POT_UP,	RIO_RX_RPM_H,

[2] Frequency-Shift Keying was added as a fallback to transmit data over PWM to a smartphone microphone input.

```
RIO_TX_POT_DOWN,
RIO_TX_NEUTRAL,
RIO_TX_GEAR_UP,
RIO_TX_GEAR_DOWN,
RIO_TX_STOP,
RIO_TX_WHEEL_PERIOD_H,
RIO_TX_WHEEL_PERIOD_L,
RIO_TX_DISTANCE_H,
RIO_TX_DISTANCE_L,
RIO_TX_BRAKE
```

```
RIO_RX_LAMBDA,      // Excess air ratio
RIO_RX_GEAR,
RIO_RX_KMH,         // Speed [km/h]
RIO_RX_KMPERL_L,    // Fuel consumption L
RIO_RX_KMPERL_H,    // Fuel consumption H
RIO_RX_REMAINING_FUEL_L,
RIO_RX_REMAINING_FUEL_H,
RIO_RX_POTENTIOMETER,
RIO_RX_STARTER,
RIO_RX_SERVO_GEAR_L,
RIO_RX_SERVO_GEAR_H
```

3.1.2 Mini

The Mini Board is responsible for the engine ignition and injection. It receives two 5 V digital (high or low) signals from the RIO. One is passed through a gate drivers and controls a MOSFET which connects the 12 V floating negative terminal of the nozzle (“Dyse”) to GND. The other control signal is passed directly to the smart AEM ignition coil which provides the voltage to the spark plug. The Mini Board provides a regulated 12 V supply to both the nozzle and the ignition coil to ensure that their performance and injection amount is independent of the fluctuating battery voltage.

3.1.3 Light

Two almost identical versions of the Light Board are used: The Front Light Board and the Back Light Board. The Back Light Board only receives commands and changes the Normal, Blink, Brake and Starter light states accordingly, while the Front Light Board also captures the brake sensor and controls the wiper, fan and horn.

The design is implemented using several MOSFETs that are capable of pulling a floating negative terminal to GND with sufficient current rating. For 2017, a more universal push-pull configuration is desired, since the front lights require full rail to rail signals.

3.1.4 Steering

See 2.7 Steering Wheel.

3.1.5 3D Printed Enclosures

All boards have custom designed 3D printed enclosures to protect them from the environment in the car. The designs are done in SolidWorks and printed on the high-quality printers of Fablab.

3.2 Power Measurement

Until now, the actual power and energy consumption of the electrical system has not been measured accurately. A Hall-sensor based system has been prepared for current measurement and is to be implemented for 2017. A measurement range of 1-100 A is expected.

3.3 Bus Communication

The implementation from 2016 uses a RS-485 bus as communication interface between the various boards in the car. An upgrade to CANBUS is expected in 2017, while maintaining a similar protocol. The differential bus system works by sharing a single set of 4 cables throughout the car: +12 V, GND, BUSA / CANH, BUSB / CANL. A large number of boards can be connected to the same data bus, however only one can communicate at the time. The Main Board acts as the bus master and sends data write commands or data read requests to the target board. All boards receive all messages and check the target ID to see if it matches their ID. In the case of a read request, the target board "answers" by writing its data to the bus.

Protocol: See Code/Shared/rs485protocol.h

3.4 Data Log via Smartphone to Webpage

A custom Android app running on a Smartphone receives telemetry data from the Motor Board and uploads it to the webpage located at http://dtucar.com/d/ (or http://dtucar.com/i for "Innovator"). It adds GPS location to the data. The data is parsed by PHP and saved in a MySQL database. The front end webpage fetches the data through Javascript AJAX calls to PHP scripts.

All resources are located in the Homepage folder.

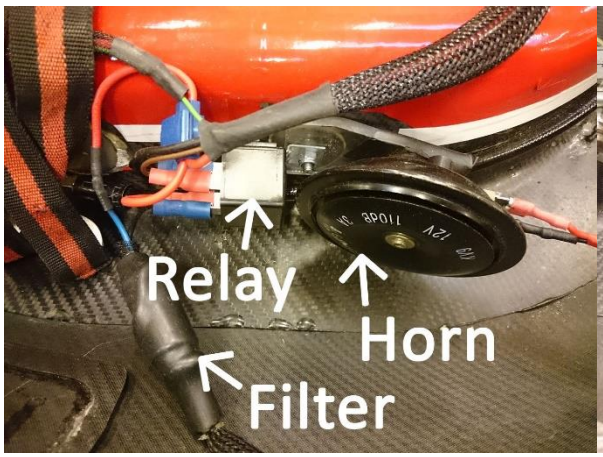
4 Notes

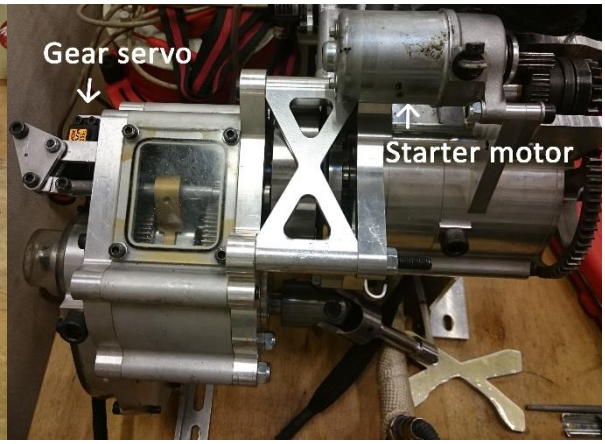
4.1 Components

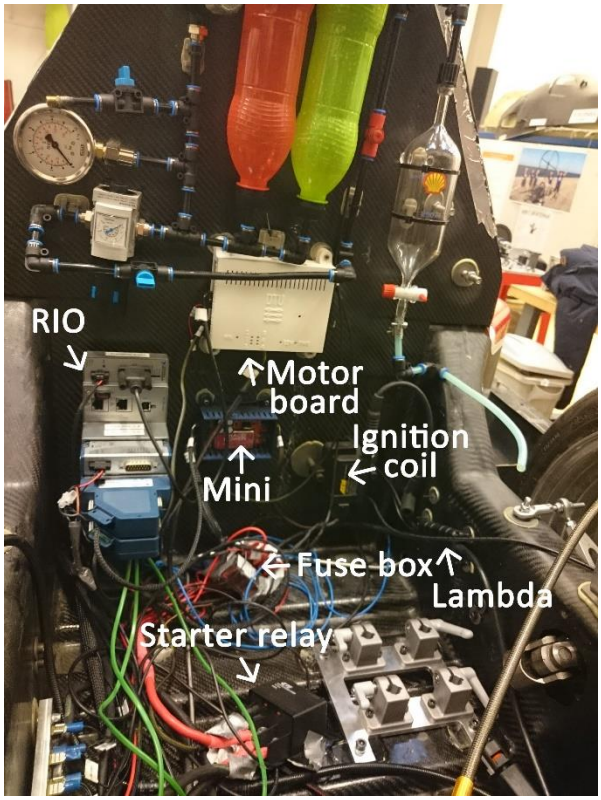
Most electronic components have been ordered from RS Online. A few components are from Farnell and Mouser. Many hardware parts are bought from Ebay, Amazon UK, Amazon DE and AliExpress, often from China, where significantly lower prices and high availability are possible, at the cost of slow delivery. Custom PCBs have been produced by PCBWay. For some assembled boards, Flikto, Eckstein and Exp-Tech have been used.

