R V COLLEGE OF ENGINEERING

BANGALURU- 560059

(An Autonomous Institution Affiliated to VTU, Belagavi)

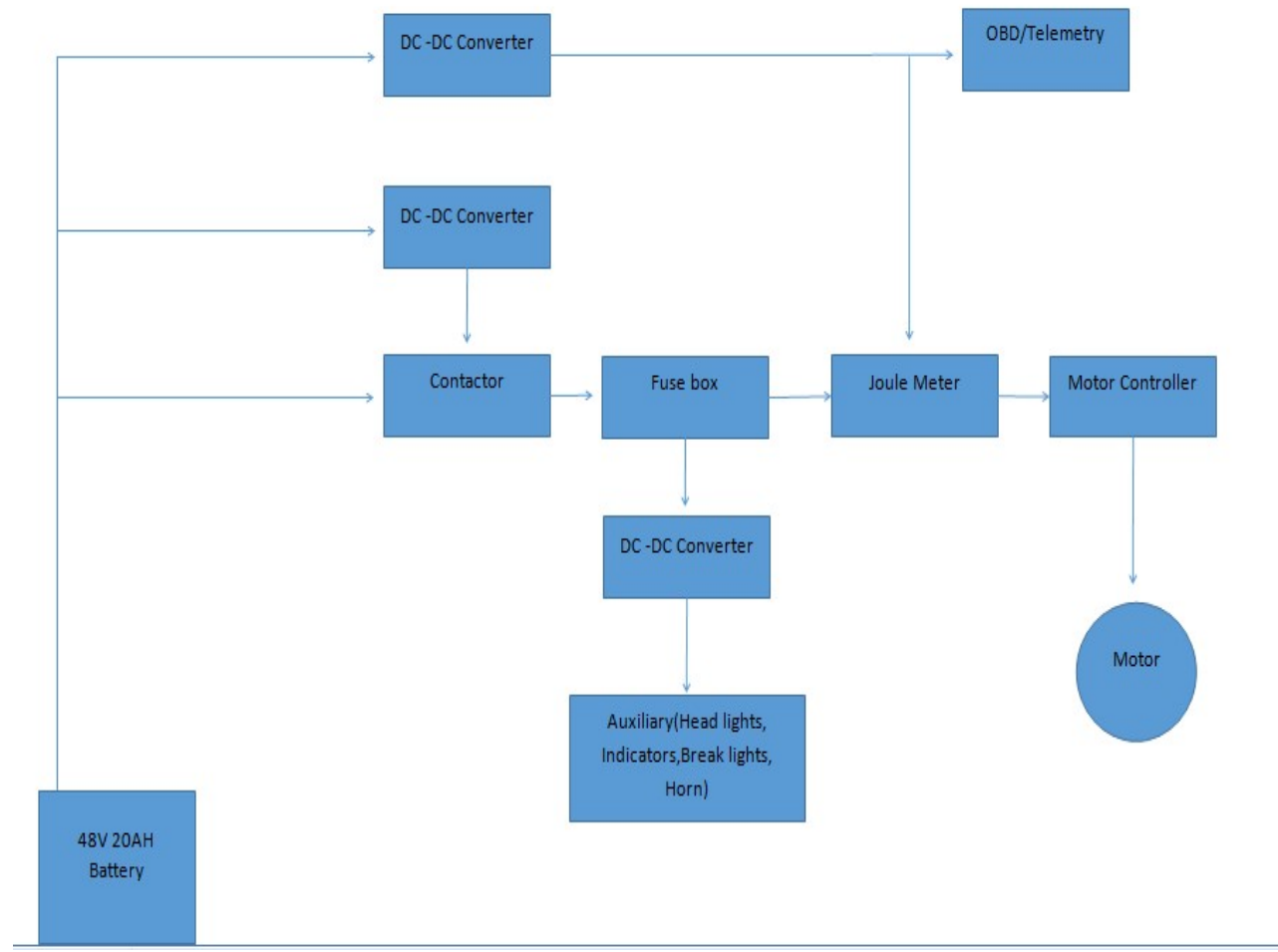# *Project Garuda*

"VAJRA 2017"
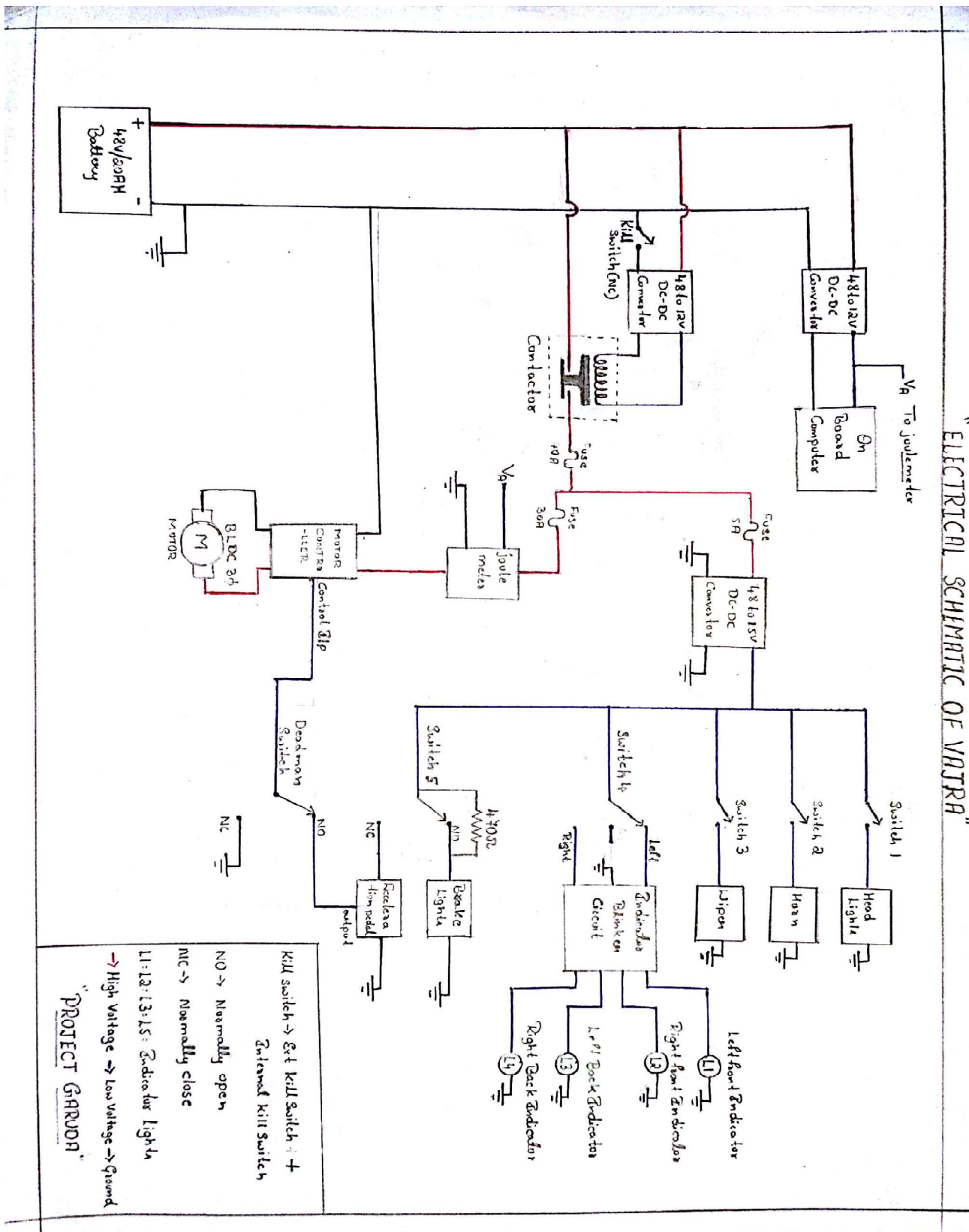
Technical Report

Sl.no	Contents	Pg.no

1. Energy Flow Diagram

The above diagram shows the flow of energy through the various components of the car. The main source of energy comes from the 48V 20Ah Li-ion battery capable of delivering a power of approximately 1KWh. It first powers the DC-DC converters which in turn activate the contactor switch that passes 48V to the motor through the fuse box, joule meter and the motor controller. The power from the motor is then transferred to the wheels through a transmission assembly having a 10:1 gear ratio. It also powers the vehicles auxiliary systems where the voltage is stepped down to 15V. The battery powers the on–board computer/telemetry system through a Dc-Dc converter (48V -12V) which is independent of the contactor switch and capable of delivering a continuous 1Ampere current.

2.Electrical Schematic

"ELECTRICAL SCHEMATIC OF VAJRA"

48V/20AH Battery

Kill Switch(nc)

48 to 12v Dc-Dc Converter

48 to 12v Dc-Dc Converter

On Board Computer

Va To joulemeter

Contactor

Fuse 40A

Fuse 30A

Va joule meter

Fuse 5A

48 to 15v Dc-Dc Converter

BLDC 3φ MOTOR

MOTOR Control Zip -ller

Control Zip

Deadman Switch

NC

NO

Accelera -tion pedal output

NC

Switch 5

47Ω

Switch 4

Brake Lights

Right

Left

Switch 3

Switch 2

Switch 1

Indicator Blinker Circuit

Wipen

Horn

Head Lights

L4 Right Back Indicator

L3 Left Back Indicator

L2 Right Front Indicator

L1 Left Front Indicator

Kill switch -> Ext kill switch +
Internal kill switch

NO -> Normally open

NC -> Normally close

L1:L2:L3:L5: Indicator Lights

→ High Voltage

→ High Voltage => Low Voltage => Ground

"PROJECT GARUDA"

The above diagram shows the electrical schematic of VAJRA. The three main components powered are the motor , auxiliary systems and the on-board computer/telemetry system.

MOTOR:-

The one which we used in our car is 3-phase BLDC motor that runs as per the sequence generated in 3phase pattern using controller which is level shifted to high power using NMOS and PMOS Bridge

AUXILIARY SYSTEMS:-

This includes Headlights, Horn, Indicators, Break lights, Wiper. All the above systems runs on 15 volts DC power that as been step down from 48V battery using step down buck converter shown in page-5

ON-BOARD COMPUTER:-

As its mentioned in SHELL DOCUMENTS this piece of component will be provided by the SEM and as per its power requirements we have given a Dedicated Isolated type DC-DC converter that is capable of giving 12 volts 1 Amp continuously and is protected through fuse at its input side.

BATTERY:-

 VAJRA is equipped with a 48V 20Ah battery which is capable of delivering a power of 1Kw approximately. The battery has in-built battery management system (BMS). This gives protection against over-current, over-voltage and other parameters which prevents the battery from damage also safety to the user

DC-DC CONVERTERS:-

 A DC-to-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high. There are 3 converters in the car. The first converter is to convert 48V to 12V to actuate the contactor. The second converter is to convert 48V to 15V, which powers the auxiliary components of the car. The third converter is to convert 48V to 12V, with 1ampere continuous current delivery capability to power the on-board telemetry system.

FUSE BOX :-

 A fuse is an electrical safety device that operates to provide over-current protection of an electrical circuit including the source of power and the load. It is an essential component is a metal wire or strip that melts when too much current flows through it, thereby interrupting the flow of current. It is a sacrificial device and once a fuse has operated it is an open circuit, and it must be replaced or rewired.

VAJRA is equipped with a customized purpose built fuse box with led indicators which indicate the working of each particular fuse. Fuse protection is separately given to each electrical

component. A 40A, 30A and a 5A fuse is used each for the main circuit , motor controller and other auxiliary components.

KILL SWITCHES:-

A kill switch, also known as an emergency stop or e-stop, is a safety mechanism used to shut off a device or machinery in an emergency situation in which it cannot be shut down in the usual manner. Unlike a normal shut-down switch/procedure, which shuts down all systems in an orderly fashion and turns the machine off without damaging it, a kill switch is designed and configured to completely and as quickly as possible abort the operation.

VAJRA is equipped with two kill switches, one on the shell of the car and the second one on the dashboard, which is accessible to the driver.
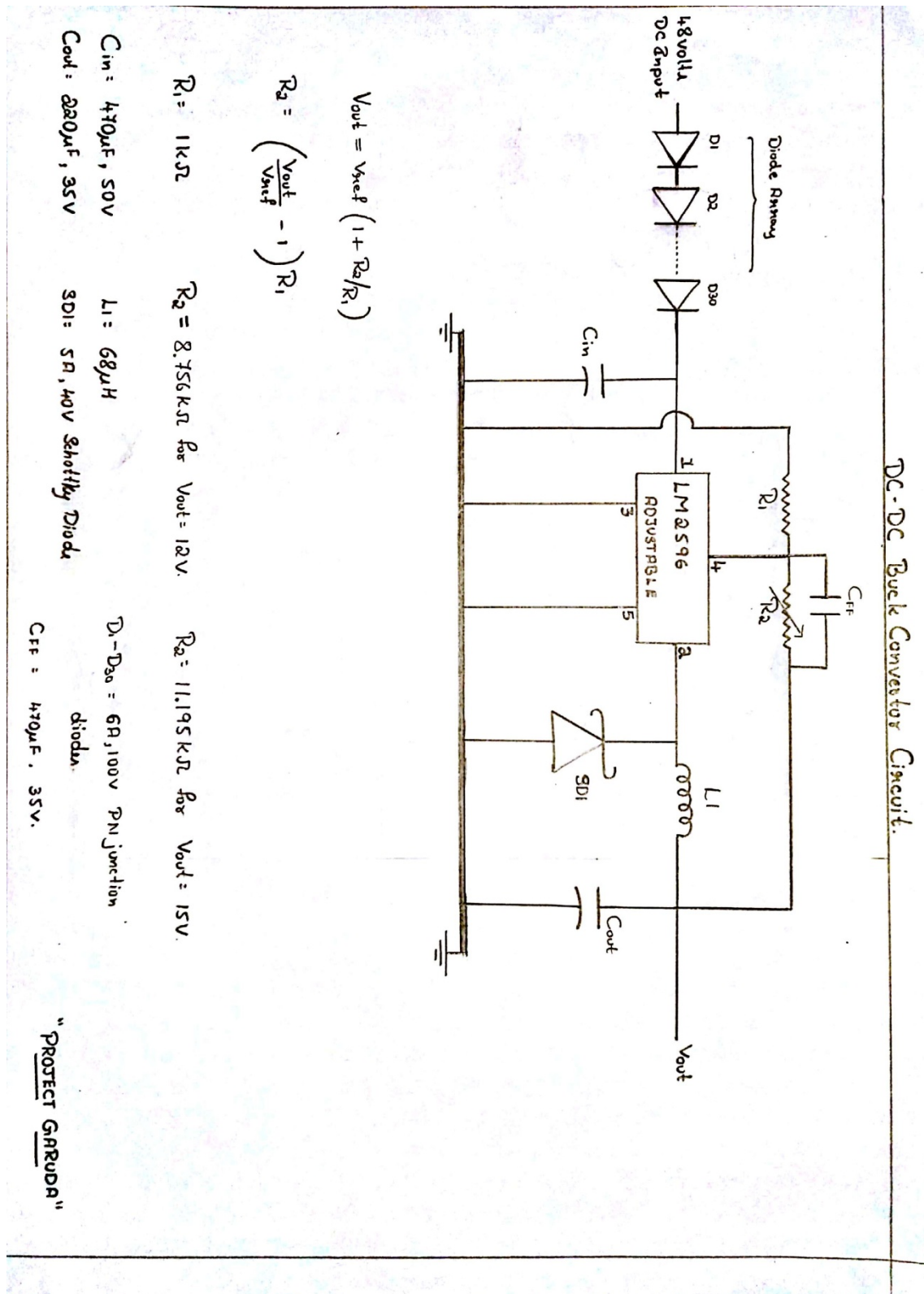
DEADMAN'S SWITCH:-

A dead man's switch is a switch that is automatically operated if the human operator becomes incapacitated, such as through death, loss of consciousness, or being bodily removed from control.