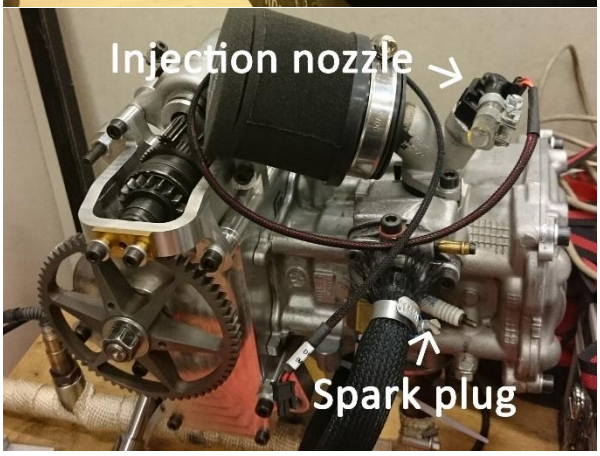
Select orders can be found in the Documentation/Orders folder and in Appendix F. For an almost complete overview of all components and their location, I refer to the Excel sheet "List of Ecocar Electronics Components". It is advised to add all new components to that list, as well as provide a label in the respective box, minimally referring to the RS number.

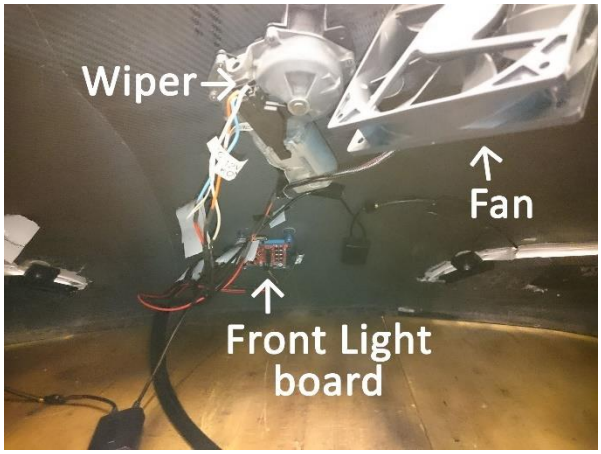
Appendix A. Images

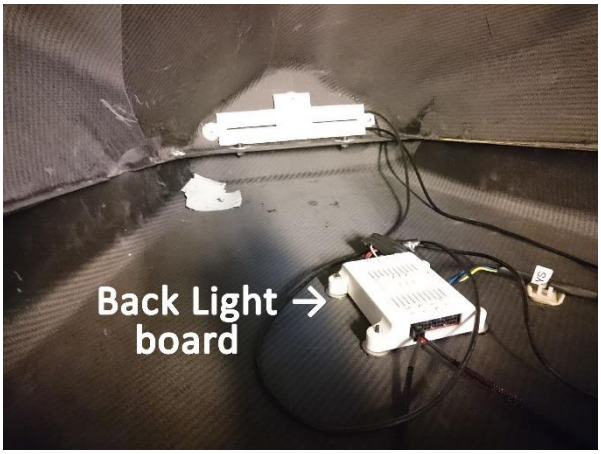