INDICATOR CIRCUIT:-

A customized low power consumption indicator blinking circuit is also employed in VAJRA.

3.DC to DC Convertor

DC-DC Buck Convertor Circuit.

48volts DC Input

Diode Array
D1 D2 ... D50

LM2596 ADJUSTABLE

$V_{out} = V_{ref}\left(1 + R_2/R_1\right)$

$R_2 = \left(\dfrac{V_{out}}{V_{ref}} - 1\right) R_1$

$R_1 = 1k\Omega$

$R_2 = 8.756 k\Omega$ for $V_{out} = 12V$.

$R_2 = 11.195 k\Omega$ for $V_{out} = 15V$.

$C_{in} = 470\mu F, 50V$

$C_{out} = 220\mu F, 35V$

$L_1 = 68\mu H$

$SD_1 = 5A, 40V$ Schottky Diode

$D_1 - D_{50} = 6A, 100V$ PN junction diodes.

$C_{FF} = 470\mu F, 35V.$

"PROJECT GARUDA"

DC-DC CONVERTER:-

The figure in page 7 shows the circuit level diagram of Step down DC to DC converter in which we have used an array of diodes in order to bring back the input Dynamic range to the level that the rest of the Switching Buck converter can with stand and it falls in its dynamic range.

The main circuit can be seen as two separate blocks

1. Diode Array's
2. Switching Buck converter

Diode Array:-

The main idea of going to diode array is to reduce the input dynamic range and to have compact design of the circuit so that it can easily mounted in car.

Max input voltage- 100 volts

Max current through diodes- 6A

Datasheet of diode MIC6A4 https://www.diodes.com/assets/Datasheets/ds28009.pdf

Switching Buck Convertor:-

It uses LM2596 IC to switch the high level input dc to low voltage and also does the work of regulation

Max input supply – 45volts

Output Dynamic range 1.23- 37volts

Max current -3Amps

Datasheet of LM2596 buck converter http://www.ti.com/lit/ds/symlink/lm2596.pdf

4.Indicator Blinking Circuit
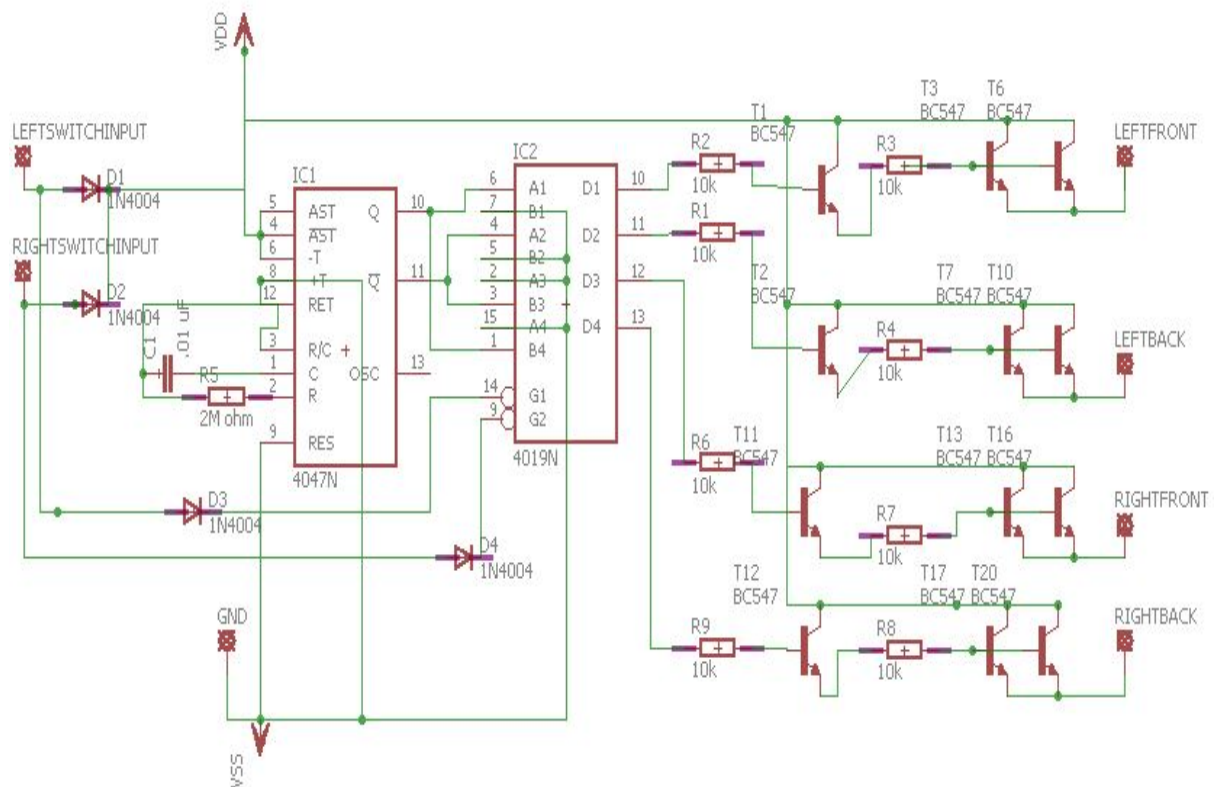
1. In VAJRA there are 4 indicator lights, 2 lights at front and 2 at rear

2. One end of these lights are connected to VSS(GND) and other to VDD through a control circuit whose schematic is as shown below.

3. A left, right switch at dash board is used to pass input signal to circuits and also power to the circuit.

   The figure shown in page 7 shows the circuit level implementation of the blinker board used for indicators
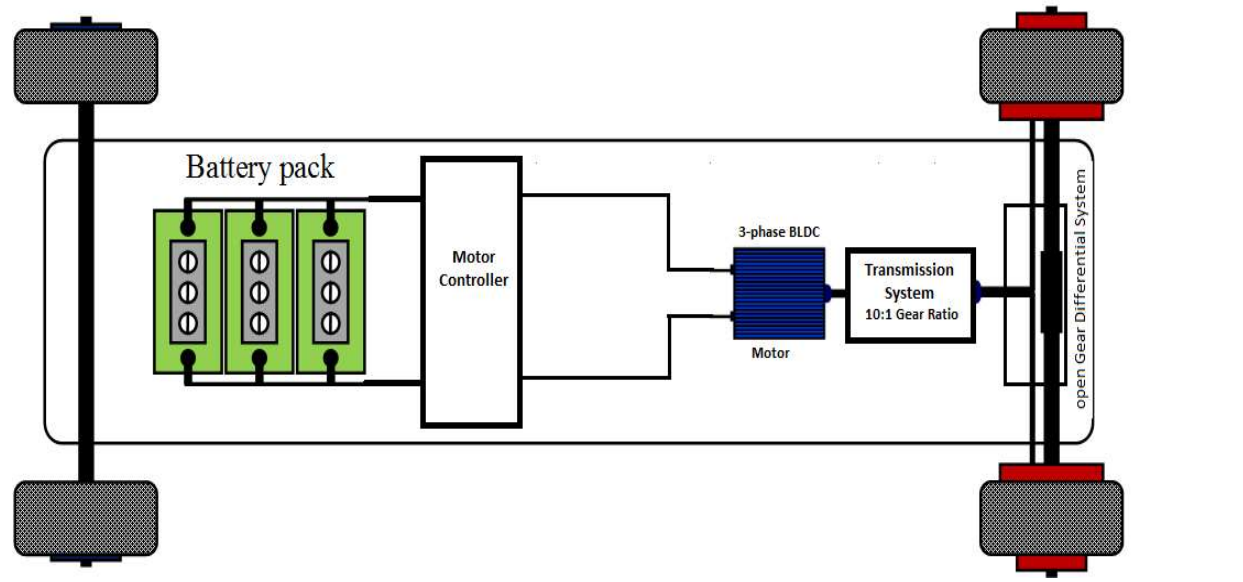
   Blinking Rate – 2Hz.

   Peak output voltage 15volts.

   Max input level 15 volts.

   Datasheet of 4047 oscillator IC - http://experimentalistsanonymous.com/diy/Datasheets/HEF4047Bpdf.pdf.

5.Propulsion System

The above figure shows the propulsion system of the car **VAJRA** in which the Power from battery is supplied to the A indigenously made motor controller which controls the speed of the 3-phase BLDC motor(max RPM of 3600).

The motor is connected to gear box which has open differential from which the shaft is connected to a free wheel and from there to wheel.

6.Battery Specifications

Specification of Li-ion Battery 48V 20AH with PVC Case	
Battery Model	48V 20Ah
Nominal Capacity (Ah)	20Ah
Nominal Voltage (V)	48V
Source Resistance (mΩ· ·	about 40
Cell Specification	3.7V 2.2Ah 18650
Cell Combination	9 parallel with 13 series
Cell Quantity (parallel*series)	117
Discharge Cutoff Voltage (V)	41+/- 1V
Charge Cutoff Voltage (V)	54.6V
Rated Discharge Current (A)	30A
Instantaneous Maximum Discharge Current (A)	60A
Maximum Continuous Discharge Current (A)	30A
Maximum Continuous Charge Current (A)	5A
Charge Mode	CC/CV
Standard Charge Current (A)	2A
Charge Time under Standard Charge Current	10 Hours
Fast Charge Current (A)	5A
Charge Time under Fast Charge Current	4 Hours
Charge Temperature Range	-20-60· ·
Discharge Temperature Range	-20-60· ·
Battery Size	255 mm*170mm*70mm
Chargeing Cycles	>800times
Recommender for Moto	Less than 1440W
Battery Gross Weight	5.5 kgs
Parts included: Lithium Battery + PVC case + Built-in BMS board + Charger(54.6V 2.0A)	

BMS will cut of the input and output when over-charging and over discharge.

7. BMS Specification

A **battery management system** (**BMS**) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it.

Application and characteristic of BMS:

1. Applies to 13 series lithium manganate/Lithium cobaltate/Lithium ion/polymer/NMC battery pack.

2. Function: Protecting the Battery from Over charging, over discharge, short circuit and To perform Cell Balance function.

3. Protection using aluminium cooling fin, with shockproof, unbreakable and increase the thermolysis and increase the strength of the function.

Main control IC with highly integrated dedicated battery protection IC, with reliable protection and stability, low self-loss and anti-ESD.

Specification of BMS

SL no	Test Item	Min	Typ	Max	Unit
1	Charging Voltage	54.40	54.60	54.80	V
2	Limit of Charging Voltage of MOS tube			75(DC)	V
3	Limit of Discharge Voltage of MOS tube			75(DC)	V
4	Continuous Discharge Current		30	32	A
5	Charging Current		5	7	A
6	Over Discharge protection	80	90	105	A
7	Over Discharge protection	300	400	500	mS
8	3.30V consuming current of single cell	15	25	33	uA
9	4.20V Balance Current of single cell	44	49	54	mA
10	Balance current of single cell	4.16	4.18	4.2	V
11	Single overcharge detection Voltage	4.17	4.2	4.25	V
12	Single over charging recovery voltage	4.00	4.10	4.15	V
13	Single overcharge detection delay	0.5	1.0	2.0	S
14	Single over discharge detection voltage	2.67	2.75	2.83	V

15	Single over discharge recovery voltage	2.90	3.00	3.10	V
16	Single over discharge detection delay	0.5	1.0	2.0	S
17	Recoverability Condition of short circuit	Remove load auto recovery			
18	Recoverability Condition of overcharging and discharge	Disconnect the charger (discharge load) and all the individual battery voltage drops to overcharge recovery (rise to over discharge recovery) Voltage			
19	Short circuit Protection delay	300	500	700	uS
20	Protection of circuit resistance		8	15	mΩ
21	Operation Temperature Range	-20	25	45	C
22	Save Ambient temperature range	20	25	30	C
23	Storage Humidity range	<40%			

Protection Method used in BMS :-

In the BMS enclosed within the battery cuts of the connection to the load when ever it is shorted or when over discharge is detected. Recovery of the BMS to its old state is done when load is disconnected from the batter.

The BMS may prevent operation outside the battery's safe operating area by:

- Including an internal switch (such as a relay or solid state device) which is opened if the battery is operated outside its safe operating area
- Requesting the devices to which the battery is connected to reduce or even terminate using the battery.
- Actively controlling the environment, such as through heaters, fans, air conditioning or liquid cooling

8.Motor Controller

Electric motors are capable of large amounts of power, and are relatively light weight. A typical electric motor is capable of 200 watts per kilogram, while a typical human muscle is only capable of about 50 watts per kilogram of power.

Electric motors come in two major varieties: brushed and brushless. Brushed motors are the most common and the easiest to use. Brushed motors work by having two magnets in the stator and an electromagnet in the rotor. The motor continues to spin by the electromagnet changing orientation, which is controlled by the brushes that act as contact switches. Brushed motors are very easy to use, and will run by simply applying a dc voltage across the motor leads. The current Electric Vehicles in the college uses exclusively brushed motors, with motor controllers set up for the brushed motors.

There are several issues with brushed motors. The constant contact of the brushes will limit the top speed of the motor and eventually the brushes wear out, necessitating replacement. The brushes also result in sparking and electrical noise, which leads to variation in the motor constants, as observed by the laboratory. Another disadvantage is that the component of the motor that heats up, the electromagnet, is in the rotor and is nearly impossible to cool without opening the motor to blow air through it.

Conversely, brushless motors do not contain brushes. The electromagnet for the motor is in the stator and does not rotate, while the rotor contains rare earth magnets. The changing of the polarity to continue to make the motor spin is controlled by a computer, making the control more precise and efficient, since the computer can factor in the speed of the motor. Without the brushes, the motor has less frictional losses and less variable motor constants and properties. Also, with the electromagnets in the stator the motor will be much easier to cool, which means the motor will be able to run longer at higher power values without overheating.

The major drawback of the brushless motor is that they are much more difficult to control. A brushless motor requires a computer to sense the position of the rotor and apply the appropriate voltage across the appropriate electromagnet to force the motor to spin. Hence, the goal of this project is to design and build a motor controller board to enable control of a brushless motor and create a motor controller to run the vehicle.

II. Methods and Results

A. Motor Description

The motor used is a Yu Feng, brushless, 1000 Watt, corresponding to the 48 volt motor. The spec sheet for the motor was not found. A picture of the motor is displayed below in Figure 1.
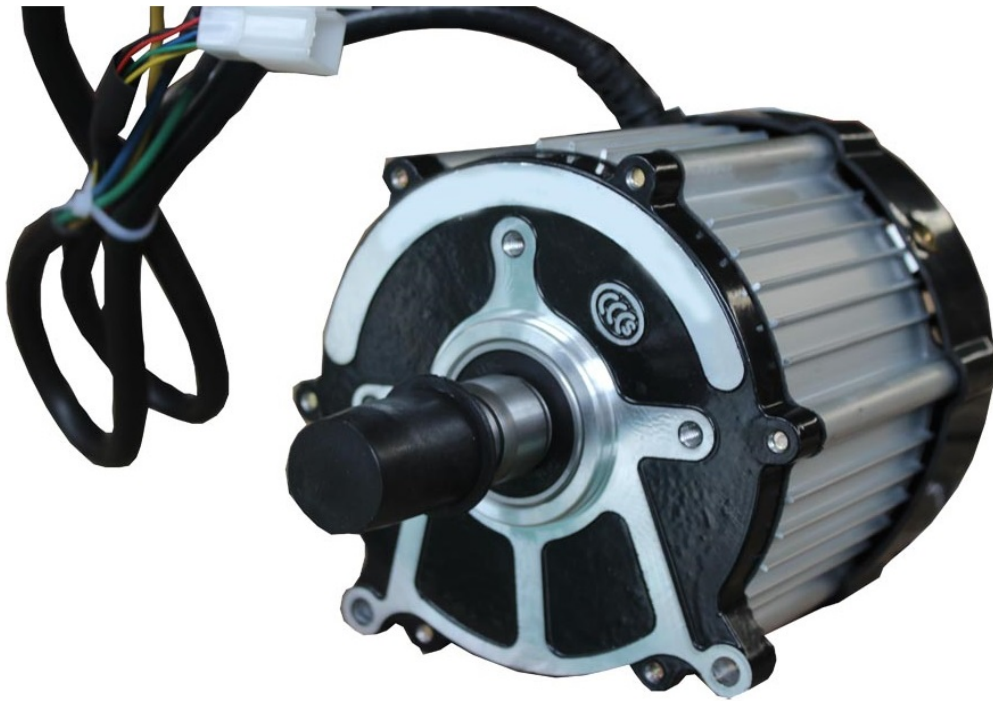

Figure 1: Picture of the brushless motor supplied.

As depicted in the figure, the motor has eight wires attaching to it. There is one power wire for each of the three phase windings, one power wire for the Hall effect sensors, one ground wire for the Hall effect sensors, and one signal wire for each of the three Hall effect sensors. The Hall sensors are built into the motor to detect the position of the rotor. The Hall sensors return a high value when rotor is in one orientation and a low when the rotor is 180 degrees away from the high. In actual use, the Hall sensor returns a high for the 180-degree section while the rotor is closest to the sensor and a low voltage of zero for the rest of the time. The motor uses three Hall sensors, and by determining which sensors are on at any given time, the appropriate orientation of the electromagnetic field can be applied.

B. Motor Controller

The basic principal of the motor controller is to use the Hall effect sensors to determine the orientation of the rotor and apply a magnetic field perpendicular to the rotor magnets. To control the speed of the motor, the voltage applied is Pulse Width Modulated (PWM). It is also necessary to determine the speed of the motor, which can be accomplished by measuring the time for the Hall sensors to go through one full rotation, corresponding to one revolution of the motor. The diagram below shows the possible sequence of MOSFET activity to achieve one full rotation of the rotor. In the diagram, each winding is attached between two MOSFETs, and by controlling which MOSFETs are active controls the flow of current into the motor and ultimately the direction of the magnetic field.

Fig 4.   Motor rotation Q1 to Q6 switch sequence
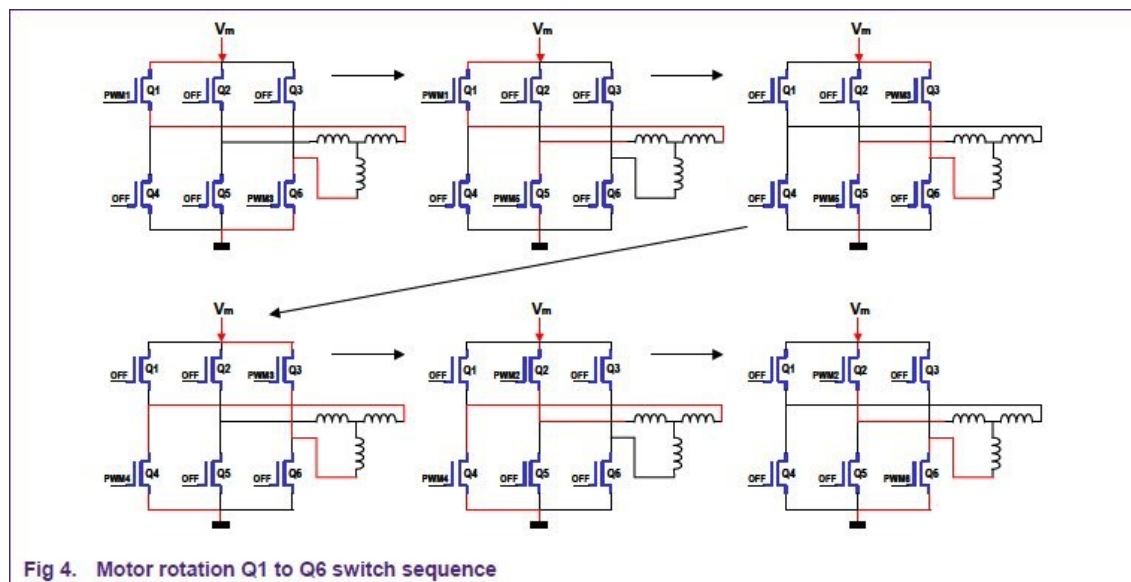
Figure 6: Depicts the flow of current through the MOSFETs and motor windings, as a progression of the rotation of the motor. The figure is from the **Brushless DC motor control using the LPC2141** article from the NPX website.

The actual implementation of this strategy utilizes a block commutation scheme provided in the Maxon EC motor guide. This strategy is depicted in Figure 7, below. As depicted below there are six cases, where the high sensor is: 1, 1 and 2, 2, 2 and 3, 3, 3 and 1. In the code, the variable hall_sensor_code is comprised of three bits: sensor 3 is assigned bit 0, sensor 2 is assigned bit 1, and sensor 1 is assigned bit 2. The actual motor code takes on a switch-case structure, which allows for the six cases listed above, as well as the potential to go in the reverse direction. In each case, it is first determined which winding is getting the voltage applied to it. Next, it is determined which two MOSFETs are set to the on position. For example, phase 1 in the diagram below has Hall sensors 1 and 3 set to on. This gives a value of 101 for hall_sensor_code, in binary, or 5 in decimal. In the diagram, U_{1-2} is on, with the shaded portion on the positive side.

This means that the lowside MOSFETs for windings 1 and 2 are set to on, and the lowside MOSFET for winding 3 is off. Also, since the top is shaded, the first number of the subscript has the voltage applied to it, so in the code, winding 1 gets the voltage. This example is depicted as the second state in Figure 6. The specific section of code is as follows:
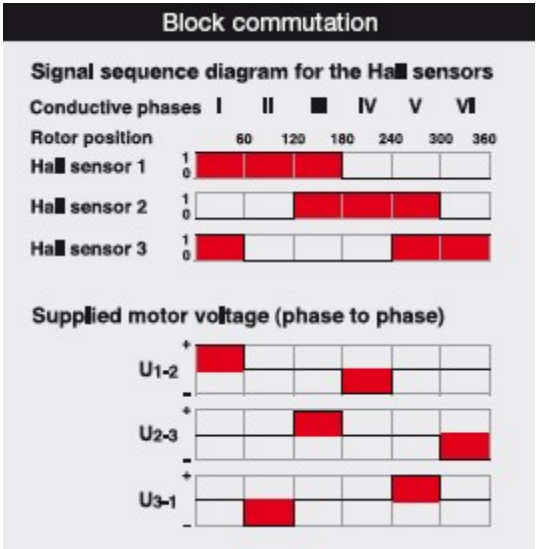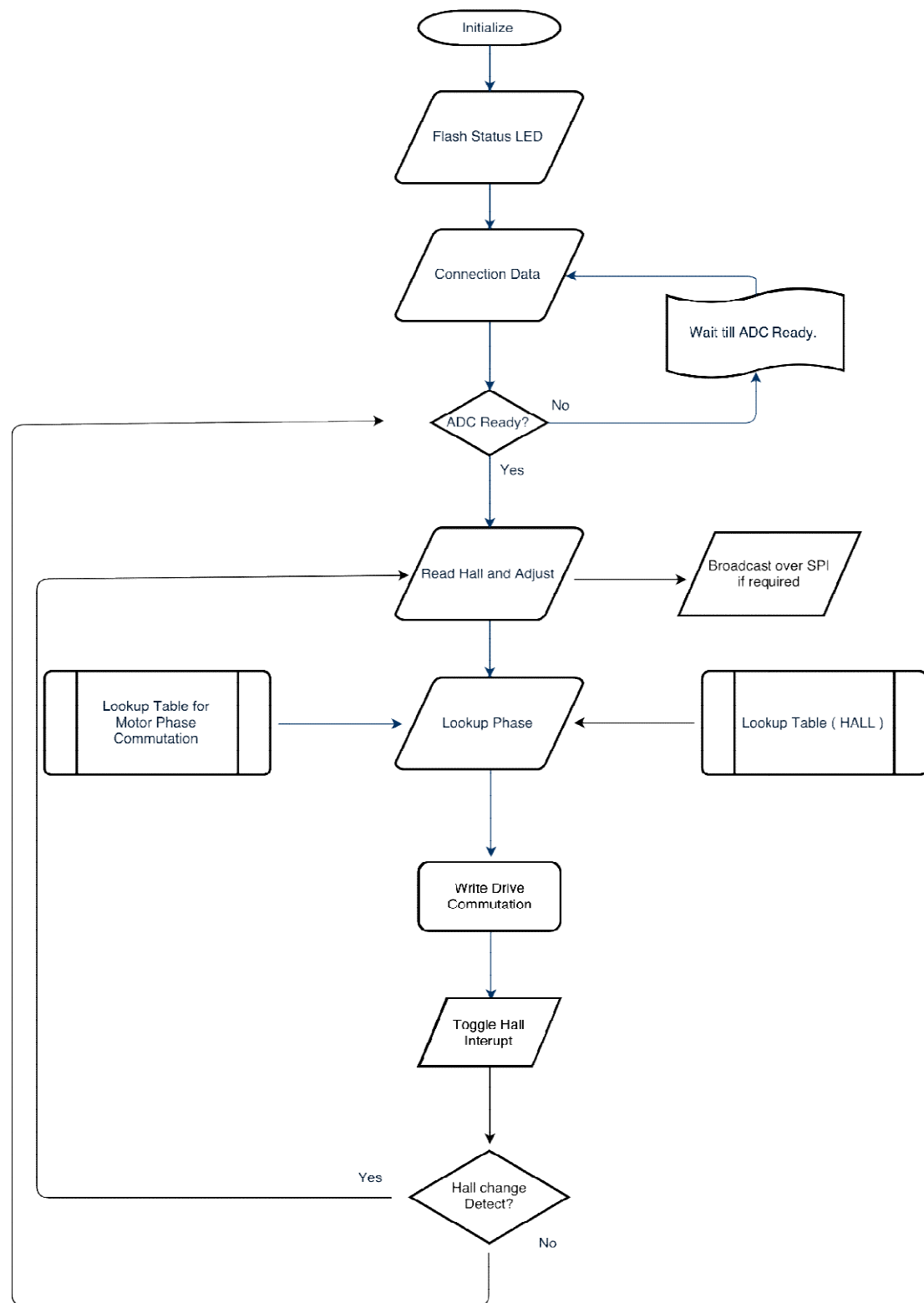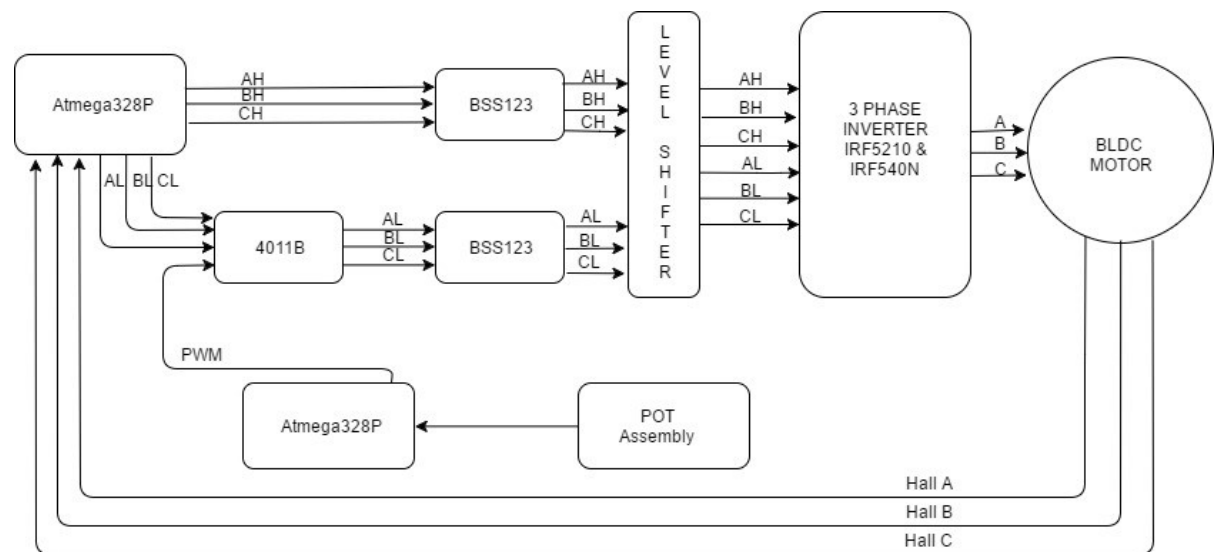