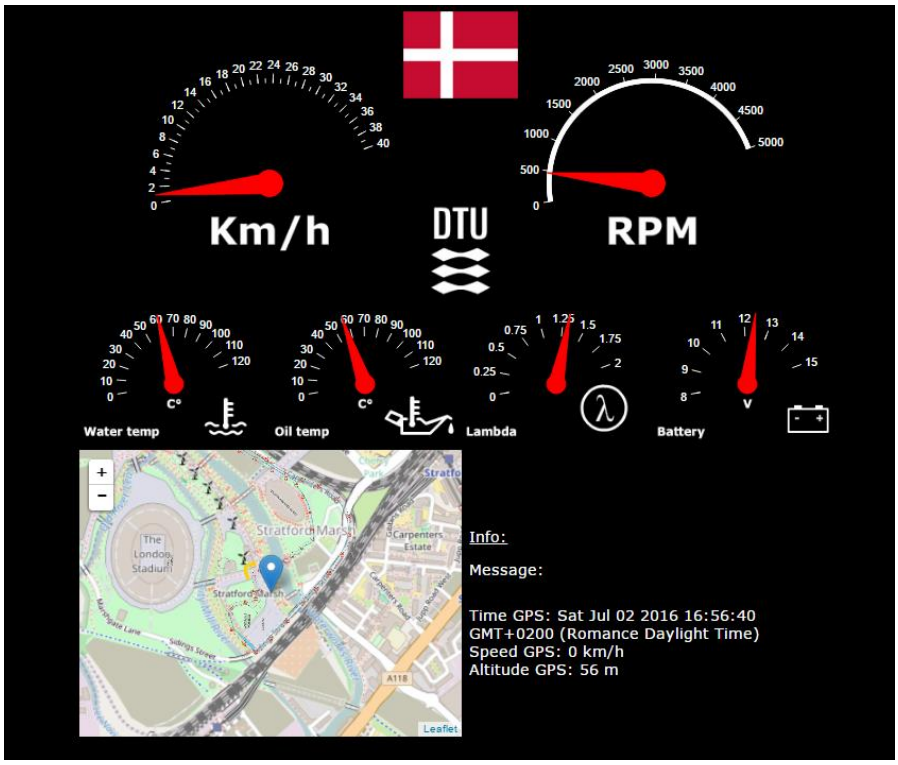




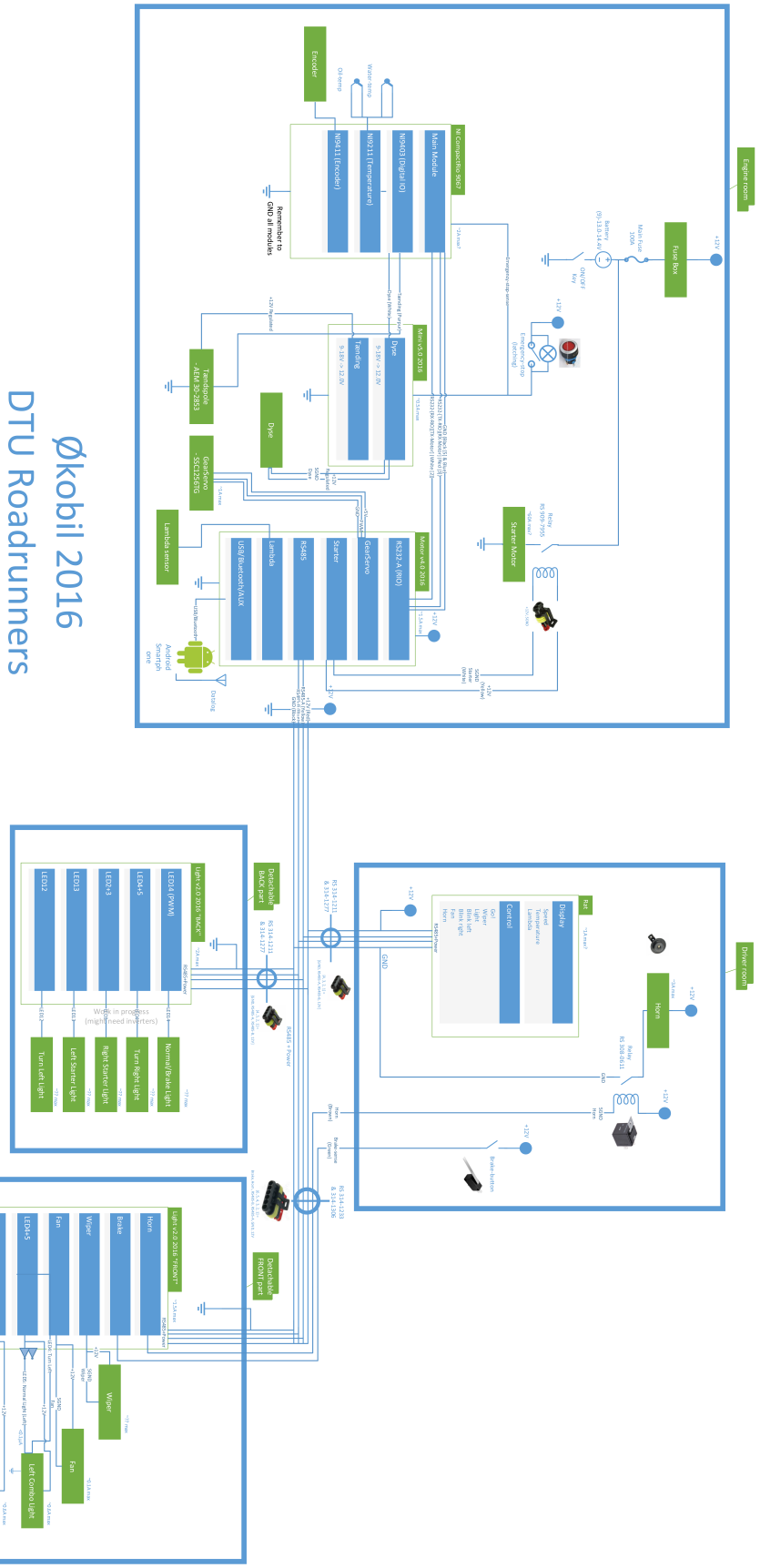




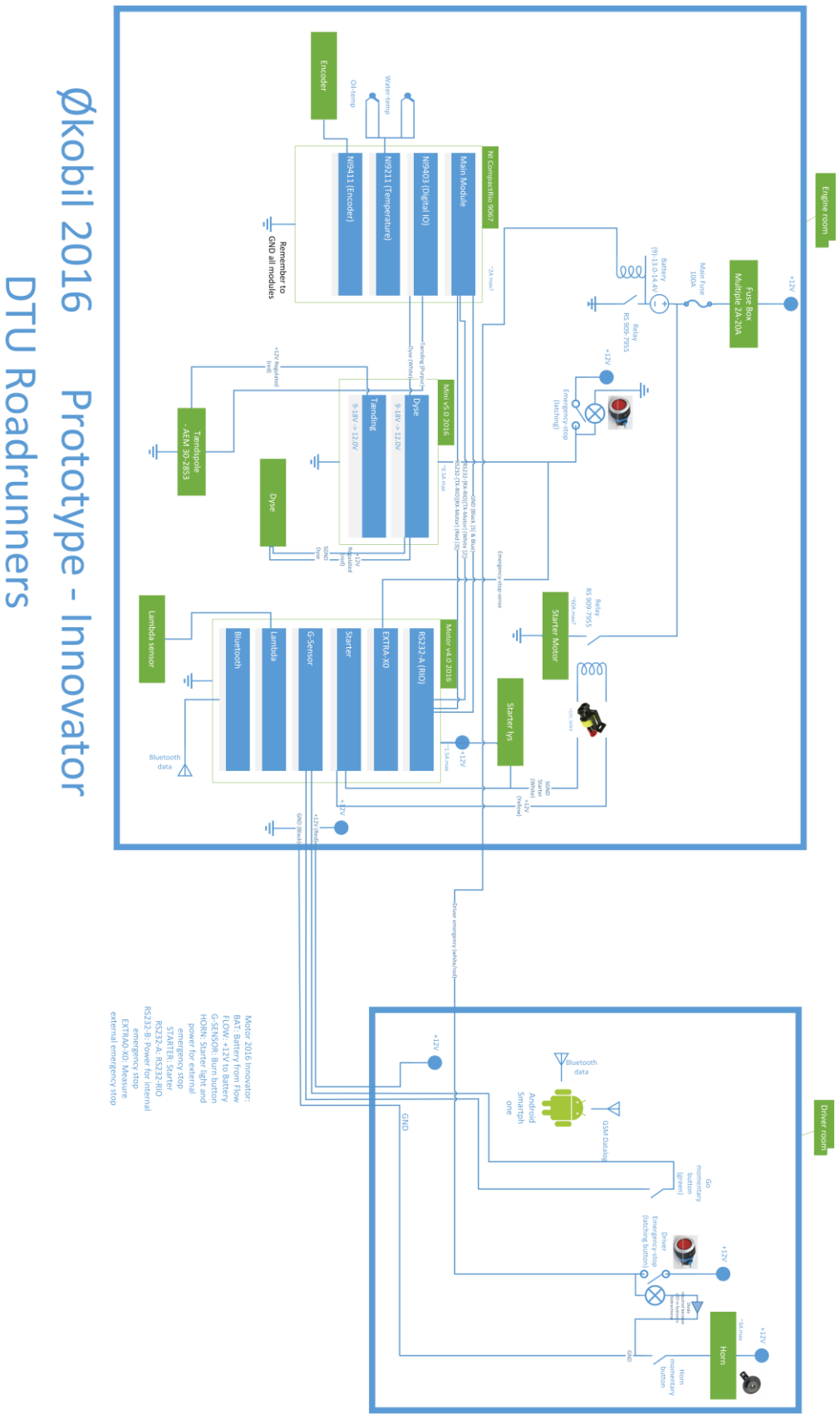
Data logging webpage



Appendix B. DTU Dynamo Diagram



Appendix C. DTU Innovator Diagram



Appendix D. Relevant Rules

The following relevant rules are excerpted from the Shell Eco-Marathon 2017 Official Rules Chapter I. They are selected, due to their immediate relevance to the electrical aspects of the car. It is highly advised to always check the entire set of rules.