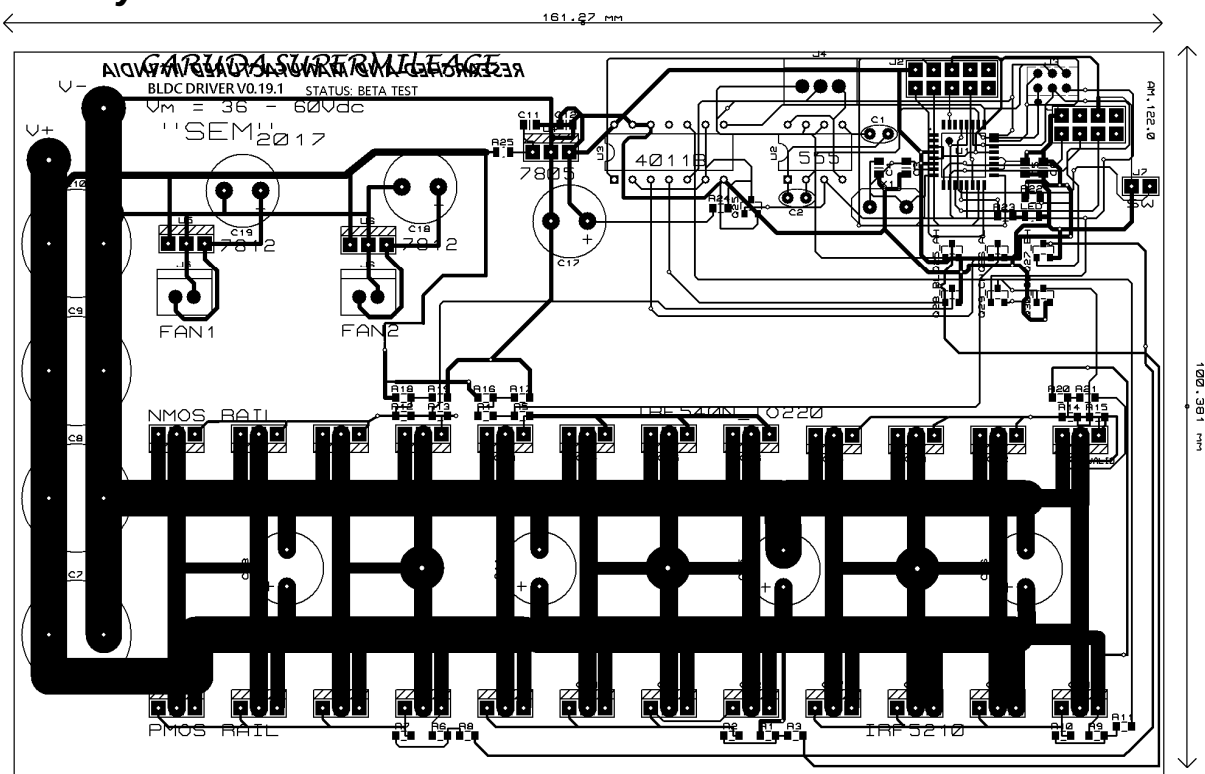**Figure 7:** Block commutation scheme from Maxon's motor guide
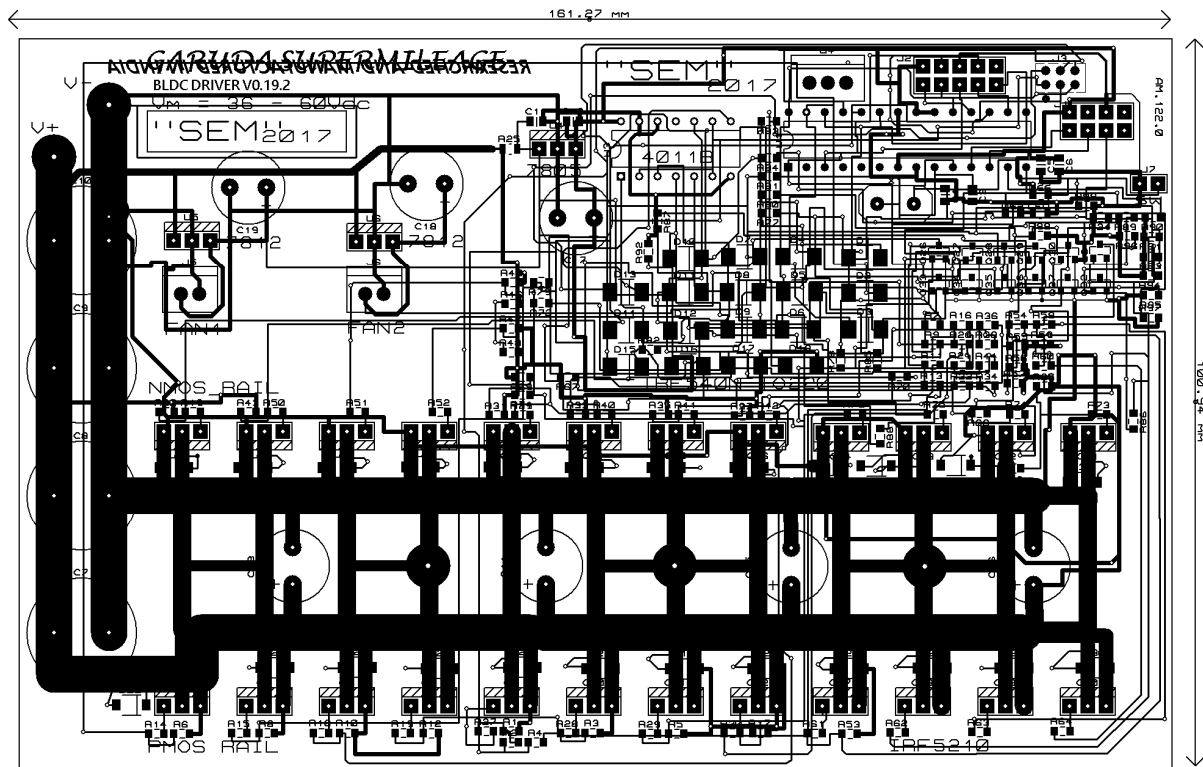
C. Data Flow structure

D. Electrical Flow structure

E. PCB layout.

Prototype V19.1A

Prototype V19.2

III. Discussion

Upon the completion of the project, we have a working motor controller for a brushless dc motor; however, the motor controller can be improved. Currently all of the code for the motor controller is in the main loop of the c file. This may cause a problem at high speed, since the motor may be turning faster than the main loop can keep up with. This problem could be solved by putting the code into an interrupt; let the motor run until a hall sensor switches on, then apply the necessary voltage to the necessary windings. This would also be useful for determining the speed of the motor by counting the interrupts. A working motor controller has been made, but many modifications are necessary before the code is good enough to use on a vehicle.

IV. Appendices

Motor Controller Code:

```
volatile uint8_t phase = 0; // motor firing phase
volatile long position = 0; // current position
volatile bool sample_and_hold_pin = false; // flag to tell loop to
sample current position
volatile byte position_buffer[] = {0, 0, 0, 0}; // buffer for
transfering single bytes of position over spi
```

```
void setup() {

  // configure motor control outputs
  DDRC |= 0x3F;  // A0-A5 as outputs
  // configure uC control pins
  DDRD &= !0xEF; // 0-3, 5-7 as inputs (will break serial communication
and require ISP programmer to undo)
  DDRD |= 0x10;  // 4 as output, used for software pin change interrupt
    pinMode(0, INPUT);  // sample and hold
    pinMode(1, INPUT);  // motor direction
    pinMode(2, INPUT);  // encoder channel B
    pinMode(3, INPUT);  // encoder channel A
    pinMode(4, OUTPUT); // used for software initiated pin change
interrupt
    pinMode(5,OUTPUT); digitalWrite(5, HIGH);
    pinMode(6, INPUT);  // hall sensor 3
    pinMode(7, INPUT);  // hall sensor 2
    pinMode(8, INPUT);  // hall sensor 1
    pinMode(9,OUTPUT); digitalWrite(9, LOW);
    //pinMode(8, OUTPUT); // status LED
    pinMode(10, INPUT);  // pwm pin, master controls this
    pinMode(MISO, OUTPUT);
    pinMode(SS, INPUT); // /SS pin
  SPCR |= 0b00;        // SPI speed f_osc/4 (4MHz with 16MHz chip)
  SPCR &= ~_BV(DORD); // MSB first
  SPCR &= ~_BV(MSTR); // slave mode
  SPCR &= ~_BV(CPOL); // clock low when idle
  SPCR &= ~_BV(CPHA); // sample on clock rising edge
  SPCR |= _BV(SPE);  // enable SPI
  SPCR |= _BV(SPIE); // enable SPI interrupts

  // initialize interrupts
  initInterrupt();

  // setup phase to correct motor position by triggering pin change
interrupt a few times
  // fills in hall variable in pin change ISR
  delay(1);
  digitalWrite(4, LOW);
  delay(1);
digitalWrite(4, HIGH);
  delay(1);
  digitalWrite(4, LOW);

  // flash LED thrice on reset
  for (int i = 0; i < 6; i++) {
    PINB |= _BV(0);
    delay(80);
  }
}



void loop() {

  static long sample_position = 0;
  static bool sample_and_hold_set = false;
```

```c
  // sample and hold event
  if (sample_and_hold_pin == true && sample_and_hold_set == false) {
    sample_position = position;                   // sample position
    position_buffer[0] = sample_position >> 24; // divide sampled
position
    position_buffer[1] = sample_position >> 16; // into byte sized
chuncks
    position_buffer[2] = sample_position >> 8;  // for SPI transfer
    position_buffer[3] = sample_position;       //
    sample_and_hold_set = true;                   // set flag that sample
has been taken
    PINB |= _BV(0);                               // toggle LED
  } else if (sample_and_hold_pin == false && sample_and_hold_set ==
true) {
    sample_and_hold_set = false;                  // remove sample flag
  }

  // commutate motor
  commutate(phase);
}




void initInterrupt() {

  cli();                 //disable interrupts while changing settings
  PCICR |= 1 << PCIE2;   // set bit 2 in PCICR for PCINT23:16 (port D)
  PCMSK2 |= 0xFF;        // enable pin change interrupts on port D (all
pins)
  sei();

}




ISR(PCINT2_vect) { // run every time there is a pin change on port D
pin change

  // lookup tabel for position incrementing (3-phase version of
quadrature)
  static int8_t hall_inc[] = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, -
1, 0, 0, 0, 0, 0, -1, 0, 0, 1, 0, 0, -1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 1, -1, 0, 0, 1, 0, 0, -1, 0, 0, 0, 0, 0, -1, 0, 1, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0};

  // lookup table for setting next motor phase, extended to allow
reverse direction
  static uint8_t phase_lookup[] = {0, 2, 4, 3, 6, 1, 5, 2, 4, 3};

  static int hall = 0;
  static uint8_t dir = 0;
  static bool sample_and_hold_set = false;

  int port = PIND; // read the port

  sample_and_hold_pin = port & 1; // flag to tell loop to store current
position in buffer
```

```
  dir = (port >> 1) & 1; // direction value, 1 or 0
  hall = hall << 3;       // preserve last read for position
in/decrement
  hall |= port >> 5;      // shift to read only hall sensors

  if (dir == 0) {
    phase = phase_lookup[(hall & 0x07)];    // determine next phase to
fire on the motor
  } else {
    phase = phase_lookup[(hall & 0x07) + 3]; // adding 3 to lookup
index has the effect of reversing the motor (MAGIC!)
  }

  position += hall_inc[hall & 0x3F]; // use <hall_prev><hall_current>
as lookup index to which will increment, decrement or do nothing to
position value

  PINB |= _BV(0);                              // toggle LED
}




ISR(SPI_STC_vect) { // spi handler

  byte position_byte = SPDR; // read in command from master (which byte
of position to send next)
  SPDR = position_buffer[position_byte]; // send a single byte from
position_buffer

}

void commutate(uint8_t _phase) {

  //                              {lowers on, Bh:Al,    Ch:Al,
Ch:Bl,    Ah:Bl,    Ah:Cl,    Bh:Cl}
  static uint8_t phase_to_port_ABC[] = {0b000000, 0b010001, 0b100001,
0b100010, 0b001010, 0b001100, 0b010100};
  static uint8_t phase_to_port_ACB[] = {0b000111, 0b100001, 0b010001,
0b010100, 0b001100, 0b001010, 0b100010};
  static uint8_t phase_to_port_BAC[] = {0b000111, 0b001010, 0b100010,
0b100001, 0b010001, 0b010100, 0b001100};
  static uint8_t phase_to_port_BCA[] = {0b000111, 0b001100, 0b010100,
0b010001, 0b100001, 0b100010, 0b001010};
  static uint8_t phase_to_port_CAB[] = {0b000111, 0b100010, 0b001010,
0b001100, 0b010100, 0b010001, 0b100001};
  static uint8_t phase_to_port_CBA[] = {0b000111, 0b010100, 0b001100,
0b001010, 0b100010, 0b100001, 0b010001};

  // the order of the 3 motor wires will dictate which of the above
lookup tables to use.

  PORTC = phase_to_port_ABC[_phase];
```

9.Chassis

The chassis is the internal framework, which comprises of the frame, wheels and its equipment of a vehicle. The main purpose of the chassis is to shield the inside occupants from any harm caused by external invasion. Therefore, it is expected for the chassis to be structurally sound in every way during the expected life of the vehicle while supporting the body and other components.

9.1. Design of chassis

A few ideas were evaluated and the chassis designs were done in Solidworks software following the SEMA competition rules and considering standard measurements. Computer analysis was done using Ansys software. The final design was chosen using an evaluation system where weight, cost, manufacturing, ergonomics, stress and torsion analysis were considered.

Comparison was made using Quality Function Development (QFD) approach which is presented in Table 1.

Priority Points	Type → Factor ↓	Backbone	Ladder	Spaceframe	Monocoque
10	Ease of Manufacture	4	4	4	3
9	Weight	5	4	4	4
9	Strength / Stiffness	1	2	5	3
9	Cost	5	5	4	2
	Priority Sum	133	132	140	106
	Best	140			

Table 1.Chassis type selection

Based on Table 1, space frame chassis was adopted. CAD model of the chassis is shown in Fig. 1.
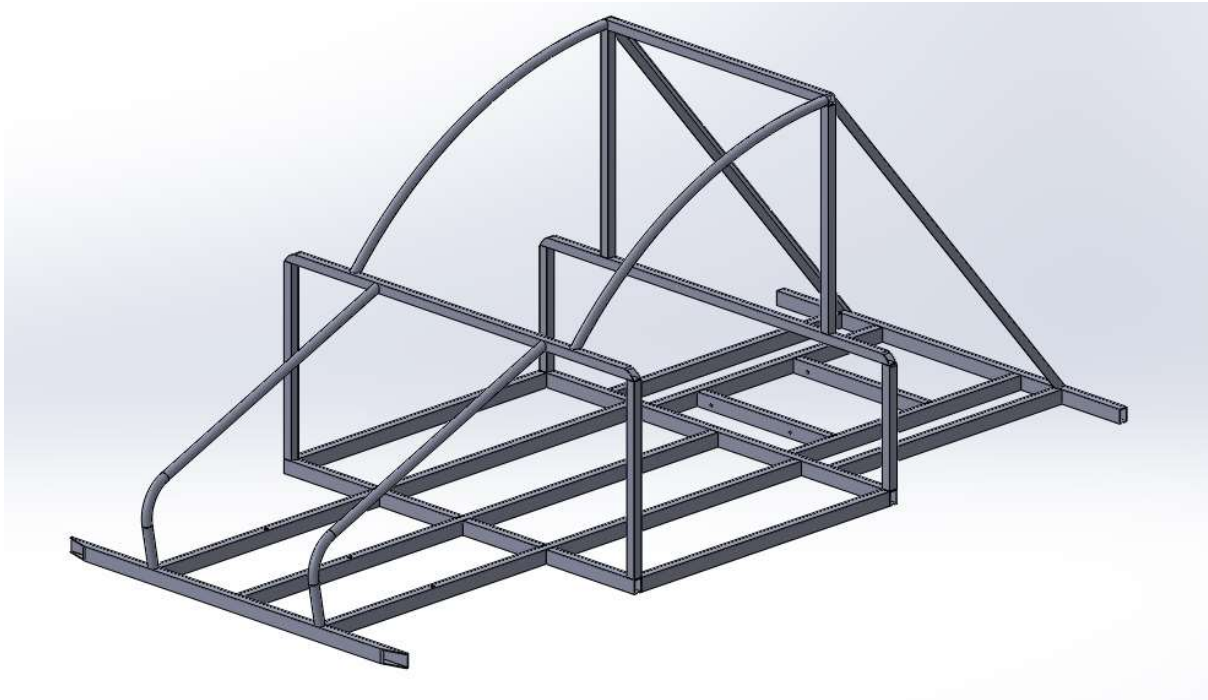
Fig 1. CAD model of chassis

Although the previous year's designs resulted in a successful vehicle, a lot of improvements such as weight reduction and optimisation of chassis were done. In order reduce weight, unwanted members were eliminated and curved shapes were used to make the chassis aerodynamic. The chassis is designed efficiently to accommodate and mount all the necessary electrical and mechanical components.

The key specifications of 2017 chassis are given in Table 2.

Specification	Dimension (mm)
Track Width	1060
Wheel Base	1600
Chassis Length	2500
Ground Clearance	200
Chassis Height	1000
Chassis Width	1200

Table 2. Specifications of 2017chassis

9.2. Material Selection

For selection of material to build the chassis, another QFD matrix was constructed which is shown in Table 3.

Priority Points	Material→ Factor ↓	Aluminium 6063	Carbon Fibre	Stainless Steel 1020	Mild Steel	Chromoly Steel
10	Weight	4	5	2	2	3
9	Strength	3	5	4	4	4
9	Ease of Manufacture	4	1	4	4	4
8	Cost	3	1	3	4	2
	Priority Sum	127	112	116	124	118
	Best	127				

Table 3.Materail selection of chassis

Based on the above table, Aluminium 6063 was selected as the chassis material. L shaped, rectangular, square and circular cross sections were used in the construction of chassis to obtain higher torsional rigidity, load bearing and higher impact strength. Tungsten Inert Gas welding was chosen to join the different sections as Al 6063 is highly weldable using tungsten inert gas welding.

9.3. Analysis of chassis

A simplified model of the chassis was subjected to structural analysis in ANSYS, the result of which is shown in Fig. 2. Tetrahedral meshing with finer mesh in critical regions was employed. Point loads were applied at the key points. The maximum stress in the chassis was found to be 13 MPa, which is safely below the yield point of Aluminium 6063 (70 MPa). The resulting static deflection was 3.0 mm and the factor of safety was found to be 3.0

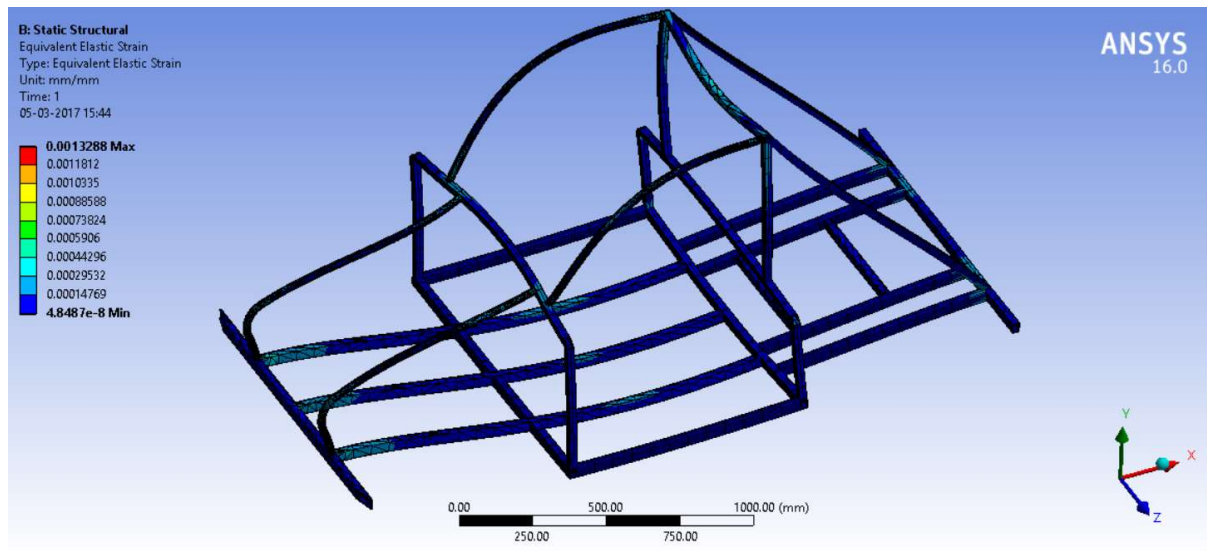The maximum stress induced due to applied force is as shown below:

Fig 2.Maximum stress on chassis

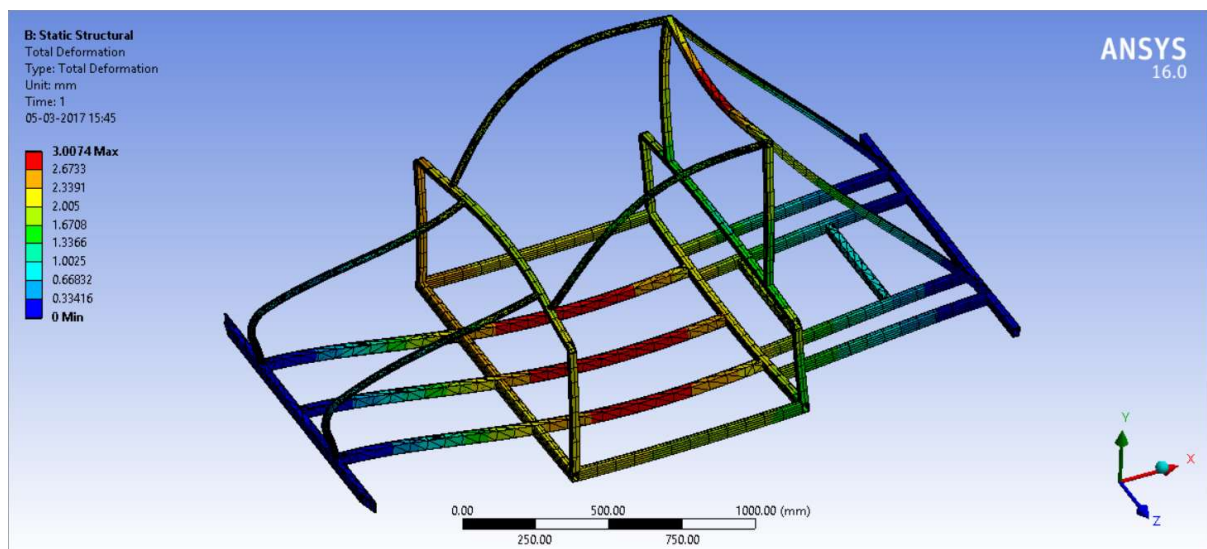The total deformation ocurred due to applied force is as shown below:

Fig 3.Maximum deformation on chassis

The maximum stress and deformation were found at the driver seating position and at the roll bar where maximum load was applied.

Model (B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	Equivalent Elastic Strain	Total Deformation
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent Elastic Strain	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Integration Point Results		
Display Option	Averaged	
Average Across Bodies	No	
Results		
Minimum	4.8487e-008 mm/mm	0. mm
Maximum	1.3288e-003 mm/mm	3.0074 mm

Fig 4.Equivalent Elastic Strain

Model (B4) > Static Structural (B5) > Solution (B6) > Results

| Object Name	Equivalent Elastic Strain	Total Deformation
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Equivalent Elastic Strain	Total Deformation
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Integration Point Results		
Display Option	Averaged	
Average Across Bodies	No	
Results		
Minimum	4.8487e-008 mm/mm	0. mm
Maximum	1.3288e-003 mm/mm	3.0074 mm

Fig 5.Total Deformation

As the stress induced is less than the yield stress the chassis design is safe.

After the complete design and analysis of the chassis, Al 6063 bars of required cross sections were procured. The Al 6063 bars were cut into desired dimensions and were joined by riveting with the help of gussets and the circular bars were bent using CNC bending machine. Tungsten Inert Gas welding was performed for rigid support and strength. The fabrication phase pictures are shown below:

10. Steering

A rack and pinion is a pair of gears which convert rotational motion into linear motion. The circular pinion engages teeth on a flat bar - the rack. Rotational motion applied to the pinion
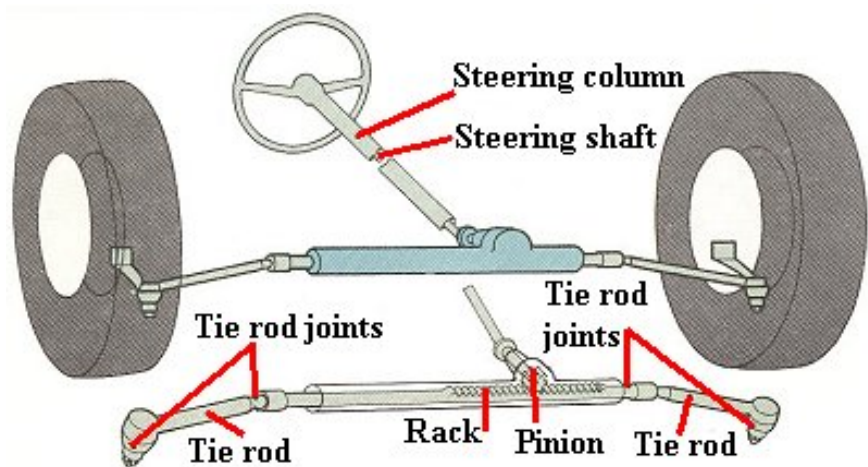
will cause the rack to move to the side, up to the limit of its travel. Rack and pinion steering is quickly becoming the most common type of steering on cars, small truck sand SUVs. A rack-and-pinion gear set is enclosed in a metal tube, with each end of the rack protruding from the rack housing. A rod, called a tie rod, connects to each end of the rack. The pinion gear is attached to the steering shaft. When you turn the steering wheel, the gear spins ,moving the rack. The tie rod at each end of the rack connects to the steering arm on the spindle.

The rack and pinion gear-set does two things:

• It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels.

• It provides a gear reduction, making it easier to turn the wheels.

The rack, also known as a steering rack, is a long piece of metal that is flat on at least one side. The flat side contains teeth running the length of the rack. The teeth are cut perpendicular to the edges of the rack, meaning they run side by side from one end of the rack to the other. The pinion shaft comes into the rack at a ninety-degree angle and the teeth on the pinion mesh withthe teeth on the rack. The pinion is connected directly to the steering column, so when the steeringwheel is turned to the left, for instance in the case of Ackerman geometry the pinion rotates counterclockwise .Thus the rotary motion of the pinion is changed to transverse motion by the rack. Therack moves to the right, making the wheels go left. The car turns left.