Article 31: HORN

a) Each vehicle must be equipped with a battery powered electric horn. The horn must be mounted towards the front of the vehicle, in such a manner that is effectively audible to other vehicles and track marshals. With the vehicle in normal running condition, it must emit a sound greater than 85 dBA when measured 4 meters horizontally from the vehicle. Horns powered by a built-in independent battery are permissible.

b) The horn must have a high tone (pitch) of equal or greater than 420 Hz. The horn must produce a continuous sound when activated. Siren like horns are not permitted. Battery powered electric horns are available as bike or cycling horns with outputs greater 100 dBA. These horns are powered by AA, AAA, or 9 VDC batteries. Many of these horns are configurable to emit a range of bell, chirp, siren or other sounds and may or may not include a constant tone. When selecting your battery powered horn, Participants must ensure to choose a horn that will provide the required constant tone.

c) The horn will be tested at the end of each attempt on the track. If the horn is not operating correctly, the attempt will be invalidated.

Article 50: LIGHTING

The vehicle must have a functional external lighting system, including:

a) Two front headlights.

b) Two front turn indicators.

c) Two rear turn indicators.

d) Two red brake lights in the rear.

e) Two red rear lights (may be combined with the brake lights).

f) The centre of each headlight unit must be located at an equal distance and at least 30 cm from the centre-line of the vehicle.

g) The mandatory red indicator light for the self-starter operation must be separate from any of the above (see Article 1:c).

Article 37: EMERGENCY SHUT-DOWN

a) The purpose of the emergency shutdown system is to disable the propulsion system of the vehicle. Different types of propulsion systems require different measures to accomplish this:

b) Spark ignition engines (gasoline, ethanol, CNG) will require the emergency shutdown mechanism to shut down the ignition. It is not necessary to isolate the accessory battery. In addition, for CNG powered vehicles, the emergency shut-down system must also cut off the flow of gas.

f) There must be both an internal and an external shutdown mechanism.

i. The internal emergency shutdown mechanism is for Driver operation and can be designed in any effective way.

ii. The external emergency shutdown mechanism must be at the rear of the vehicle and permanently installed on a non-detachable part of the bodywork.

iii. A standard "Battery Master Switch" sticker (Blue triangle with red electrical arc) provided by the Organiser with sticker kit must be positioned on the vehicle body to clearly indicate the exterior position of the emergency shutdown actuator.

g) The external emergency shutdown mechanism must be achieved by means of a latching red push button, which can only be re-activated by rotating it. Push/pull levers are no longer accepted.

h) In addition to the above devices, all vehicles must be equipped with a "dead man's safety device" or sometimes referred to as "operator presence control." The purpose for this device is to ensure that in case the driver becomes incapacitated the vehicle's propulsion power is automatically disengaged (i.e. returns to an idle condition). This device may consist of a spring loaded hand operated accelerator or foot pedal lever. An electric dead man switch is permissible as long as the switch is located on the steering wheel. If an electric dead-man's switch is used, the Driver must directly (for example by thumb or index finger) engage the switch at all times while driving.

i. This device is a separate switch from the required "emergency shut-down" mechanisms identified in Article 1:a).

ii. If an ICE Prototype vehicle is designed with a WOT (wide open throttle) operation the deadman's switch must switch off the ignition system.

Article 64: STARTER

a) An electric starter may be used during the competition, provided that it can operate only when the ignition and fuel systems are activated.

b) It must be clearly established that the starter is never capable of providing any forward propulsion to the vehicle.

c) Starter light: A clearly visible red indicator light, equivalent in its luminescence to a 21 W light bulb, must be installed on the rear of the vehicle and must be clearly visible from both sides of the track in order to signal any operation of the starter motor.

d) In the event that Track Marshalls report the repeated or intensive use of the electric starter by a Team, the Organisers reserve the right to order an immediate inspection of the vehicle. If any noncompliance is observed, the Team will be penalised accordingly.

e) At the start, the starter and hence the starter light must be extinguished by the time the rear wheel of the vehicle crosses the start line. Failing to comply will invalidate the run and count towards the maximum number of attempts.

Article 23: DRIVER COMFORT (Cooling Fan)

a) It is recommended to properly ventilate the inside of the vehicle to provide cooling to the Driver.

Article 46: VEHICLE BODY (Windshield Wiper)

g) A windscreen with effective wiper(s) is mandatory.

Article 47: TURNING RADIUS AND STEERING

a) Vehicle steering must be achieved by one system operated with both hands using a turning motion. It must be precise, with no play or delay. Steering must be operated predominately through the front wheels.

b) Steering must be achieved using a steering wheel or sections of a wheel with a diameter of not less than 25cm.

c) Steering bars, tillers, joysticks, indirect or electric systems are not permitted.

Article 57: VEHICLE ELECTRICAL SYSTEMS

a) For safety reasons, the maximum voltage on board of any vehicle at any point must not exceed 48 Volts nominal and 60 Volts max (this includes on-board batteries, external batteries, Super Capacitors, fuel cell stack, etc.).

> *Battery definition: A 'battery' is defined as a source of electrical energy, which has exactly two connectors and comes as a single unit. This single unit may contain more than one sub-unit.*

b) For all vehicles only one on-board battery is allowed. For ICE and hydrogen fuel cell vehicles this is the accessory battery (see Article 1:i). For battery electric vehicles this is known as the propulsion battery.

c) If Lithium-based batteries are used,

> i. Battery Management Systems (BMS) tailored to this chemistry must be used to control and protect the battery against risk of fire.
>
> ii. The BMS must provide cell balancing and overvoltage protection during off-track charging.

iii. If a lithium battery contains more than one sub-unit or cell, the basic sub-unit must first be connected in series, before being connected in parallel. Otherwise it would be impossible for the BMS to monitor the current of each individual cell.

v. For Lithium-based accessory batteries (non-E-mobility vehicles), the BMS cell balancing and overvoltage protection may be contained as part of the off-board charger.

vi. The maximum capacity of any Lithium-based battery used in any propulsion energy class vehicle is 1,000 Wh. For batteries not rated in Wh, the Wh rating is calculated by multiplying the amp-hour rating of the battery by its nominal voltage.