DESIGN AND CALCULATION:

Rack and pinion:

- The steering design has been done for a turning radius of 4.14m.
- The Ackerman angle for a wheel base of 1.6m and a track width of 1.02m was found to be 18.53°.
- According to Ackerman Steering Geometry condition, it was found that the inner wheel had toturn through an angle of 20°.
- The wheel diameter is taken to be 56cm.The figures below illustrate the Ackerman

Steering Geometry
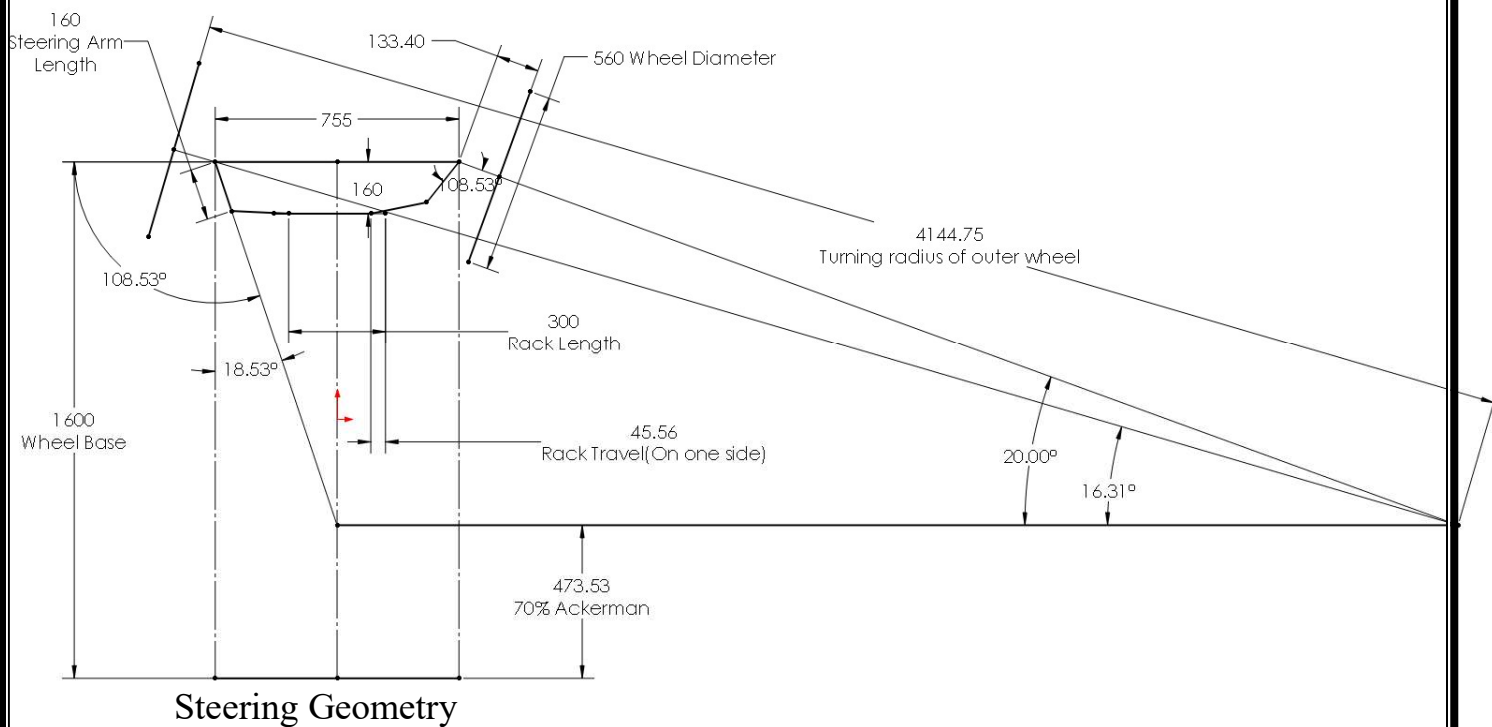
All dimensions are in mm

α – Outer Steering angle=20°

β – Inner Steering angle=16.31°

a – Track width = 1.02m

w- Wheel base = 1.6m

Then the condition for perfect steering is calculated using the formula:

$$cot\alpha - cot\beta = \frac{a}{w}$$

Rack Travel

Considering the maximum angle through which the inner wheel could be turned for the given track width the rack travel required was calculated. Maximum angle through which the inner wheel could be turned = 20°

For that, the rack travel required would be 91 mm.

Pinion Dimensions

For the calculated rack travel, the dimensions of the pinion are found out. Let the maximum steering wheel rotation angle on either side be taken 60°. Therefore this angle of rotation should match with 91 mm of rack travel.

Let, r = Pitch circle radius of pinion, X = half of total rack travel, m = module of pinion, z = No. of teeth of pinion.

So,

$$X = \frac{(2 \times \pi \times r)}{3}$$

$$45.5 = \frac{(2 \times \pi \times r)}{6}$$

Standard module for pinion and rack is chosen to be m = 1.5,

So, m= d/z: 1.5 = 45/z

Therefore z = 30 teeth.

Let: R=steering wheel radius = 250mm, z = number of pinion teeth = 30

Rack Dimensional Data

Teeth dimensions are found to be,

- Pressure angle for the rack α = 20°,
- Module = 1.5,

- Total rack length = 300mm

Force Analysis

We will study the highest value of the force required to turn the wheels. This force appears when thecar is stopped and it starts the movement of the wheel.

The wheels rest on the floor on a surface, so two friction forces will act on it

R = Steering arm length = 160 mm

For equilibrium -

$\Sigma F_x = 0;$
$F_L - F_r = 0$ .... (1)
$\Sigma F_y = 0;$
$N - mg = 0$ .... (2)
$\Sigma M_y = 0;$
$F_L*R_s - 2*F_r*r = 0$ .... (3)

From equation (1) we calculate:

$F_L = F_r$

From (2) we have:

$N = mg$

Let the mass 'm' of the car be **200 kg** including the driver.

Then N = **1962** Newton.

Let us assume that 50 % of the total weight is supported by the front wheels.

Then the total load on the two front wheels = **1962/2 = 981 N**

Then on each wheel the load will be **981/2 = 490.5 N**

To calculate the F_r:

$F_r = \mu*N;$

Where μ is the friction coefficient. On the same way than before we are going to take a high value of μ in order to establish a safety coefficient. So we take $\mu = 0.7$.

Now we calculate the friction force:

$F_r = \mu*N = 490.5$ N

And from equation (1), $F_r = F_L$

So, **$F_L = 343.35$N**, It is the force that the rack has to transmit to the tie rods and these to the steering arms to move the wheel.

To calculate the torque we use the following equation:

$T = F * r_{pinion}$,

In our case we have a pinion with a diameter of 45 mm so:

$T = 343.35*22.5 = 7725.37$ N-mm

This is the torque in the pinion and it is transmitted through the steering column.

Steering Column Material

With this force we can calculate if the material for the steering column is adequate for the torque that is transmitted by the force on the steering wheel.

The steering column is subjected to shear stress:

$\tau_{max} = T*r / J$

Where, T is the torque on the steering column

$J = \pi * (D^4) / 32$

Where: D = 16mm

$J = 6434$ mm^4

r = 8mm

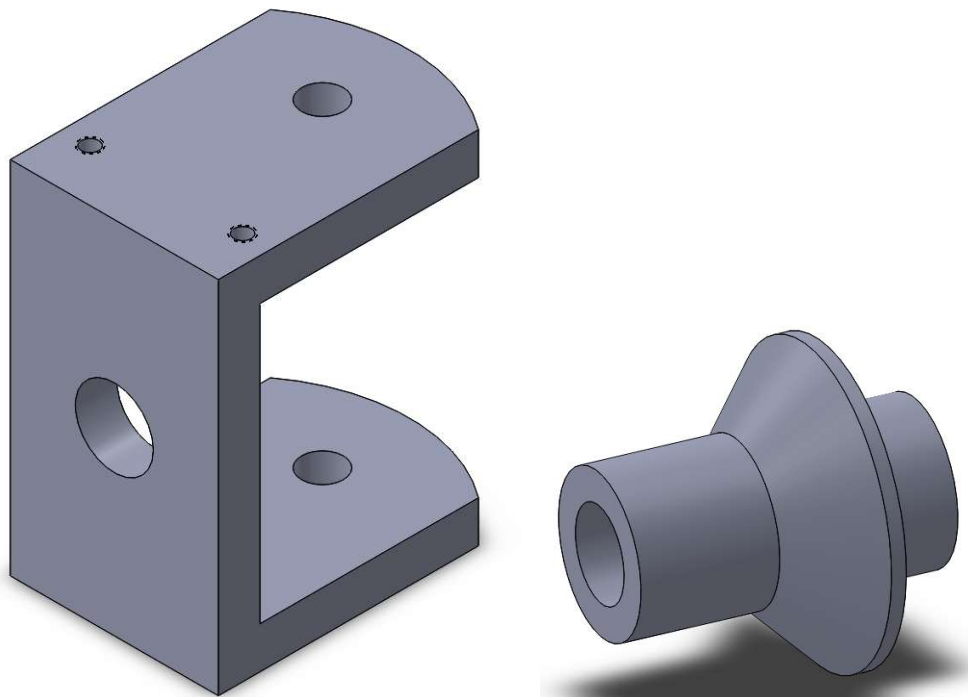T = 7725.37 N-mm

$\tau_{max} = 9.6$ MPa

A **universal joint** is added by splitting the steering column at a suitable length, for **flexibility** and **ease of movement** inside the driver's compartment. A standard U joint made of alloy steel is chosen.
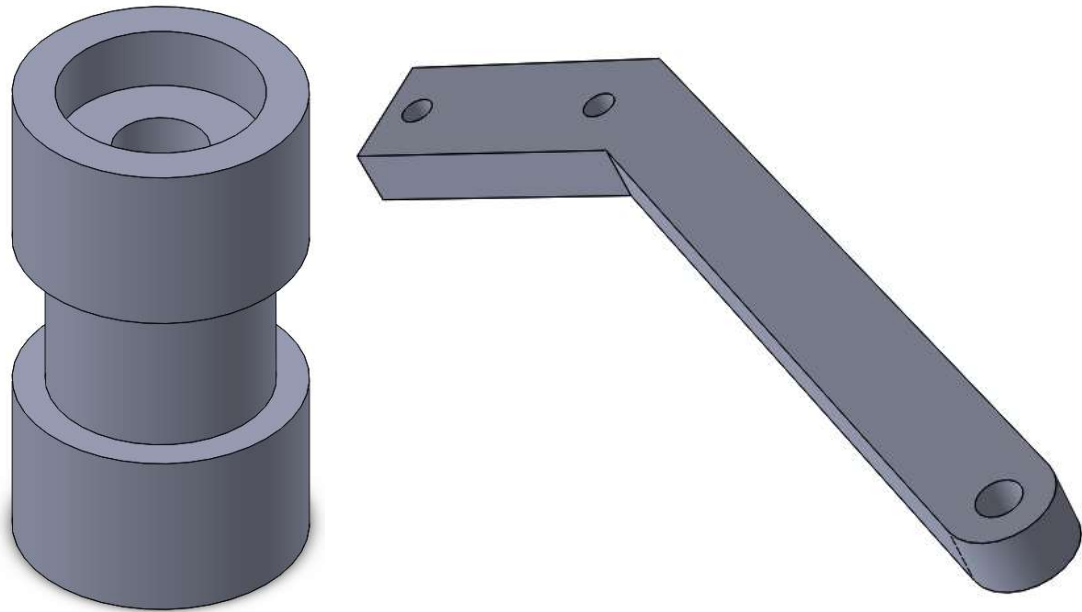
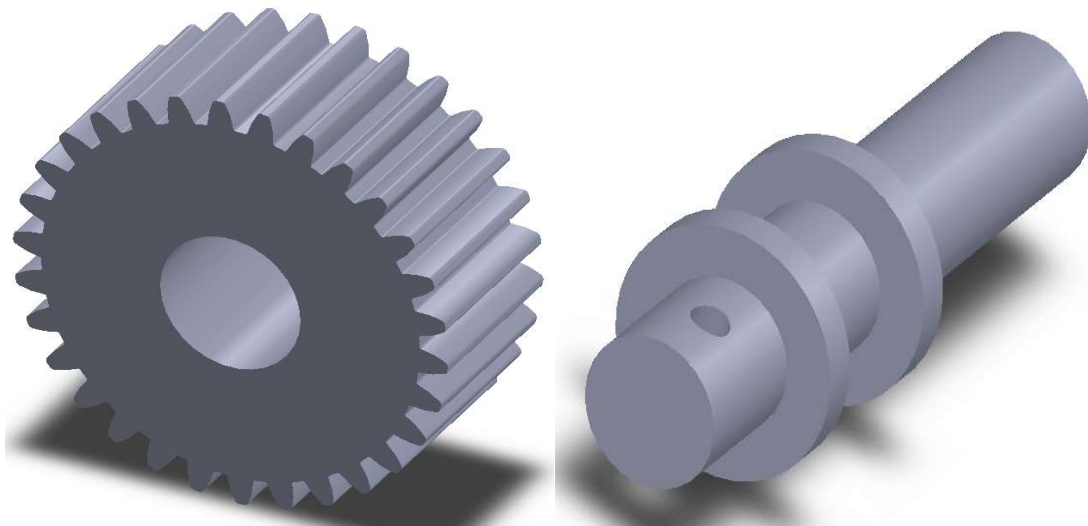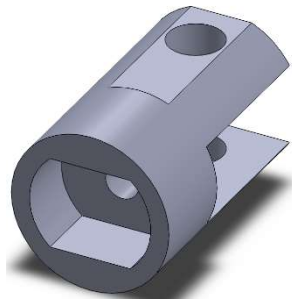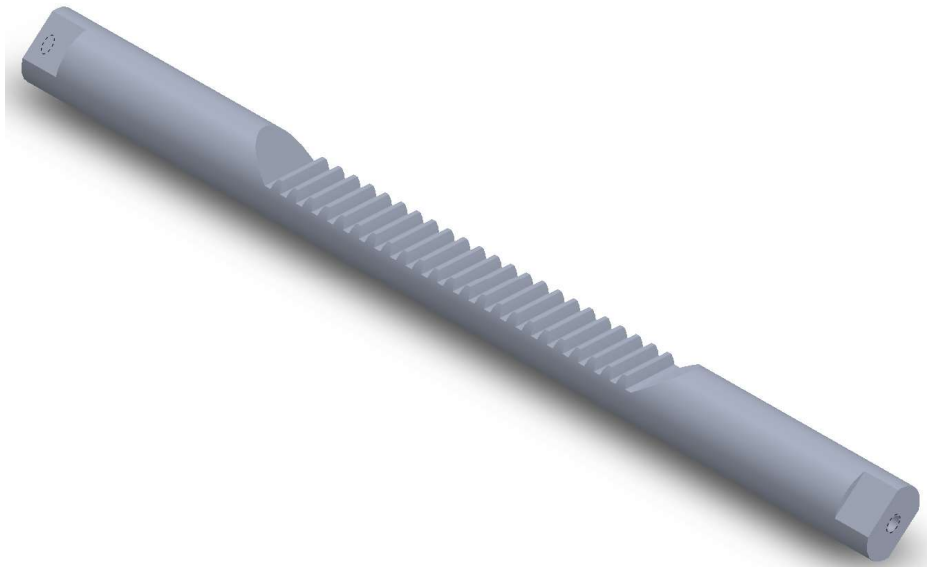## Parts of Steering Assembly:

Complete assembly:

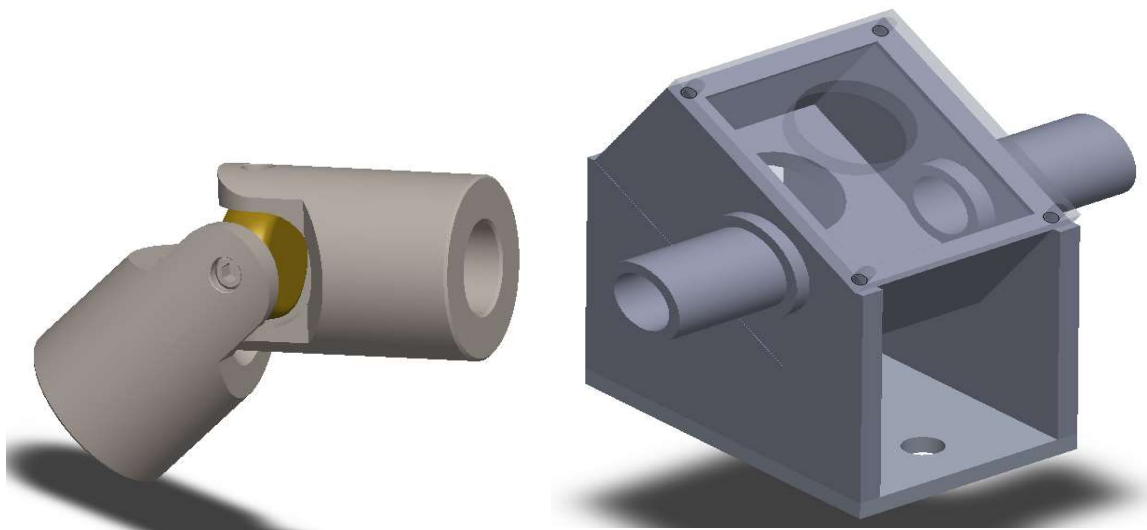**C clamp:**

Kingpin cylinder & Steering arm

Pinion & pinion mount:

Rack and rack external mount:

U joint & housing:

11. Powertrain

The design of the power system started with the selection of the wheels using the QFD approach. The tire must provide enough support for the entire weight of the vehicle while supplying adequate steering control and direction stability. Considerations were given to rolling resistance, availability and cost. Dimensions of the wheels considered were in line with the rules of the competition. Table 4 gives the QFD matrix used.

Priority Points	Rim Diameter (inches)	13	14	15	16	17
	Factors					
10	Rolling Resistance	1	2	3	4	5
9	Availability	1	1	1	2	3
8	Cost	4	4	3	2	1
	Priority Sum	51	61	63	74	85
	Best	85				

Table 4. Selection of wheels

100/80-17 51 P was the tire dimension selected based on the above matrix. The tire rim assembly wasprocured from TVS Apache RTR 180, which is a local motorbike in India.

Based on the track details given, 12 km is to be completed in 29 minutes, an average speed of 25 kmph was necessary to successfully complete the competition. Considering the acceleration, deceleration, cornering times, pit stops and drag loss at high speeds, the top speed was decided to be limited to 40 kmph. The following formula was used to calculate the resisting force acting on the car, which takes into account the drag force, acceleration force, rolling resistance as well as the inclination force, using which the required power was calculated:

Given

M=190Kg   [mass of driver (70kg) + mass of car(100kg)]

v=40kmph=11.11m/s [desired max speed]

u=0kmph=0m/s [initial velocity]

t=20s [time taken to reach desired speed (assumption)]

Cd=0.5 [selected from charts]

A=1.2m^2 [assumption]

ρ=1.225kg/m^3

g=9.81m/s^2

μ=0.018 [asphalt and tyres, avg conditions]

r=0.275m [radius of selected wheel]

Calculation

$F = F_{drag} + F_{friction} + F_{accln} = 0.5C_d\rho Av^2 + \mu Mg + M(v-u)/t$

F=0.5(0.5)(1.225)(1.2)(11.11^2) + 0.018(190)(9.81) + 190(11.11-0)/20

F=45.36N + 33.6N + 105.55N

F=184.51N

T=F*R=184.51(0.275) = 50.74Nm

P=F*v=184.51(11.11) = 2049.9W = 2.049KW (1.96hp)

V=r*ω

N=60v/2πr=60(11.11)/2(π)(0.275)=385.98rpm

Inference

As per above calculation a torque of 50.74Nm at wheel is sufficient to power a vehicle to reach max speed of 40kmph in 20sec covering 100m.Torque 21.72@350rpm is reqd to maintain the vehicle at 40kmph and accordingly power required is 0.877kW.

Therefore an electric motor with Power around 1 KW will be suitable to run the car in above condition.
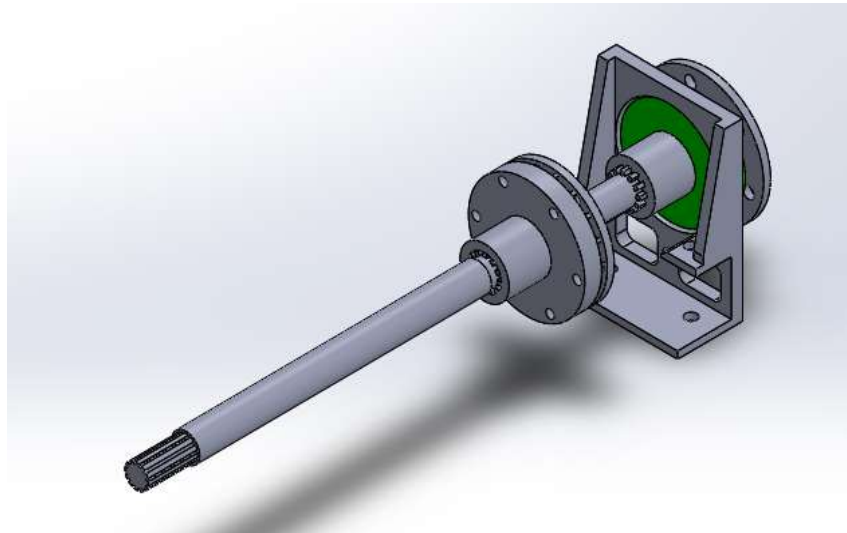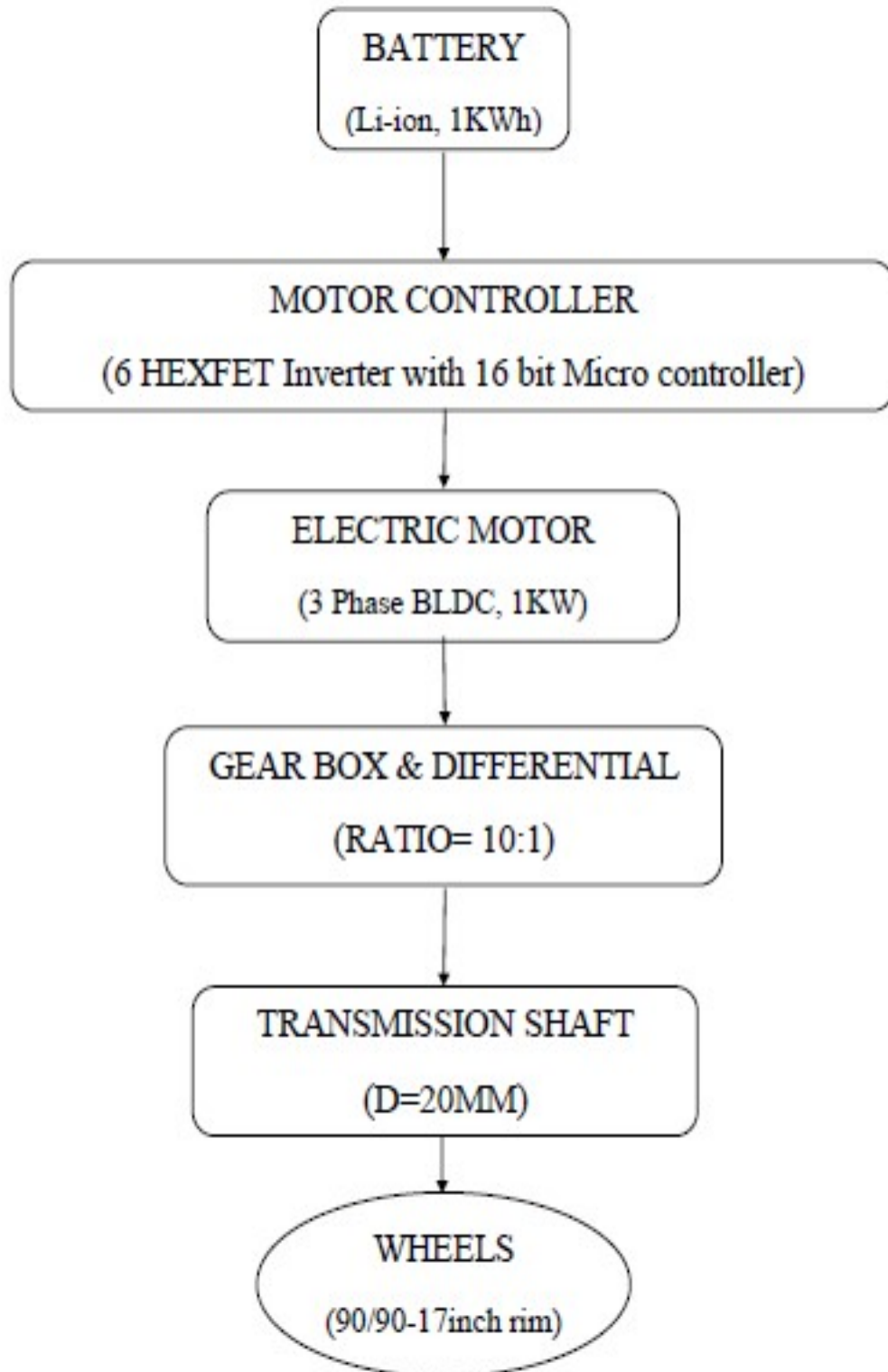

Free wheel assembly along with upright and hub

The freewheel mechanism is adopted for cruising conditions even when the motor is stopped.

PROPULSION SYSTEM BLOCK DIAGRAM

Components from MOTOR to ROAD:

BATTERY

(Li-ion, 1KWh)

↓

MOTOR CONTROLLER

(6 HEXFET Inverter with 16 bit Micro controller)

↓

ELECTRIC MOTOR

(3 Phase BLDC, 1KW)

↓

GEAR BOX & DIFFERENTIAL

(RATIO= 10:1)

↓

TRANSMISSION SHAFT

(D=20MM)

↓

WHEELS

(90/90-17inch rim)

Braking System

2017 Shell Eco Marathon requires participants to be equipped with four disc hydraulic braking system, with a brake pedal, with a minimum area of 25cm^2. The brakes must operate independently on the front and rear axles or in an X pattern. A single master cylinder may be used, provided that it has a dual circuit. The vehicle must remain immobile when it is placed on a 20 degree incline with the main brake in place.

Disc brakes, which are better than drum and rim brakes, consist of two parts: the disc and the brake caliper assembly. Hydraulic systems comprises of three basic components- the master cylinder, slave cylinder and reservoir- and connecting tubes that are filled with incompressible fluids. The pressure applied on the small area of the brake pedal is transferred through this fluid directly to the slave cylinder or the piston in the brake calliper assembly.

To calculate the breaking force required, stopping distance, initial distance and braking time of 5m, 40 kmph and 5 s respectively was assumed.

Deceleration was obtained to be a = -3.64 ms^{-2}

$$s = ut + 0.5at^2$$

For a car mass of 200 kg, total braking force to be achieved is 728 N. Since the brakes are applied at all four wheels, braking force required at each wheel is 182 N.
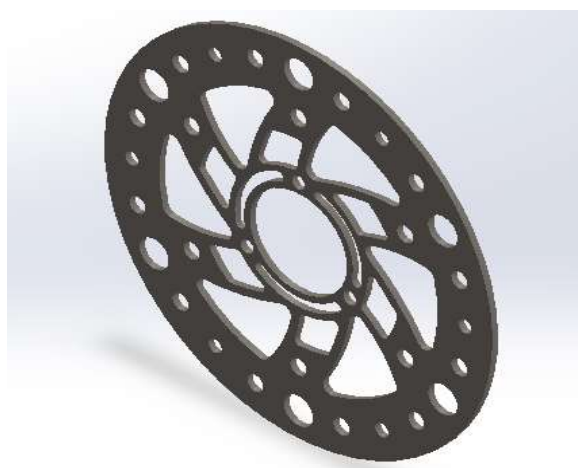
Brake disc

Based on the calculations it was inferred that TVS Apache RTR brake calipers and TATA ACE Master Cylinder were most apt. Tandem master cylinder and brake disc specification is given in below table.