vii. Protection for Lithium-based battery charging, whether in or out of the vehicle must be provided, see Article 24(i).

d) Any Lithium based battery must be equipped with a metal containment under the battery OR the battery must be enclosed in a battery charging bag suitable to prevent the battery, in the event of a fire or battery incident, from burning through the battery mounting or the vehicle body and dropping to the ground.

e) All batteries and Super Capacitors must be short circuit protected. Protection may be in the form of a fuse, fusible link, or a current interrupting device (circuit breaker). Automatic reclosing current interrupting devices are not allowed. Short circuit protection devices must be located on the positive conductor and as close as possible (maximum 30 cm from the positive terminal) to the battery or Super Capacitor itself. The rating of the short circuit protection device must be such that the battery or Super Capacitor will be able to supply enough short circuit current at all times to open the device. For vehicles with a starter motor, the starter motor cable is NOT required to be protected.

f) For safety reasons, both the positive and negative circuits of the propulsion battery or Super Capacitors must be electrically isolated from the vehicle frame.

g) All vehicle electrical circuits must be protected against electrical overload. Overload protection may be in the form of fixed current limits within electric controllers or by the insertion of individual circuit fuses. For Internal Combustion vehicles, overload protection is required for the motor controller, ignition system, and other accessory load circuits.

h) The accessory battery (see Article 1:i) must maintain a negative ground.

i) Accessory battery

i. The accessory battery provides for all allowed electrical needs such as safety devices (windscreen wipers, lights, hydrogen sensors, hydrogen relays and hydrogen shutdown valve), ignition, fuel injection control, starter motor, and ventilation/cooling fan for the Driver. For Internal Combustion vehicles only the accessory battery may also be used for engine management systems.

ii. The capacity of the accessory battery must be sufficient to power all the accessory loads and the installed vehicle telemetry on-board computer (see Article 70:) with a

sufficient safety margin. An accessory battery load analysis will be reviewed during technical inspection to validate sufficient battery capacity.

j) All teams will be required to install at least one joulemeter, to measure the quantity of total energy provided by the battery.

k) Both propulsion and accessory batteries must be installed outside of the Driver's compartment behind the bulkhead.

l) The following devices may be powered by batteries other than the propulsion or accessory battery provided they use built-in or small capacity batteries: radio communication system, GPS system, data loggers excluding engine management units, Driver ventilators. The vehicle horn is required to be powered by a built-in battery.

m) All teams are required to provide an on-board DC-to-DC power supply for the telemetry on-board computer sensor systems (see Article 70:). The input to the DC-to-DC converter shall be from the vehicle electrical system. The required DC-to-DC output characteristics are: isolated 12 V DC, < +-5% output voltage regulation, and minimum 1 amp continuous current rating. The on-board computer power interface shall be through screw terminals of a separate terminal block suitable for an 18 AWG wire and be located in the engine compartment.

n) All electrical/electronic enclosures built and populated by the Teams must be made of transparent material or at least have a transparent cover to allow the technical inspectors to view the contents.

o) Charging of batteries must be done with the battery charger that comes with a purchased battery or a purpose built charger specifically suited to the given type of battery and its rated capacity. For self-built batteries, Teams must demonstrate that the charger function is suitable and is integrated with the BMS system.

p) Electrical wiring should be in good condition, neat, clearly labelled, secured and not close to any moving parts (e.g. wheels, chains). "Spaghetti" wiring is prohibited, and the Organisers may ask the Team to re-wire the electrical system (it should be clear where each wire is going for easy inspection).

'Spaghetti' wiring describes any wiring arrangement that looks like a plate of spaghetti, or a rat's nest.

q) Electrical connections should be secure and not likely to come loose.

Article 58: TECHNICAL DOCUMENTATION

c) Technical Documentation – at event (to be reviewed during Technical Inspection)

i. Participants must have printed documentation describing selective technical aspects of the vehicle available for inspection with the vehicle. The printed documentation must be bound and divided into the following sections. The specific required sections for each energy category are defined below.

ICE (liquid and CNG) energy category

- Energy Supply Diagram (MEK)
- Propulsion System Diagram (MEK)
- Electrical Schematic: provide a vehicle level schematic showing all vehicle wiring and associated components and connections. The schematic should include component values such as voltage levels and fuse ratings. Schematics of components such as the engine management system or fuel cell controller are not required in this section.
- Hybrid System (KERS, only if installed): include manufacturers' component specifications at the lowest level of purchased components. Include diagrams describing the power flow into and out of the hybrid system. Include super capacitor documentation (see the Super Capacitor section below).
- Battery/BMS (If a Lithium-based accessory battery is included in the vehicle): Provide battery/BMS manufacturer component specifications at the lowest level of purchased components. At minimum, the battery documentation should include cell chemistry, cell electrical characteristics, cell series or parallel configurations, battery voltage, and current ratings. The BMS data MUST include:
    - 1. Cell over-voltage and under-voltage protection limits.
    - 2. Battery over-current limit (not required for accessory battery).
    - 3. Operation of cell balancing (how and when).
    - 4. Battery over-temperature limit (not required for accessory battery).
    - 5. How the BMS will protect the battery when an over-voltage, under-voltage, overcurrent or over-temperature condition is reached, i.e. how will the BMS protect or isolate the battery, in the case of Battery Electric Vehicles, when these limits are reached?
- Motor/Motor Controller: Provide motor/motor controller manufacturers component specifications at the lowest level of purchased components. For Battery Electric Vehicles, include design documentation on the purpose built motor controller. The documentation may contain control flow diagrams, motor controller and sub-component schematics and PC board layouts if PC boards were used. Also include software documentation if software was written as part of the motor controller development.

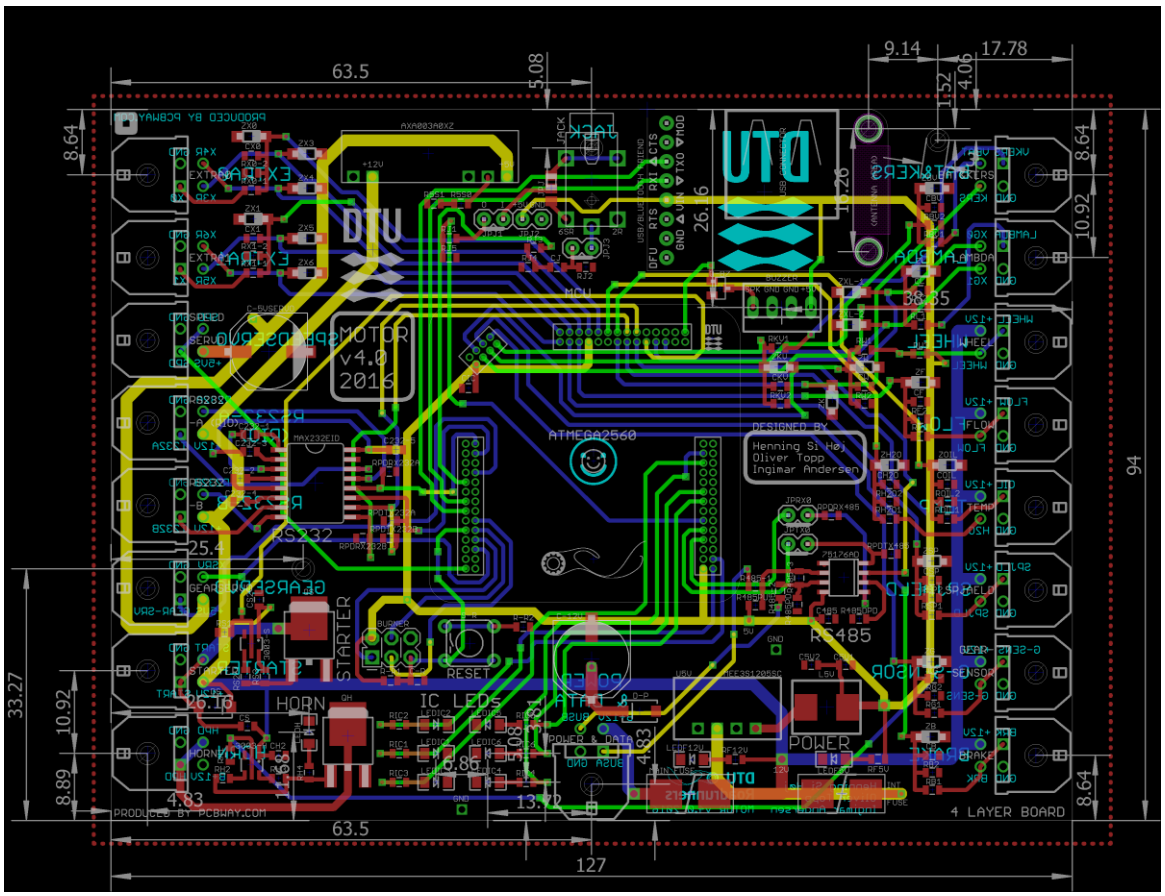
Appendix E. Tips for Schematic Design

See the "Tips for Schematic Design .pdf", "1 Remarks for schematic design.pdf" and "2 Remarks for schematic design.pdf" documents.

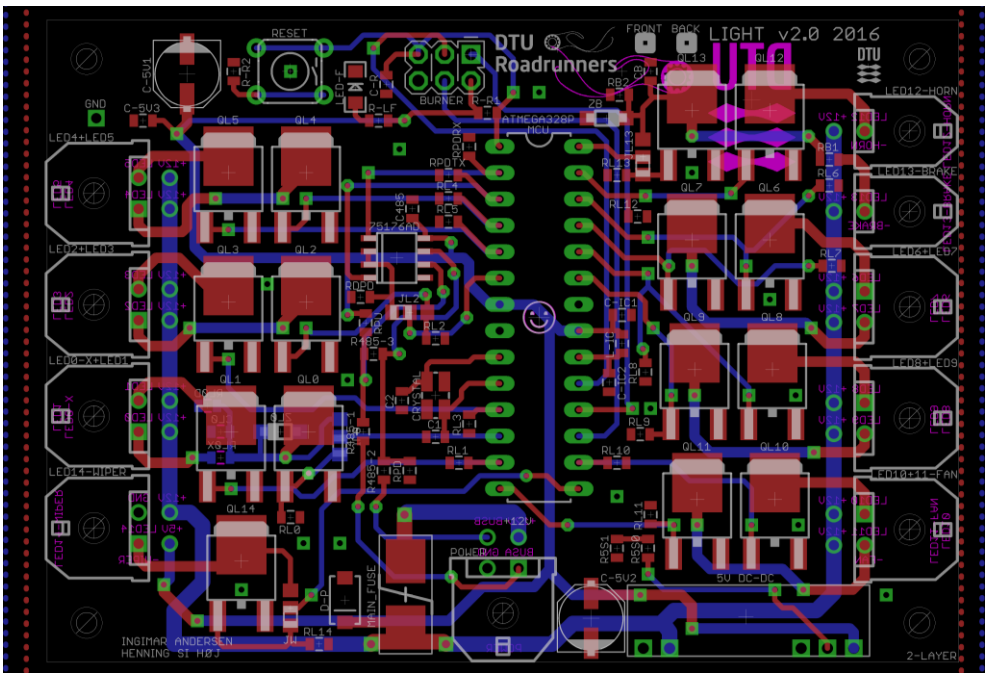
Appendix F. Tips for Board Design

See the "Tips for Board Design.pdf" document as well as the "Custom SparkFun Electronics Eagle Rules.pdf" document.

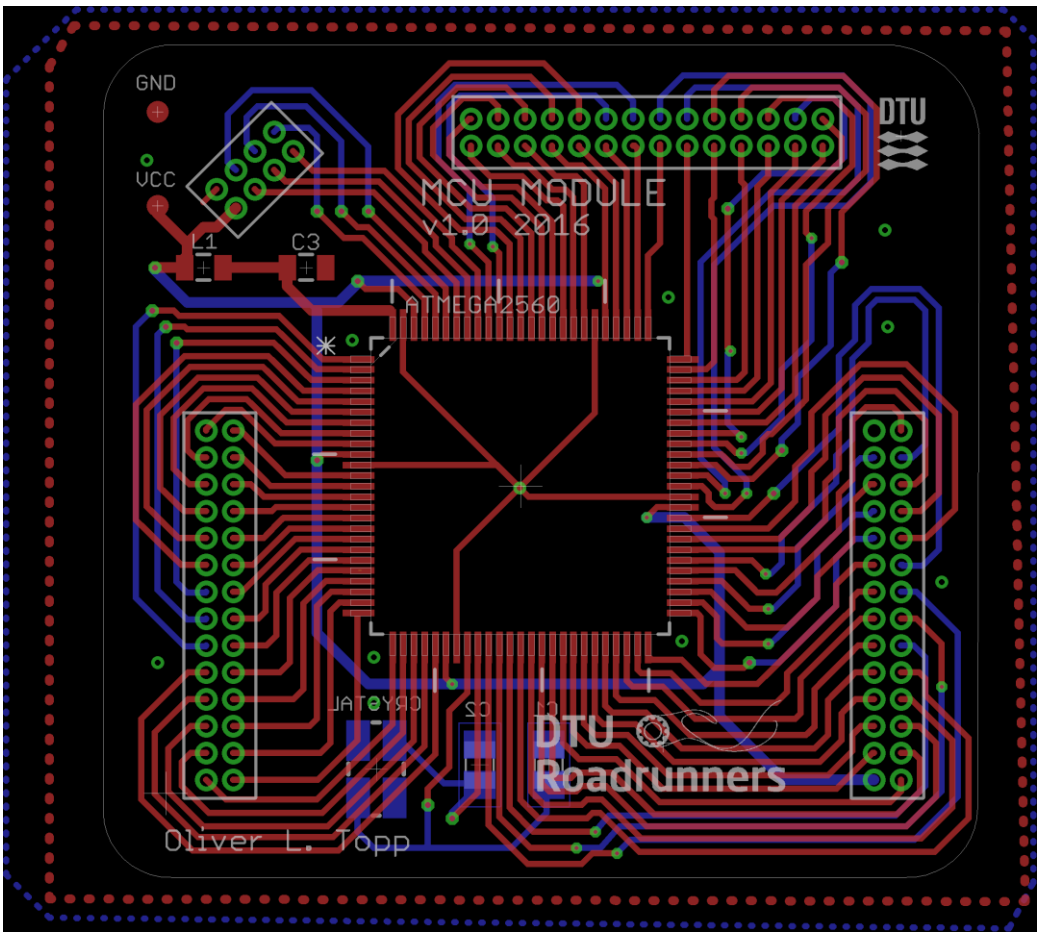
Appendix G. Motor v4.0 2016 Board



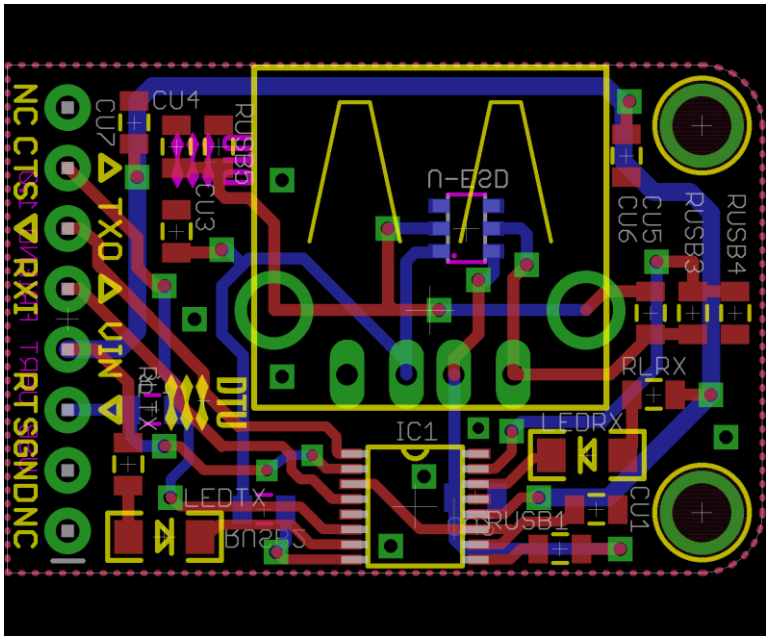
Appendix A. Light v2.0 2016 Board



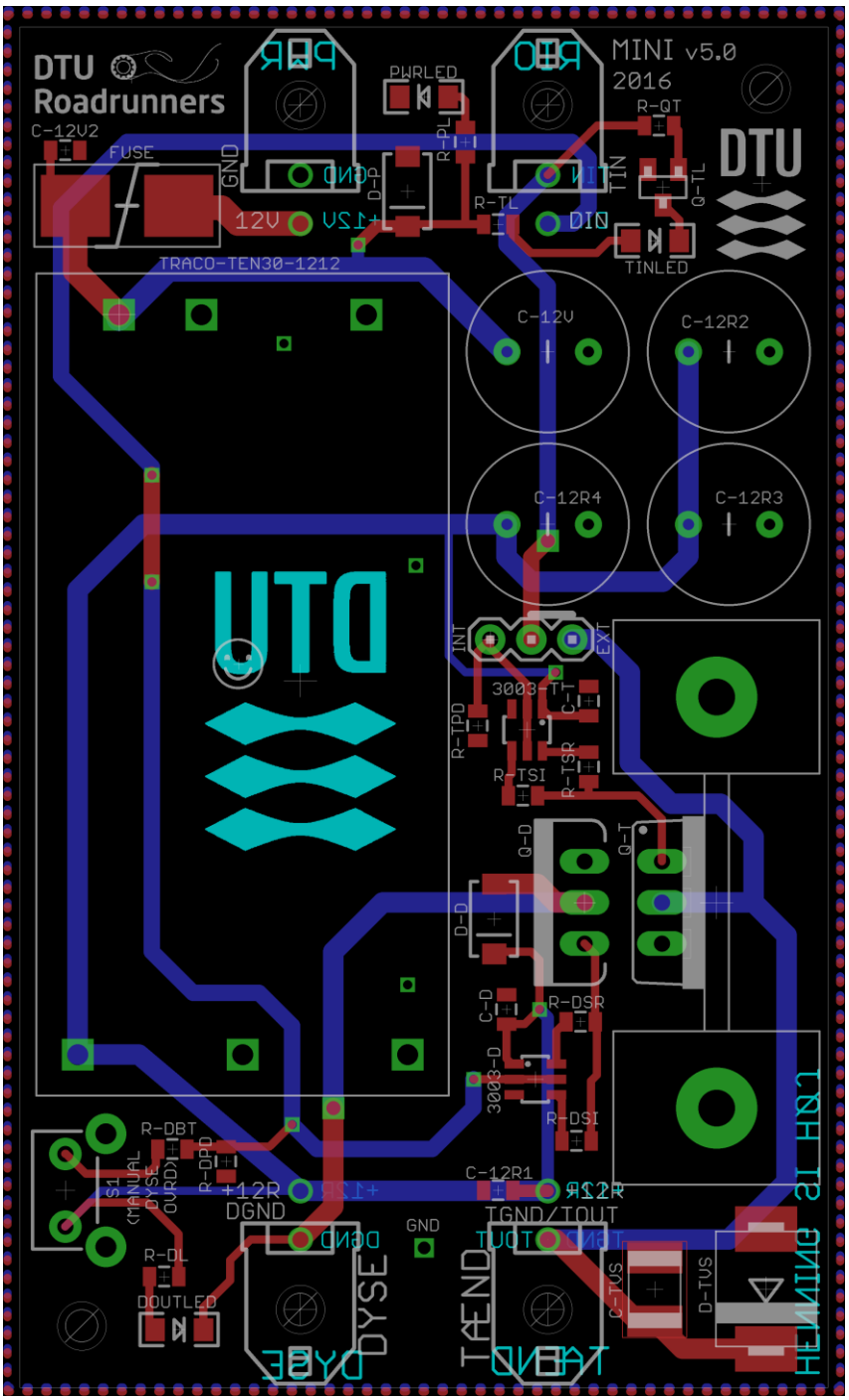
Appendix B. MCU Module v1.0



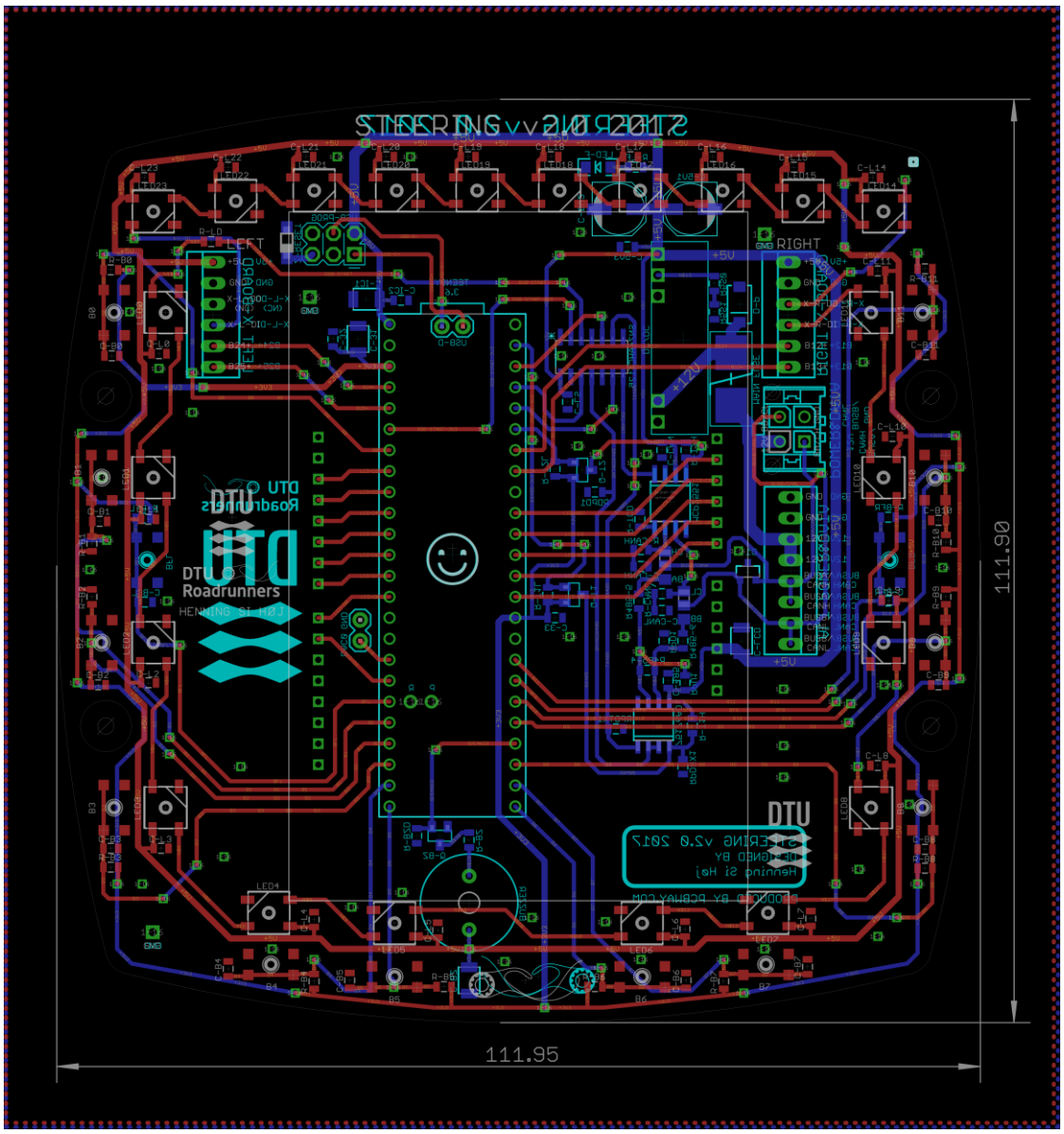
Appendix C. USB UART Friend v1.0



Appendix D. Mini v5.0 2016 Board



Appendix E. Steering v2.0 2017 Board



Appendix F. Other orders

Sequential Front Light

Originally bought from Vettura Lighting at Ebay.

- WHITE WIRE - The white wire is the positive for the DRL
- BLACK WIRE - The black wire is ground for the entire strip
- YELLOW WIRE - The yellow wire is for the positive of the indicator
- RED WIRE - The red wire is for the power of the entire strip

Features:

- Size: 600*14*10 mm length cuttable every 3 LEDs
- Color: White: DRL, Yellow: Turning *Sweeping*
- LED Chip: 335SMD
- LED quantity: White: 126PCS; Yellow: 114PCS
- Brightness: White: 700LM; Yellow: 30~400LM
- Out cover: Silicone
- Shape: Flexible strip
- Lifetime: 30,000 hours

Starter Light

Originally bought on Ebay

48 x 5630 SMD LED 5.9 cm x 4.3 cm

NOTE: The positive and negative poles are labelled incorrectly on some of these panels.

Back Light

Originally bought on Ebay

- Size: 8.04x0.51inch (20.4x1.3cm)
- Cable Length: Approx 39.4inch (100cm)
- LED Type: 2835 SMD
- Number of LED: 32 SMD Total, 12 Amber Turn Signals 20 Brake and Tail Light
- LED light color: Amber (Turn Signal) & Red (Brake / Running)
- Current: 0.03 A for running, 0.15 A for brake and 0.04 A for turning left or right.
- Voltage: DC 12-15V

Wiring instructions:

- Black for negative
- Red for brake light
- White for running light
- Green and Yellow for left/right turn signal light.

Steering Wheel 3.5” Screen

3.5” TFT Screen for Arduino 480x320 Mega2560 ILI9481 (Banggood, AliExpress)

Multimeter

AideTek VC97+ (AliExpress)

Flux

Chip Quik SMD 291 Syringe (Amazon UK)

Tweezer

ESD-15 Tweezer Fine Tip Curved (AliExpress)

Soldering Tin

Fixpoint 0.56 mm, L-Sn 60 % , Pb 38 % , Cu 2 %, Flux 2 %, Melting point 182 ° C (AV-Cables)

Programmer

USBasp (USB ISP) AVR Programmer (AliExpress) and 10 pin to 6 pin (AliExpress)

Wire Stripper

Jokari 20050 (Amazon DE)

AEM Smart Coil

AEM High Output IGBT Inductive "Smart" Coil 30-2853 (Qualitec)

Gear Servo

Savox SC-1256TG High Torque Titanium Gear (HobbyKarl)

Spark Plug

NGK CR9EIA9 (Amazon)