Piston / Bore Diameter	2.86 cm
Piston Stroke / Push Rod Travel	2.8 cm
Volume Output Ratio (A/B)	2:1
Pressure Output Ratio (A/B)	50 / 50
Reservoir Capacity: Primary (A)	229 cm^3
Secondary (B)	139 cm^3

Tandem master cylinder specification

|	Front	Rear
Number of pistons per caliper	2	1
Outer diameter of piston in caliper (mm)	27	32
Number of pads per wheel	2	2
Number of calipers per wheel	1	1
Thickness of new disc (mm)	3.5	3.5
External diameter of disc (mm)	240	240
External diameter of pads rubbing surface (mm)	240	240
Overall friction length of pads (mm)	74.5	60.4

Brake disc – caliper specification

12. Body Work/Shell

The focus in this design includes producing a drag coefficient to less than 0.2, reducing therolling resistance coefficient to less than 0.007, reducing the weight of the vehicle with innovativedesigns and materials and attempting to gain a motor and drive train efficiency greater than 80%.Taking safety into account, the body and frame should combine to make a sturdy and structurallysafe aerodynamic shell. Its construction must consist of a mixture of lightweight materials:aluminium, carbon, polycarbonate sheets and glass-reinforced fibres.

12.1.DESIGN AND ANALYSIS:

The lesser resistance to air, more is the efficiency of the car, keeping this fundamental law in mind.We set out to design to an aerodynamic shell which accentuates the car's efficiency. When it comes to the body shell, the biggest issues are aerodynamics and weight. To reduce drag,an elongated tear drop shape was analysed for the shell in addition to maintaining the stability ofthe car. Solidworks 2016 was used in the design of the car and both solid and surface modelling were used. Elongated tear drop is the most aerodynamic with 0.02 Cd value but accommodating this in the design would be hard given the dimensional constraint in length and also the need for material reduction to bring about weight reduction which would in turn increase the mileage. To do this, various designs were made on Solidworks and finally, the following design was finalized upon.
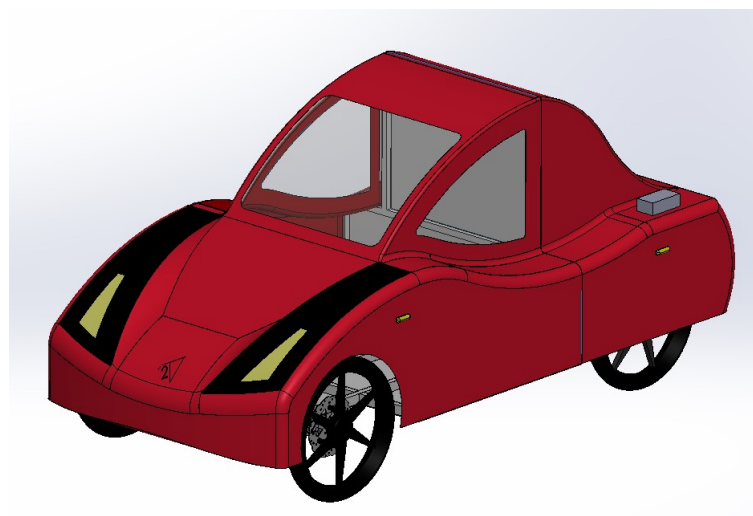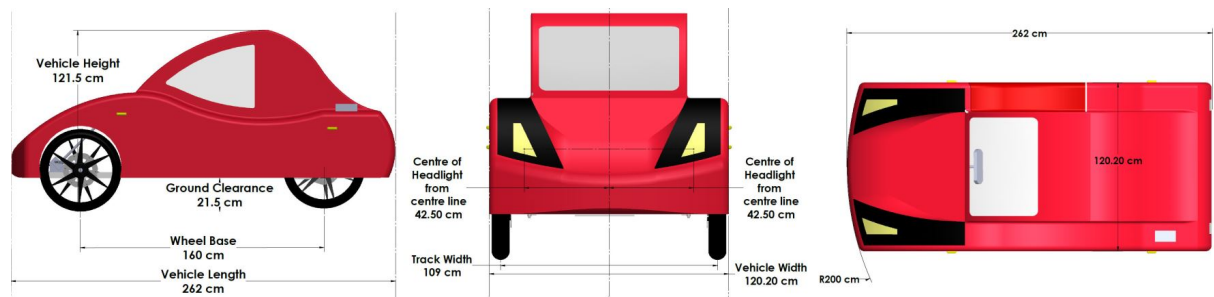
It can been seen from the above pics that the shell has contours and lacks any sharp edges. Thesehelp in easier air flow over the shell surface and hence gives lesser resistance to air. The backsideis given a slope to again help is easier air movement across the surface of the shell. The shell was taken as a solid part to run Flow Simulation on Solidworks to analyse the flow and find out the dynamic pressure, fluid force and co-efficient of drag, Cd. The flow simulation wizard was used and the following values and parameters were used:
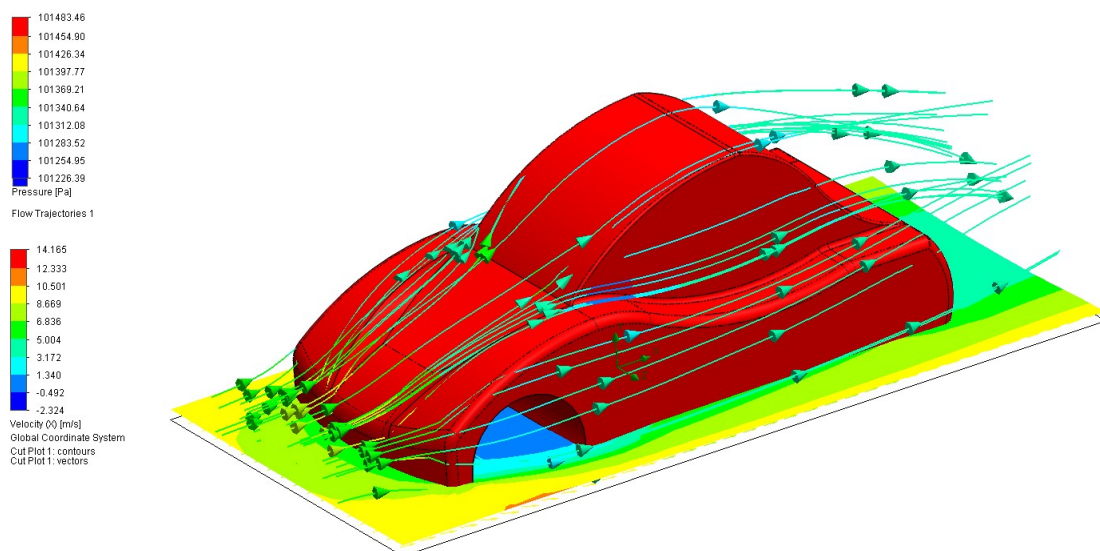
Velocity = 10m/s
Real gas – Air
Wall roughness – 200 micrometer
Mesh size – fine (5)

After carrying this out, the computational domain was reduced as per requirements and global goals were added for force, pressure and velocity. After this, the flow simulation was run and results were computed. Cut plots and flow trajectories were added as shown:

Also, in order to calculate the co-efficient of drag, equation goal is necessary. The following equation was added in equation goal:

$$Cd = \frac{D}{\rho V^2 A / 2}$$

Finally, the co-efficient of drag was calculated and a value of approximately 0.09 was obtained. This value is near to the Cd value of half tear drop shape. This is shown below:
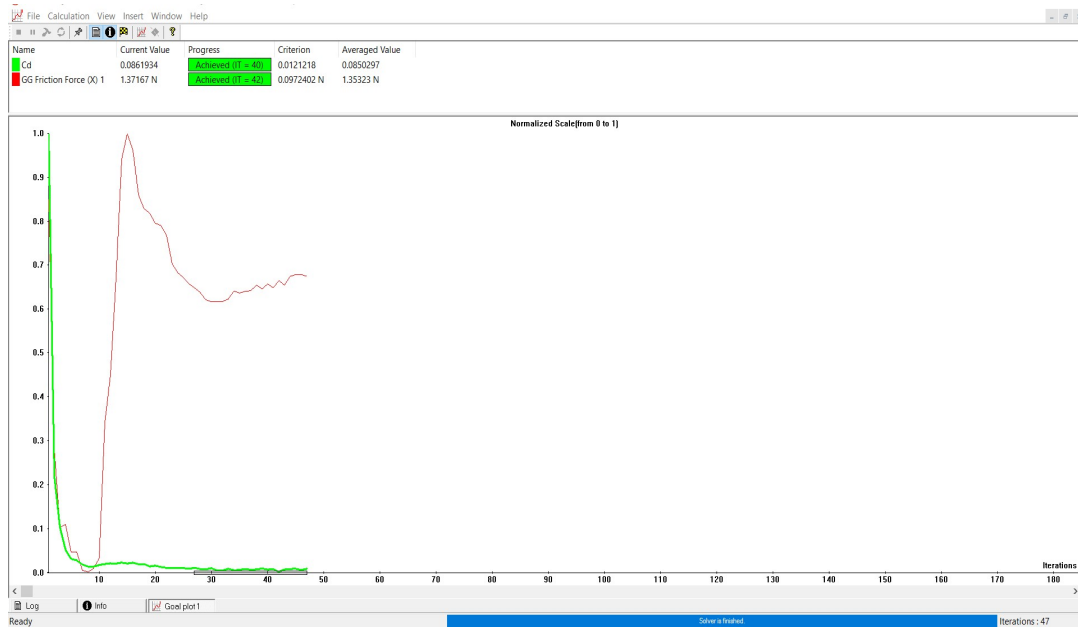
12.2.MATERIAL AND PROCESS SELECTION:

Being that weight is an important factor of the design, carbon fibre is one of the top options of the team to build the shell, but it has a major disadvantage being the cost. Fiberglass does seema fair choice if the problem of cost persists. The strength of the materialis not extremely significant since the vehicle will not be supporting any high loads.The Shell of any car plays a major role in improving the mileage of the car. This is the deciding
factor which helps any car, especially in an event such as Shell Eco Marathon stand out by giving a boost to increase the mileage.

The following criterion were used in deciding the material:

Priority sum	Material - H Factor - V	Carbon Fibre	Glass Fibre	Basalt Fiber	Polycarbonate	Sheet metal
10	Weight	10	8	7	8	5
9	Mouldability	8	8	7	5	5
8	Strength	8	7	7	6	8
8	Economy	6	8	7	7	7
	Priority sum	284	272	245	229	215
	BEST	284				

Some of the data used while awarding these points is given below:

Material	Young's Modulus
E Glass	30-40
Carbon Fiber	125-181
Kevlar®	70.5-112.4
Epoxy	3

	Fibre Strength	Laminate Strength	Density of Laminate grams/cc	Strength-to-Weight
E Glass	3450	1500	2.66	564
Carbon Fiber	4127	1600	1.58	1013
Kevlar	2757	1430	1.44	993
Epoxy	N/A	12-40	1-1.15	28

E=Excellent, G=Good, P=Poor, F=fair

	Glass	Aramid	Carbon Fibre
Cost	E	F	P
Weight to Strength Ratio	P	E	E
Tensile Strength	E	E	E
Compressive Strength	G	P	E
Stiffness	F	G	E
Fatigue Resistance	G-E	E	G
Abrasion Resistance	F	E	F
Sanding/Machining	E	P	E
Conductivity	P	P	E
Heat Resistance	E	F	E
Moisture Resistance	G	F	G
Resin Adhesion	E	F	E
Chemical Resistance	E	F	E

This year's car shell consists of two different materials. The materials are Carbon fibre for the entire body and Lexan(polycarbonate) Sheets for windows and wind-screen. The dashboard was fabricated using glass fibre considering that Carbon Fibre is electrically conducting.

In order to select the process, a survey was done and the following factors were considered:

Priority sum	Process - H / Factor - V	Hand Lay up	Vacuum Bagging	Resin Transfer Moulding	Compression Moulding	Autoclaving
10	Economy	10	8	5	5	5
9	Ease of fabrication	7	8	6	6	8
8	Flexibility of design	8	7	6	6	7
8	Surface Finish	6	8	8	8	8
	Priority sum	275	272	216	216	242
	BEST	275				

Therefore, the selected process was Hand Lay-up technique considering the fact that economy of the process was higher than other processes and that space was also a constraint. Also, the other processes require specialized equipment and have higher cost of consumables.

12.3. CALCULATIONS AND FABRICATION:

With reference to Autar Kaw, the formulae for volume and weight fractions were considered. These equations are given below:

Data used – Density of Carbon fibre = 1.5g/cc and density of epoxy resin = 1.2g/cc

Ideal volume fraction of fibre is 0.6 $V_f + V_m = 1$
Hence volume fraction of matrix is 0.4.
Therefore, 200g of fibre($1m^2$) needs 133g of resin.

Using density values, density value of composite is calculated using:

$$\rho_c = \rho_f V_f + \rho_m V_m$$

Using this, the values of weight of matrix and fiber is calculated.

$$W_f = \frac{\rho_f}{\rho_c} V_f \quad \text{and} \quad W_m = \frac{\rho_m}{\rho_c} V_m$$

Also, the weight of the composite is calculated as follows:

$$w_f + w_m = w_c$$

Using these formulae, the weight of the entire shell was found to be 10.4kg.

For fabrication, the mould for lay-up was prepared using Polyurethane foam. Projections of the shell were obtained in different planes on Solidworks and the same were printed on B0 size sheets. These projections were suitably stuck on the foam boards and they were sanded to the required dimensions and profiles. Pictures of the mould are below:

Next part was the composite lay-up. A negative mould was made using glass fibre and vinyl ester resin. This was used to lay up Carbon fibre. The releasing agent used was Teflon sheet. Teflon sheet removed the need for Plaster of paris, putty, oil paint, PVA and wax. It alone was sufficient to release the composite laminate from the mould while also providing a smooth surface finish. Brushes, rubber gloves and rollers were the other consumables used. The resin-hardener ratio is 1:10 as prescribed by the manufacturer. The fabrication phase pictures are shown below:

Another important feature of a car shell is to ensure the motor and other components in back compartment gets cooled naturally by air. Theshell should facilitate air cooling and this can be achieved by providing slots or slits inthe shell so that air can be sucked into the back chamber. Usually race cars have a hood spoileror a cowl spoiler on the hood of the car. Commercial cars have a provision for a mesh which islocated near the back chamber which helps in cooling process.A similar provision of the mesh has been provided for the shell. This is located right after the door, this is because as the car accelerates, air flows into the back chamber and cools it. This helps inincreasing the efficiency of the engine and hence improves the mileage.

The next process was putting stickers on the shell. It was decided to sticker instead of painting it to ensure uniformity to prevent weakening shell due to non-homogeneous spots. It was also more economical and added negligible weight to the body. The final shell on the chassis is shown below: