Preface

As an undergraduate of department of Electronic and Telecommunication engineering, University of Moratuwa, I got the opportunity for my internship at Lanka Electronics (Pvt) Ltd. This report contains the details about project I carried out in my training period, Industrial experience and the knowledge gained during the industrial training period. The first chapter contains the details about the training establishment including the details about Lanka Electronics (Pvt) Ltd, organization structure, stores and current products.

The second chapter described the project I carried out during the training period. It contains the details about the theories I learned, project I carried out and the problems I faced during the projects. The final chapter contains the conclusion about the training period and the training establishment. It contains the ability of training establishment to provide useful training, training personnel of the establishment, weakness of the training establishment and possible suggestions.

Acknowledgment

First of all ,I am grateful to the Department of Electronic and Telecommunication Engineering, Industrial Training Division of University of Moratuwa and National Apprenticeship Industrial Training Authority (NAITA) for offering a great opportunity of taking part in an industrial training program which laid a strong foundation for my future carrier.

Secondly, I would like to thank Head of Department, Dr. N.W.N Dayananda, training coordinator of the Electronic and Telecommunication Department, Dr. Peshala G. Jayasekara and all other lectures of Electronic and Telecommunication Department for giving us a great opportunity to have a good industrial training experience and valuable guidance and support given during the industrial training period.

Also I would like to extent my sincere gratitude to Eng. N.A. Wijewickrema, Director of Industrial Training Division of University of Moratuwa for giving us briefing on Internship, its importance, safety procedures and expected outcomes prior to internship and all other guidance and support during the training period.

I would like to convey my gratitude to Mrs. Jayasinghe, CEO of Lanka Electronic (Pvt) Ltd for giving the internship opportunities for engineering undergraduates at Lanka Electronic (Pvt) Ltd.

I would like to specially thank Eng. Lakni Jayasinghe , my supervisor and Prof. Kapila Jayasinghe ,Director of Technical for their unlimited support and guidance during the training period. Also I would like to express my hearties gratitude to Mr. Janka Kulathunga (Manager of Lanka Electronics research and development section) , Mr. Daham Embuldeniya(Project partner),Miss. Isuru Rajapakshe, Mr.Shalitha Pathirana, Miss. Thanuji Nanayakkara, Mr.Vidula Tharinda, Mr.Inoj Akalanka,Mr.Bhashitha Himaruwan ,Mr.Sandaru Jayawardena , Mr. Dumindu Eranda and Mr. Aloka Perera for their unlimited support and friendship during Industrial training period.

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1 Introduction of the organization

1.1 Company profile

Lanka Electronics (Pvt) Ltd was founded in 1993 as an electronic manufacturing company by a group of graduates of University of Moratuwa. Lanka Electronics (Pvt) Ltd excels in manufacturing both Professional and Consumer electronic products using 100% local technologies.

The company manufactured professional electronic devices for Sri Lankan government as well as multinational companies such as Vario systems. Lanka Electronics (Pvt) Ltd is the leading innovation company in Sri Lanka.

1.2 History of the company

Lanka Electronics (Pvt) Ltd was founded in 1993 -July by a group of graduates of University of Moratuwa with 5 initial shareholders. In 1993 they built their first factory at the Minuwangoda. The first product of the company was Laboratory training panels. In 1996 the company started manufacturing TV antennas and boosters as consumer electronic products and EDM machines as professional electronic product.

Lanka Electronic (Pvt) Ltd has come a very long journey in this 26 year and now has become one of the leading electronic products manufacturing companies in Sri Lanka. Now Lanka Electronics (Pvt) Ltd has two factories located at Minuwangoda and Anuradhapura and research and development division located at Minuwangoda.

Figure 1-1 Company Logo

1.3 Products of the company

Lanka Electronics (Pvt) Ltd is manufacturing both professional electronic and consumer electronic products. Professional electronic products are only manufactured when there is an order. Consumer electronic products are manufacturing in daily production lines.

1.3.1 Professional Electronic Products

All the following professional electronic products are developed in Lanka Electronic research and development division.

1.3.1.1 Laboratory Training Panels

In 1993 Lanka Electronic started manufacturing laboratory training panels. Laboratory training panels were the first products of the Lanka Electronics. However they discontinued manufacturing laboratory training panels in 2010.

1.3.1.2 Die-Sink EDM Machine

In 1996 They started manufacturing Die-Sink EDM machines. They build EMD machines using 100% locally developed technologies and local resources. This was the first EDM machine built in Sri Lanka.

1.3.1.3 Motor Traffic Control Lights

In 1997 Lanka Electronic started manufacturing traffic lights for Sri Lankan government. It was the first traffic light built in Sri Lanka using local technologies and local resources. Lanka Electronic able to manufactured traffic lights 10 times cheaper than imported price.

1.3.1.4 Electric Motor Bike

In 2010 Lanka Electronic started manufacturing electric Motor bikes. It was the first electric bike made in Sri Lanka. Once fully charged this electric bike able to travel up to 50 km.

1.3.1.5 Wire Winding Machine

In 2009 Lanka Electronic start manufacturing wire winding machine. Wire winding machine is used to make cable harness. This machine was manufactured for special request made by Vario systems.

Figure 1-2 Wire Harness

1.3.1.6 DOF Robot Arm

This is the latest professional electronic product of Lanka electronic (Pvt) Ltd. This robot arm can be customized for various SME applications. This is the first SME Robot made in Sri Lanka.

Figure 1-3 6 DOF Robots

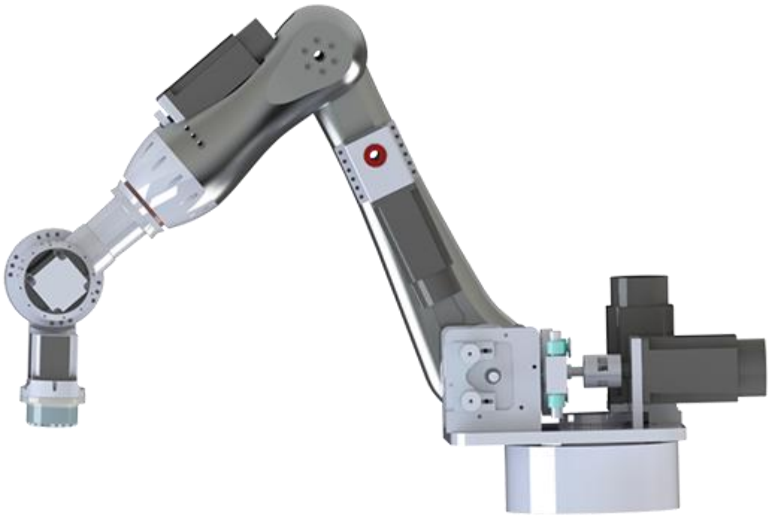


Figure 1-4 6 DOF Robots

1.3.2 Consumer Electronic Products

Lanka Electronic is manufacturing different types of consumer electronic products. TV Antennas and boosters are the main consumer products of the company.

Figure 1-5 TV Antenna Batapola

Figure 1-6 LE Antennas

1.4 Organization Structure

Lanka Electronics (Pvt) Ltd currently having two factories and one research and development division. The main office and the stores of Lanka Electronic situated in No.7A, Vijaya Mawatha, Medemulla, Minuwangoda. Currently there are more than 60 employees working for Lanka Electronics and 11 shareholders. Lanka Electronics has 3 board of directors.

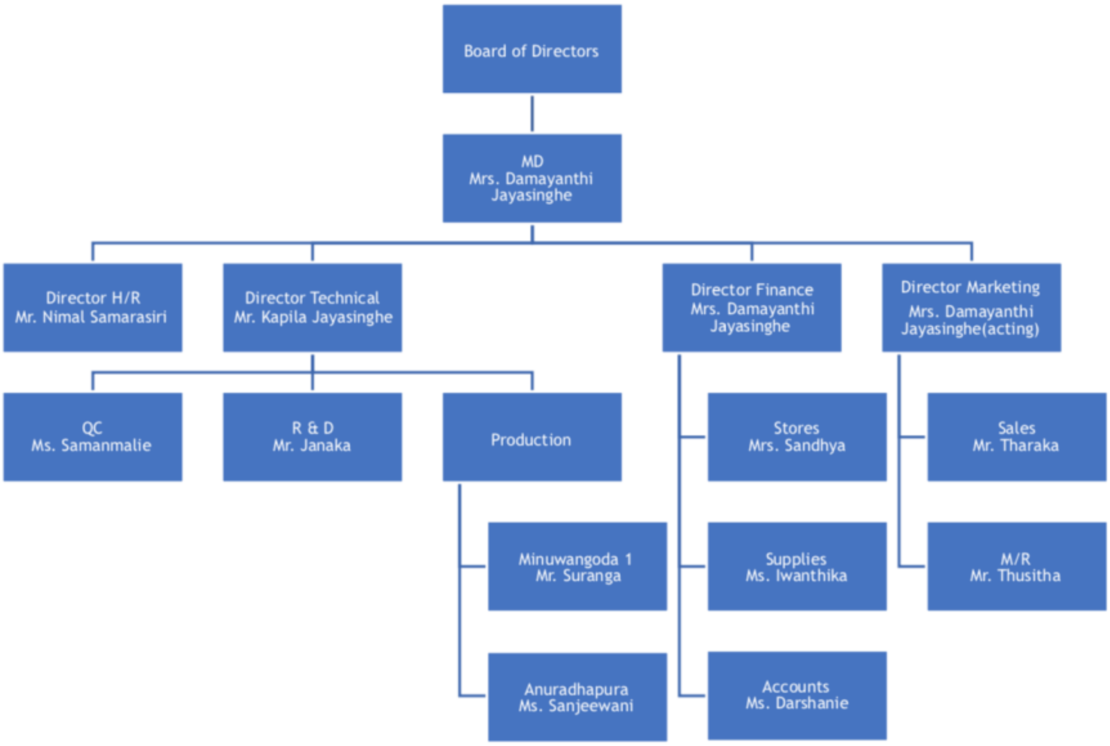


Figure 1-7 Organizational Structure

1.5 Performance Analysis of Lanka Electronic (Pvt) Ltd

1.5.1 Overall Performance and Profitability

Lanka Electronics (Pvt) Ltd earn their income by both Professional electronic and consumer electronic products. However professional electronic products are manufactured according to the customer orders. Therefore, main income generated by consumer electronics products. Their factories produce 2000-3000 antennas and boosters per month. By manufacturing consumer electronic products Lanka Electronics generates 3 - 4 million monthly revenue.

Lanka Electronics has their own distribution service which distribute electronic products all over the country. Main raw material store of Lanka Electronics main stores situated at Minuwangoda. Once a week raw material is shifted to Anuradhapura factory and finished products are taken from there to Minuwangoda factory for quality check. Also, they use Kanban store management system for their stores management. That is considering the last 3-month sales they predict their next 3-month sales. Then place monthly and weekly raw material orders to produce predicted number of products. By using monthly and weekly base raw material ordering method they reduce raw martial storing cost.

1.5.2 Usefulness to the Country

Lanka Electronic (Pvt) Ltd developed their product using 100% local technologies. Also, they manufactured their products using local resources. Therefore, these products reduce the foreign currency outflow of the country. Further professional electronic products are used by multinational companies. That will increase the foreign currency income of the country.

Lanka Electronics (Pvt) Ltd generates more than 60 job opportunities to local employees. Further by developing advanced high quality professional electronic products, Lanka Electronic shows the capabilities and technology developments of Sri Lanka to the whole world.

1.5.3 SWOT Analysis

- **Strength**

  - 26 years Of Experience in the Industry.
  - Experience and educated executive team
  - Talented and educated design team.
  - 100% technology owner ship.
  - product manufacturing using local resources.
  - well established consumer products

- **Opportunities**

  - Products for local markets.
  - 100% locally developed technologies

- **Weaknesses**

  - The less awareness about the company among the local community

- **Threats**

  - cheap products developed by Chinese market.
  - Lack of material availability in Sri Lanka.
  - raw material price and component price are change with dollar price

2 Training Experience

2.1 Introduction

I started the internship on 24th June 2019. After giving, the introduction to the company, the technical director asked us about our preferred areas. Since there were a couple of projects, he had to divide them among us. At that time the company had built two 6 DOF industrial robot arms. Since the company had come up with hardware and software upgrades, the 3rd robot LE Robot Ver. 3) was in the process of production by then. And also,4th revision of the LE robot had designed. All of LE robots can be customized for various, Small and Medium-sized enterprises applications.

The main ambition of the company is to make industrial Robot Arms under the motto "made in Sri Lanka". So they try to make their own parts as possible. The main other reason is the high cost of those parts. And they trust that every part can be made here at a lower cost.

When somebody has to design something, he has to design it using available parts. After making Ver. 2 of the LE robot, they have figured out that the available motors are too large in both size and weight for the 5th and 6th joints of their Industrial Robot ARM. Because of this reason, the required torques from below joints are not in the safety region. High precision is the main property of LE industrial robots. So the Joints should have "Harmonic Drive Gear Boxes". Since the above overweight issues of the motors, the required load cannot be handled safely. Two of Harmonic Drive Gears were damaged while operation giving a huge loss to the Company. To overcome the above Scenarios, the company gave me and my partner following tasks to complete that are briefly described in section 2.2.

2.2 Projects Handled in brief

This section contains simple explanations of the main projects that I carried On in the training Period. The later sections have detailed descriptions about them, sub-projects and data gained about some topics Not enough space in this report to present them all.

2.2.1 Design a Three Phase AC Servo Motor According to Given Parameters

Due to these reasons, the company wanted a small motor that can deliver higher torque. These motors are industrial Servo Motors. By then, they have put some stepper motors for the 5th and 6th joints instead of servo motors. The reason is that they could not find any motor that suits their application. And the cost is too much for that kind of motors. Designing an industrial servo motor that delivers a higher torque with a given physical size was essential.

2.2.2 Optimize the Servo Motor Driver or Design a new Three Phase AC Servo Motor Driver

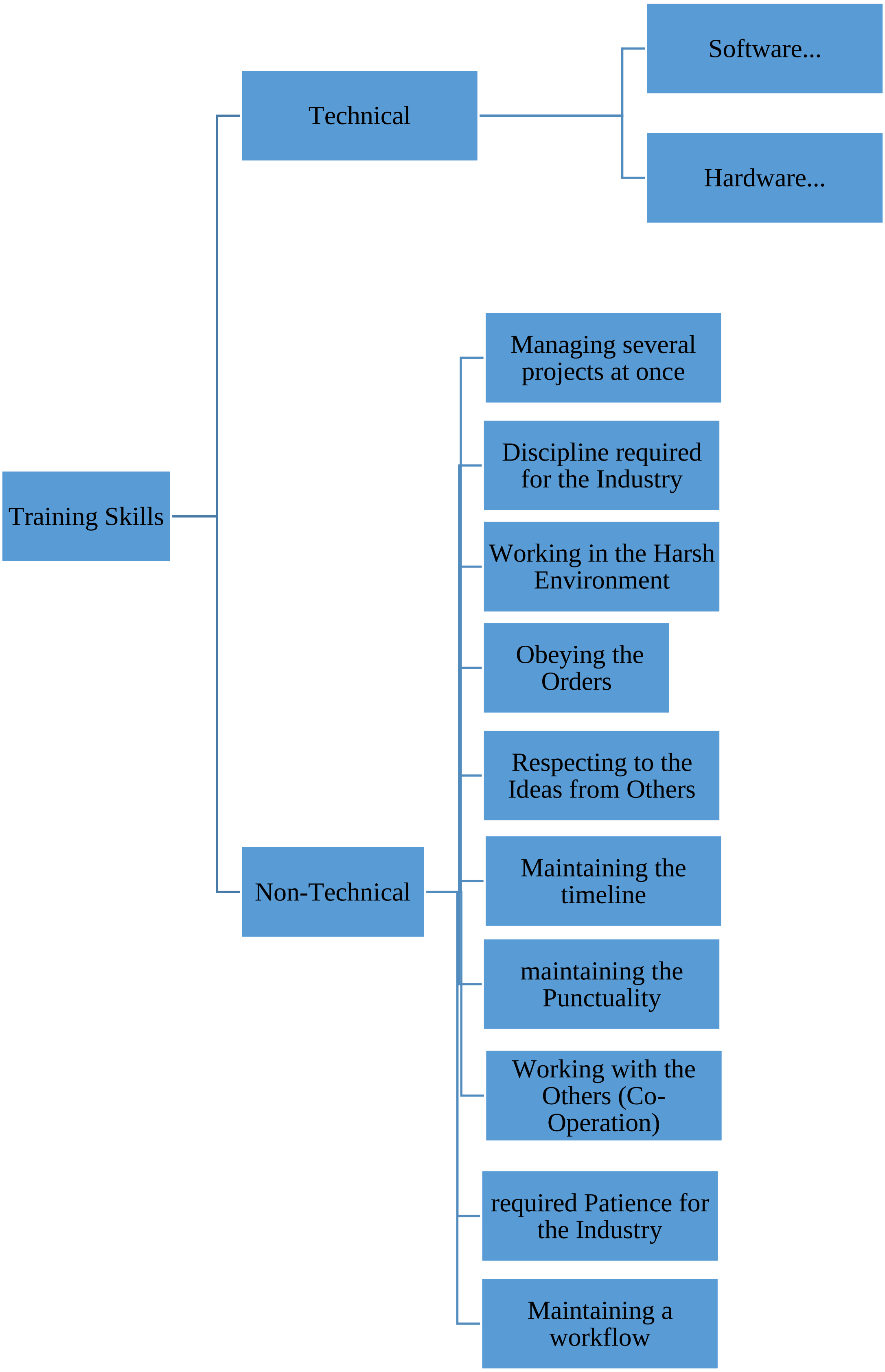
And, a commercial Servo Driver costs around Rs100 000. For Ver2 and Ver. 3 robots, they have used a reliable commercial Servo Driver called "XINJE". The company has tried over about 5 years to make such a 3 phase AC Servo Motor Driver. At the time my internship begins, they were making such a Driver. The driving algorithm (FOC 3) was implemented in a DE NANO FPGA. The driver Stage was designed based on IRF250 MOSFETS. That driver had some faults. The technical director told me that MOSFET drivers and MOSFETS were damaged while driving the motor. And also the size of this driver was too much. So optimizing this driver was essential. Or I had to design a better servo motor driver with a better power Stage.

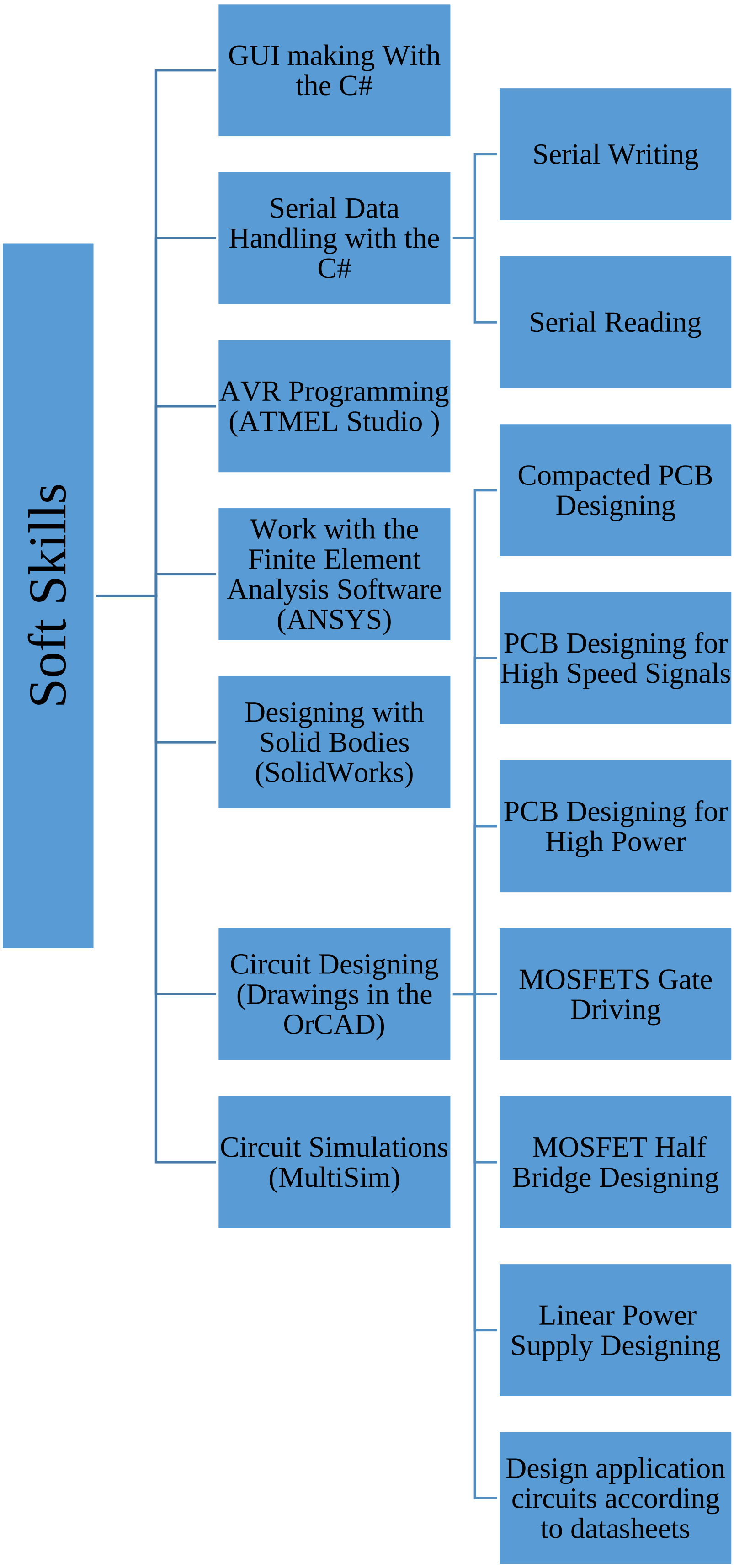
2.2.3 Make a new Finite Element Analysis Software to Simulate a given Three phase AC Servo Motor

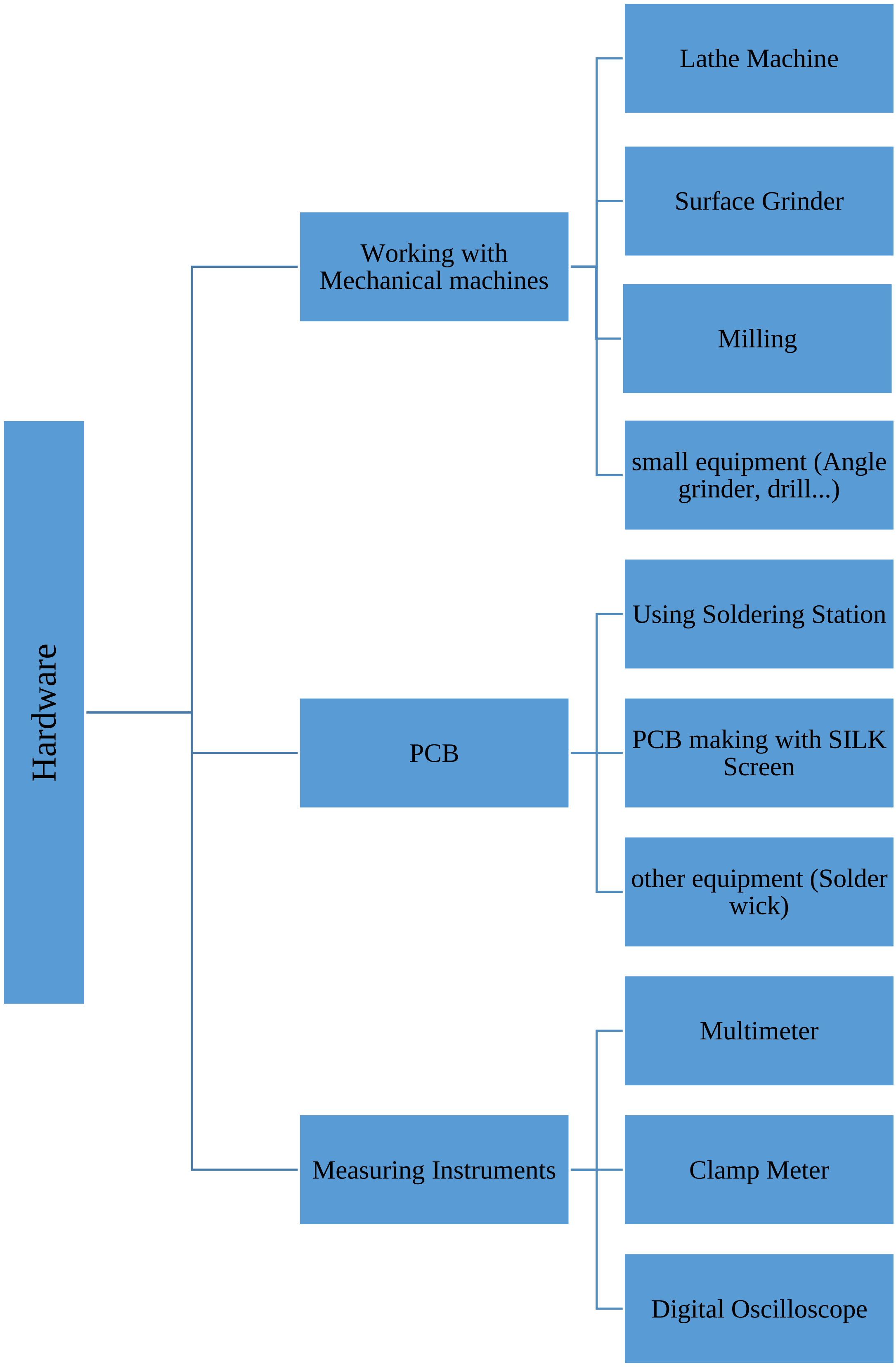
Another thing is, before designing a servo motor we need a Finite Element Analysis software (FEA). If the company is making motors for selling or for commercial purposes, that FEA software should be open-source or FEA software should be written by the company. So, making an FEA software was another task for us.

2.3 Gained Experience Within the Training Period

Most importantly, my partner and I didn't have enough experience in Finite Element Analysis, Programming with C#, Electromagnetics related to Moving Objects like 3 Phase AC synchronous machines, designing precise Half Bridge circuits related to Power Electronics, Programming Atmel Microprocessors, Circuit designing related to High-Speed Signals, at the beginning. So my partner and I had to study in deep about the required areas to complete our tasks.


Training Skills
Technical
Software...
Hardware...
Non-Technical
Managing several projects at once
Discipline required for the Industry
Working in the Harsh Environment
Obeying the Orders
Respecting to the Ideas from Others
Maintaining the timeline
maintaining the Punctuality
Working with the Others (Co-Operation)
required Patience for the Industry
Maintaining a workflow


Soft Skills
GUI making With the C#
Serial Data Handling with the C#
Serial Writing
Serial Reading
AVR Programming (ATMEL Studio)
Work with the Finite Element Analysis Software (ANSYS)
Designing with Solid Bodies (SolidWorks)
Circuit Designing (Drawings in the OrCAD)
Compacted PCB Designing
PCB Designing for High Speed Signals
PCB Designing for High Power
MOSFETS Gate Driving
MOSFET Half Bridge Designing
Linear Power Supply Designing
Design application circuits according to datasheets
Circuit Simulations (MultiSim)


Hardware
Working with Mechanical machines
Lathe Machine
Surface Grinder
Milling
small equipment (Angle grinder, drill...)
PCB
Using Soldering Station
PCB making with SILK Screen
other equipment (Solder wick)
Measuring Instruments
Multimeter
Clamp Meter
Digital Oscilloscope

2.4 Phase of Training

The flow of the Industrial training I gained is presented in this 2.4 session.

2.4.1 Introductory Sessions

The Company gave us a welcome on the starting, as usual in any company. After describing the current situation of the robots and other designs, the technical director and the supervisor divided us into mini groups which contains two or three trainees. Then they hand over the projects to us and explained each project to relevant groups. In that explanation, targets and current problems were included. Since we had a couple of targets, we didn't know where to start at the beginning. So, The supervisor and the technical director guided us towards the goals.

2.4.2 Choosing the First Project

The company gave high priority to the Servo Motor. It was a project that had the lowest improvement. For the first stage, we had to understand 3 phase ac servo motor working principles. For the next stage, my partner and I needed to make a servo motor. Before that, we had to Study about Servo motors and motors related to servo motors and had to find better Finite Element Analysis Software to simulate motor designs.

2.4.3 Learning about the background of the Projects

Some of the knowledge gained related to motor making project is given below.

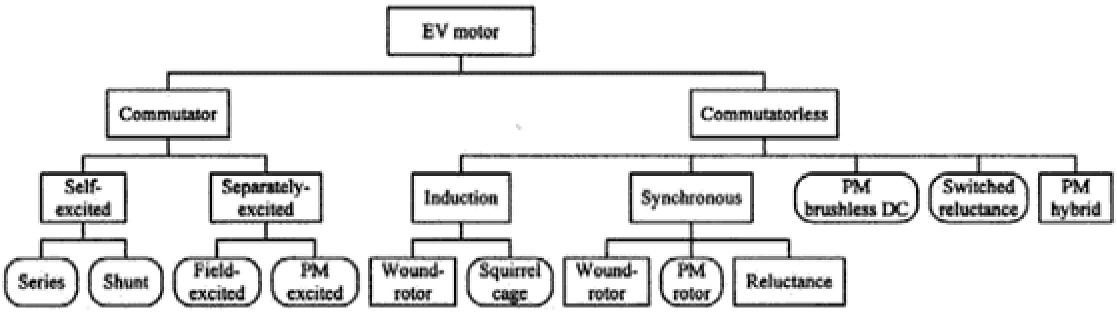
2.4.3.1 About Making the Motor.

Some important information about Motor classifications, important information about magnets, lamination steels, magnetic saturation, Servo motors, FOC algorithm… are included here.

2.4.3.1.1 Studies about the Motors

2.4.3.1.1.1 motor classification

There we were going to make 3 phase AC Servo motor. So to get a deep understanding of servo motors, I had to study other motors, to understand the differences, pros, and cons when compared to the servo motors. Because every time I solve a problem, Usually I search for any other kind of solution for that same problem. Even though it takes a certain time, the Supervisor didn't try to block me. And the technical Director wanted that kind of thinking from me.



According to this chart, we can divide Electrical motors into two main parts as commutator less motor and motors that have a commutator. Then That commutator-less motors are divided into several subsets, but we focus only on Synchronous motors. There are 3 main parts of the synchronous motors according to this diagram. In that, the "PM rotor" motor is the one we have to look for.

2.4.3.1.1.2 Selecting the correct motor for the application

Before studying servo motors, I had to build a clear image of it. And I needed to know the reasons for choosing such a servo motor.

Industrial servo motors are some kind of PMSM (Permanent magnet synchronous motors). Like every other motor, PMSM has a rotor and a stator. Here the rotor is a permanent magnet. The stator has 3 coil sets related to 3 phases. By giving perfect sinusoidal Waves which have

120 degrees phase difference to each other to these coil sets, someone can drive these motors smoothly. The driving principle of PMSMs is called FOC (Field Oriented Control).

Asynchronous motors may not rotate according to the rotating magnetic field generated by the outer stator. So, the rotor may be slipped while the operation or angular velocity of the rotor and angular velocity of the rotating magnetic field may be different from each other. And a magnetic rotor will deliver higher torque than an inductive rotor. Since the application needs continuous motion, we cannot assign a reluctance motor for the job.

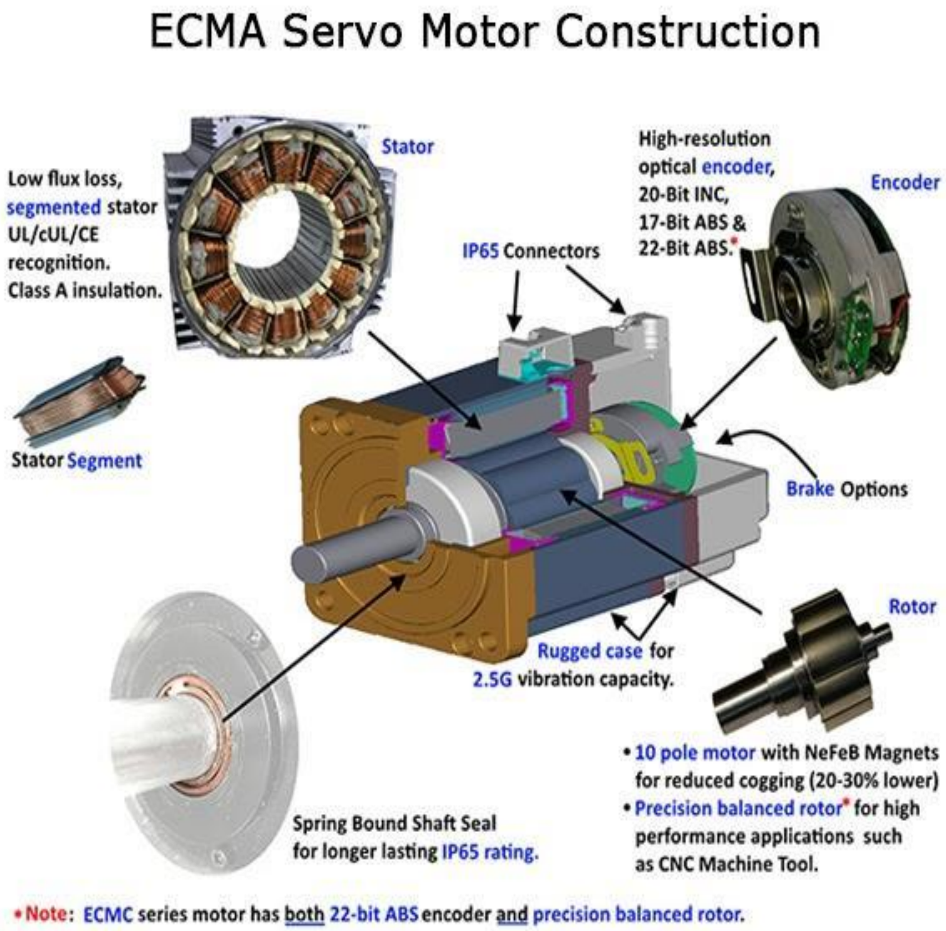
2.4.3.1.2 Servo Motors

- **What is a servo motor?**

A servo motor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity, and acceleration.

A servo motor has a precise Encoder and a clutch for braking. So, because of this integrated higher resolution encoder controller can drive the motor precisely.

Since the servo motors give higher torque, higher speeds, higher precision they are used for high reliability and high precision applications. Though there are a lot of servo motor manufacturers around the world, the most experienced company is the “YASKAWA”. So we wanted to follow them. Some of the below information is related to the “YASKAWA” motors.

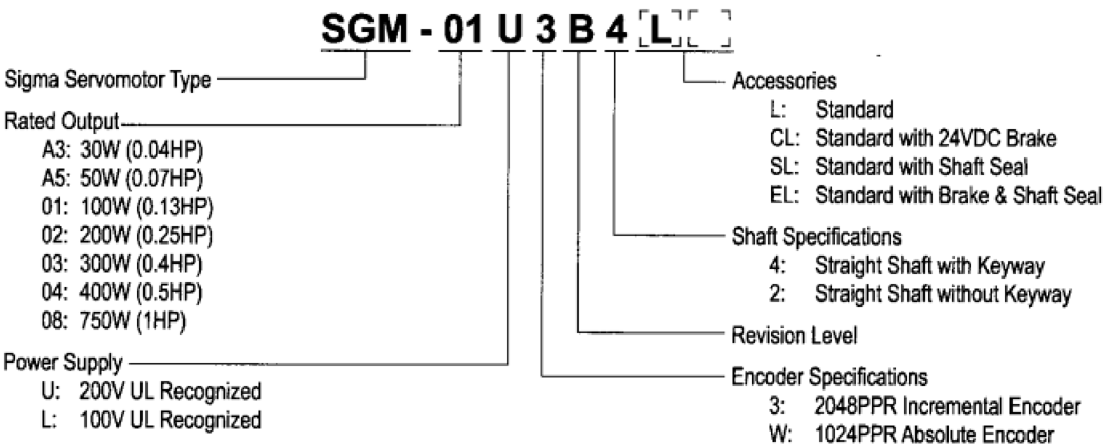


- **Precision of a Servo Motor**

Servo motors are operated with the 3phase power. So it can be controlled with higher resolution by applying some modulation techniques to the 3 phase power. That's what FOC is doing. Below application is made with using high precise servo motors.

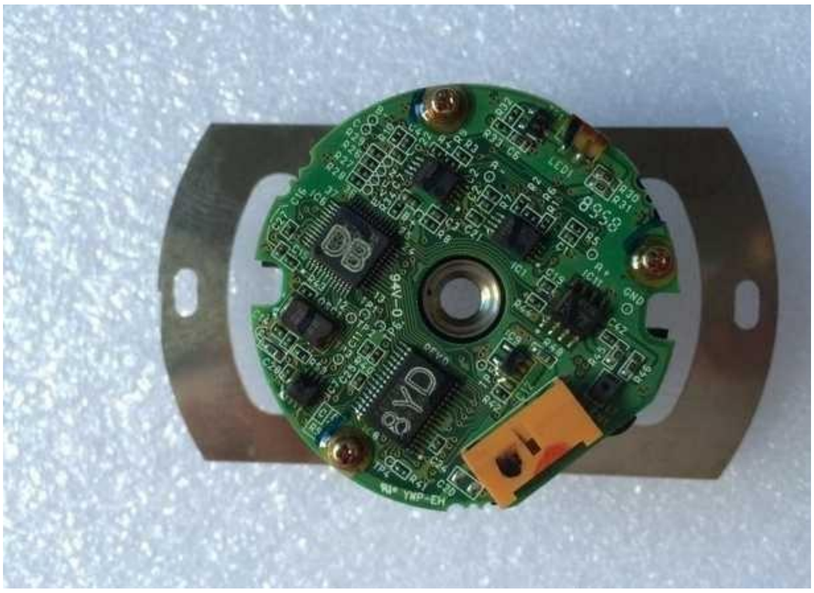
- **Codes**

Since there are a lot of servo motors out there, they have provided a code to identify the motor. According to that information, someone can understand about wattage, Voltage, PPR of the Encoder, etc.



- **Feedback**

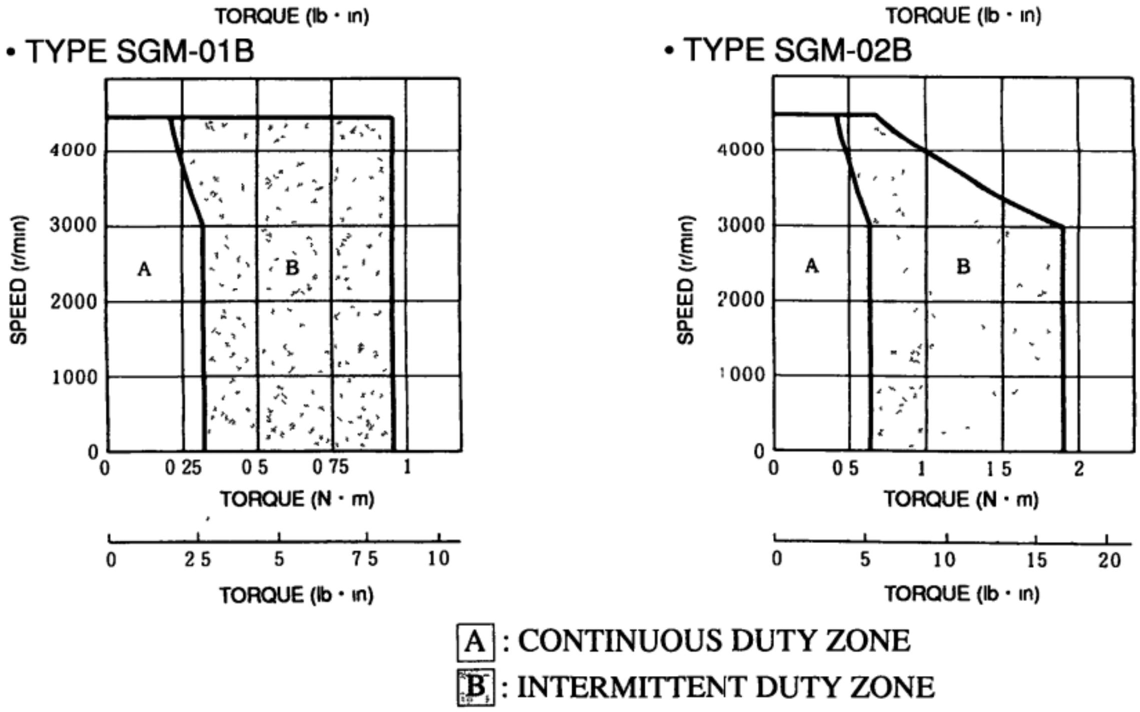
Another special thing about the servo motor is the high precision feedback mechanism. A servo motor should have such a mechanism for higher resolution operation. YASKAWA is mostly using Optical Encoder System. So that the feedback part is located at the end of the motor. There is a sticker on that enclosure indicating there is the sensitive part under that enclosure and not to give vibrations to that part.



Since servo motors have brush-less, synchronous, permanent magnet properties, it is the best selection for the application.

- **Safe operating region of a servo motor**

Every motor has a safe operating region. There are torque limit and a speed limit for a certain limit. The manufacturer must give those characteristics.



- If the operating point is in the Continuous Duty Zone, the motor can give relevant operating conditions continuously without any doubt.

- A lot of motors have given their rated operating speed in the sticker mounted on the enclosure.

- When the operating point is in the Intermittent Zone, Motor can only give operating conditions for a limited time.

- If that time is exceeded, the motor will be over-heated. At that time, the controller needs to disable the operation of the motor.

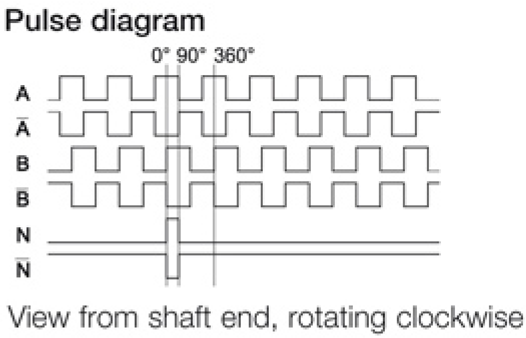
- Short Bursts is not a problem with the motors. (maximum time about 3 seconds)

- The maximum amount of torque that the motor can produce at the rated speed is called "Rated Torque"

- Below the rated speed, burst torque is available. (about 3 seconds)

So, the designer has to operate within the Continuous Duty Zone.

2.4.3.1.3 Studies about the Encoders



2.4.3.1.4 Studies about Field Oriented Control

The Field Oriented Control (FOC), alternatively named Vector Control (VC), is a method for the most energy-efficient, very accurate and reliable way of driving 2 phases (stepper motors) and 3 phases (servo motors) motors. In this FOC, there are two orthogonal components that can control the flux of the motor and the torque of the motor.

“The Field Oriented Control was independently developed by K. Hasse, TU Darmstadt, 1968, and by Felix Blaschke, TU Braunschweig, 1973. The FOC is a current regulation scheme for electro motors that takes the orientation of the magnetic field and the position of the rotor of the motor into account, regulating the strength in such a way that the motor gives that amount of torque that is requested as target torque. The FOC maximizes active power and minimizes idle power - that finally results in power dissipation - by intelligent closed-loop control illustrated by the figure given below.

Two force components act on the rotor of an electric motor. One component is just pulling in the radial direction (ID) where the other component is applying torque by pulling tangentially (IQ). The ideal FOC performs a closed-loop current control that results in a pure torque generating current IQ – without direct current ID".

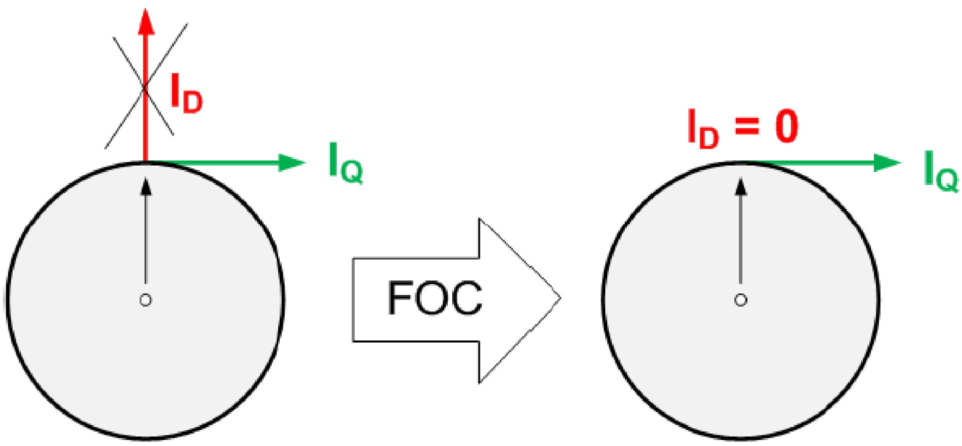
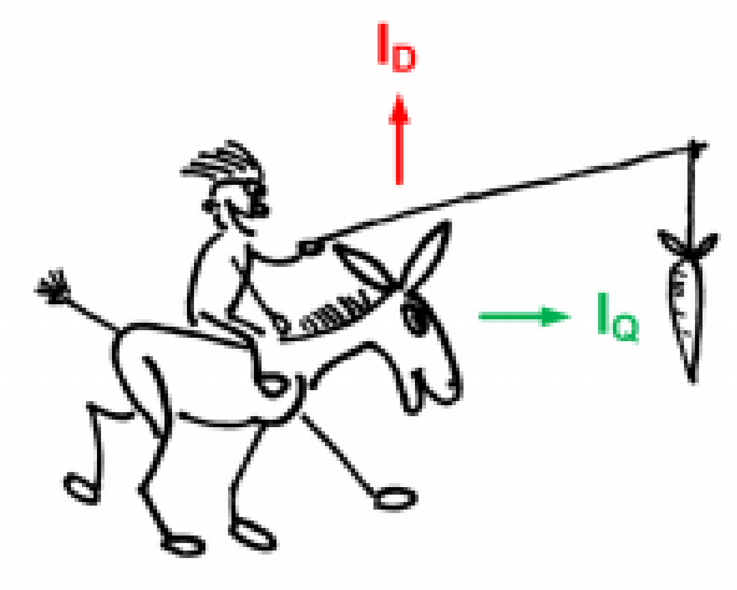


Figure 2: FOC optimizes torque by closed-loop control while maximizing IQ and minimizing ID to 0 From top point of view, the FOC for 3-phase motors uses three-phase currents of the stator interpreted as a current vector (Iu; Iv; Iw) and calculates three voltages interpreted as a voltage vector (Uu; Uv; Uw) taking the orientation of the rotor into account in a way that only a torque generating current IQ results. From top point of view, the FOC for 2-phase motors uses two-phase currents of the stator interpreted as a current vector (Ix; Iy) and calculates two voltages interpreted as a voltage vector (Ux; Uy) taking the orientation of the rotor into account in a way that only a torque generating current IQ results. To do so, the knowledge of some static parameters (number of pole pairs of the motor, number of pulses per revolution of an used encoder, orientation of encoder relative to magnetic axis of the rotor, count direction of

the encoder) is required together with some dynamic parameters (phase currents, orientation of the rotor). The adjustment of P parameter P and I parameters of two PI controllers for closed-loop control of the phase currents depends on electrical parameters of the motor (resistance, inductance, back EMF constant of the motor that is also the torque constant of the motor, supply voltage).



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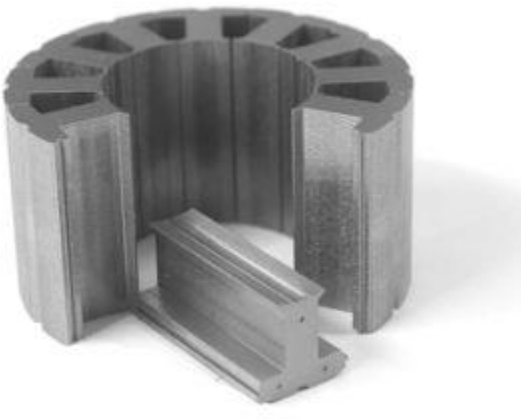
2.4.3.1.5 Studies about Target Servo Motor Types

2.4.3.1.5.1 Bridged type Motor

A bridge type motor has a core like above figure. Since Unnecessary flowing of the flux gave us lower torque in this type. Motor Ver.1, Ver.2,Ver.3 are bridged type motors.

2.4.3.1.5.2 Segmented type Motor



The above figure is showing a segmented core of a servo motor.The Stator can emit flow of flux to the rotor with a higher density.It gave us higher torques.

2.4.3.1.6 Studies about Sizing Factors and key Sizing Factors of a motor

After getting some ideas about motors and driving algorithm, we needed to find the facts that affecting the motor size and motor performance to make motors.

- **Sizing Factor of a Motor**
    - Motion Profile
    - Inertia
    - Operating Speed
    - Acceleration
    - Torque
    - Regeneration Capacity
    - Cost

- Resolution requirements
- Environment
- Power requirements
- Physical size limitation

Since we cannot look at all the facts at once, the following key Sizing factors should be considered.

- **Key Sizing Factors of Motors**

  - Inertia ratio
  - Operating Speed
  - Maximum torque at the Speed
  - RMS torque at the Speed

So to get the required Output, at least we had to consider the above facts.

2.4.3.1.7 Studies about Regeneration and reducing the regenerative back-EMF

When the motor power supply got cut down, the motor has previously gained inertia. So it will continue the motion. In this activity the motor acts as a generator. So back-EMF will be generated among the terminals of the motor. This back Power will go into controlling and driving circuitries, if not there is the proper handler for the back-EMF resulting destruction in the power stage, and controlling parts of the circuit.

So it should be eliminated or be reduced by proper mechanisms. More to the point the controlling circuit should be able to sense the passive action of the motor and should open some terminal to take out that back-power.

Dissipation of that power is a good option for this problem. So there is a power resisters called regenerative resisters to do the such a job.

2.4.3.1.8 Magnets and magnet codes

To make simulations correctly, I had to study about magnets. We were focused on neodymium magnets (also known as **NdFeB** , **NIB** or **Neo** magnet). The neodymium magnets are suitable strongest magnets that were commercially available. It is an alloy of neodymium, iron, and boron. And by changing the rates of the mixture, manufacturers make different strengths. So there are codes to identify the various neodymium magnets. Some of those details are given below.

Magnetic Characteristics

Material Type	Residual Flux Density (Br)	Coercive Force (Hc)	Intrinsic Coercive Force (Hci)	Max.Energy Product (BH)max
N35	11.7-12.1 KGs	>11.0 KOe	>12 KOe	33-35 MGOe
N38	12.2-12.6 KGs	>11.0 KOe	>12 KOe	36-38 MGOe
N40	12.6-12.9 KGs	>11.0 KOe	>12 KOe	38-40 MGOe
N42	13.0-13.2 KGs	>11.0 KOe	>12 KOe	40-42 MGOe
N45	13.3-13.7 KGs	>11.0 KOe	>12 KOe	43-45 MGOe
N48	13.8-14.2 KGs	>11.0 KOe	>12 KOe	45-48 MGOe
N50	14.1-14.5 KGs	>11.0 KOe	>11 KOe	48-50 MGOe
N52	14.5-14.8 KGs	>11.2 KOe	>11 KOe	49.5-52 MGOe
N35M	11.7-12.1 KGs	>11.4 KOe	>14 KOe	33-35 MGOe
N38M	12.2-12.6 KGs	>11.4 KOe	>14 KOe	36-38 MGOe
N40M	12.6-12.9 KGs	>11.4 KOe	>14 KOe	38-40 MGOe
N42M	13.0-13.3 KGs	>11.4 KOe	>14 KOe	40-42 MGOe
N45M	13.3-13.7 KGs	>11.4 KOe	>14 KOe	42-45 MGOe
N48M	13.6-14.2 KGs	>11.4 KOe	>14 KOe	45-48 MGOe
N50M	14.1-14.5 KGs	>11.4 KOe	>14 KOe	48-50 MGOe
N52M	14.3-14.8 KGs	>12.5 KOe	>13 KOe	49-52 MGOe
N33H	11.4-11.7 KGs	>10.3 KOe	>17 KOe	31-33 MGOe
N35H	11.7-12.1 KGs	>10.8 KOe	>17 KOe	33-35 MGOe
N38H	12.2-12.6 KGs	>11.4 KOe	>17 KOe	36-38 MGOe
N40H	12.6-12.9 KGs	>11.4 KOe	>17 KOe	38-40 MGOe
N42H	13.0-13.3 KGs	>11.4 KOe	>17 KOe	40-42 MGOe
N45H	13.3-13.7 KGs	>11.4 KOe	>17 KOe	42-45 MGOe
N48H	13.6-14.2 KGs	>11.4 KOe	>16 KOe	45-48 MGOe
N35SH	11.7-12.1 KGs	>10.8 KOe	>20 KOe	33-35 MGOe
N38SH	12.2-12.6 KGs	>11.4 KOe	>20 KOe	36-38 MGOe
N40SH	12.6-12.9 KGs	>11.4 KOe	>20 KOe	38-40 MGOe
N42SH	13.0-13.3 KGs	>11.4 KOe	>20 KOe	40-42 MGOe
N45SH	13.3-13.7 KGs	>11.4 KOe	>19 KOe	43-45 MGOe
N30UH	10.8-11.2 KGs	>10.1 KOe	>25 KOe	28-30 MGOe
N33UH	11.4-11.7 KGs	>10.3 KOe	>25 KOe	31-33 MGOe
N35UH	11.7-12.1 KGs	>10.8 KOe	>25 KOe	33-35 MGOe
N38UH	12.2-12.6 KGs	>11.4 KOe	>25 KOe	36-38 MGOe
N40UH	12.6-12.9 KGs	>11.4 KOe	>25 KOe	38-40 MGOe
N30EH	10.8-11.2 KGs	>10.1 KOe	>30 KOe	28-30 MGOe
N33EH	11.4-11.7 KGs	>10.3 KOe	>30 KOe	31-33 MGOe
N35EH	11.7-12.1 KGs	>10.8 KOe	>30 KOe	33-35 MGOe
N38EH	12.2-12.6 KGs	>10.8 KOe	>30 KOe	36-38 MGOe
N30AH	10.8-11.2 KGs	>10.1 KOe	>34 KOe	28-30 MGOe
N33AH	11.4-11.7 KGs	>10.2 KOe	>34 KOe	31-33 MGOe
N35AH	11.7-12.1 KGs	>11.0 KOe	>34 KOe	33-35 MGOe

In the scale of neodymium strengths, they are values up to 52. N52 is the strongest type. In our case, the company had imported a package of N48 magnets that have only two poles for the rotor of the motors .N48 is also a stronger magnet grade, but after some experience with making several motors finally we figured out that the N48 magnets are too strong for our application.

Thermal Characteristics

Neodymium Material Type	Maximum Operating Temp	Curie Temp
N	176°F (80°C)	590°F (310°C)
NM	212°F (100°C)	644°F (340°C)
NH	248°F (120°C)	644°F (340°C)
NSH	302°F (150°C)	644°F (340°C)
NUH	356°F (180°C)	662°F (350°C)
NEH	392°F (200°C)	662°F (350°C)
NAH	428°F (220°C)	662°F (350°C)

The second table describes some letters which are followed by the number indicating maximum operating temperatures.

These codes are very important for ordering new magnets from the suppliers.

In the process of making motors, it was very hard to insert magnetic rotors to the motor, resulting in broken or damaged bearings, deformed iron stators, deformed axels and flux leakages to the environment. So the lifetime of earlier versions of motors was not as long as we expected.

So after that, we decided to order magnets from china which have 4 pole pairs, and the grade around N35.Because the magnet that we got from the dissected YASKAWA servo motor is not as strong as the magnets that were ordered from china.

2.4.3.1.9 Silicon Electrical Steel grades and Guages

Lamination steels also Known as Silicon electrical steels are essential for motor making, transformer making processes. They contain some specific magnetic properties. Like, low core loss and high permeability. Every steel sheet has an insulation coating on both sides. That coat has increased permeability of the overall sheet while maintaining the isolating activity.

So making some insulation sheets with some insulation coating will not give the exact performance like original electrical steel sheets.

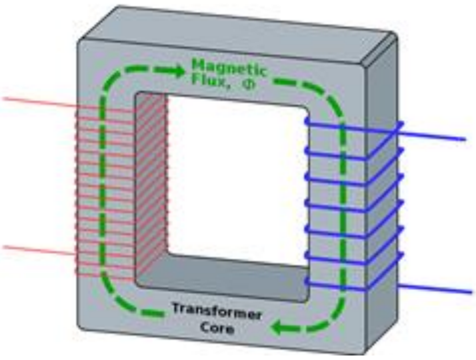
There are two main types of electrical steel.

1. Oriented Electrical Steels.
2. Non-Oriented Electrical Steel\

1. **Oriented Electrical Steels**

Gain-Oriented electrical steels have properties such that their magnetization ability to certain direction may not equal to magnetization ability to another direction. That means they have Some special directions that can have a strong magnetization property.

As an example, a transformer will change its directions of magnetic flux into only finite directions.



2. **Non-Oriented Electrical Steels**

With compared to Oriented Electrical steels, Non-Oriented electrical steels have equal magnetization ability in every direction. So for the rotating applications, like generators, larger Motors, the non-oriented Silicon electrical steels are perfect.

With these facts, I decided to use non-oriented silicon electrical steels for making stator core for final versions of servo motors.

- **Example code for silicon steel grade**

While doing the simulation on the software ANSYS, there were some code names for silicon electrical steels. As an Example below code can be given.

M36_24G

- Here 36 followed by "M" indicates the grade of the silicon steel. Different grades have different properties.
- And the 24 with the " G" indicates the gauge(thickness) of the silicon electrical steel sheet.

Thickness	Grade	Specific Cores Loss W/Kg. At.		Magnetic Induction	Hardness
		1.0 T 50Hz	1.5 T 50 Hz	At 5000 AT/m(T)	(VPN)
0.50mm (0.020)	M-36	1.84	3.57	1.60	160-180
	M-43	1.70	4.01	1.61	160-180
	M-45	2.30	5.31	1.64	130-150
	M-47	4.00	6.98	1.68	130-150
0.65mm (0.026)	M-36	2.16	4.18	1.60	160-180
	M-43	2.52	4.70	1.60	150-170
	M-45	3.03	6.27	1.64	130-150

The above table is indicating about Steel grades while the below table is indicating about steel gauges.

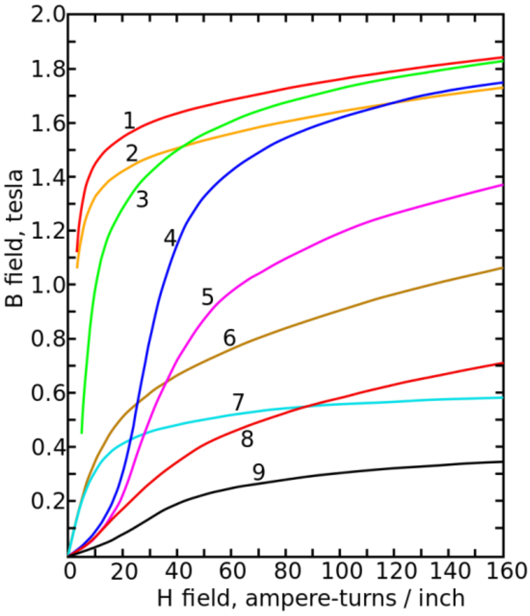
Inch	Mm	Steel gage
0.001	0.025	
0.002	0.050	
0.004	0.10	
0.006	0.15	
0.009	0.23	
0.010	0.25	
0.011	0.27	
0.012	0.30	
0.014	0.35	29
0.019	0.50	26
0.025	0.63	24

2.4.3.1.10 Magnetic Saturation of a magnetic Conductor

The magnetic conductor is a thing that allows passing through external magnetic flux across it. The more the magnetic conductance of a material, the more the flux is going through it. But for every conductor has a conductive limit. That conductor cannot conduct anything larger than that limit. The same theory affects the magnetic conductors. There is an effect called magnetic Saturation which is limiting the conduction of magnetic flux.

Magnetization curves of 9 ferromagnetic materials, showing saturation.

1. Sheet steel,



2. Silicon steel,

3. Cast steel,

4. Tungsten steel,

5. Magnet steel,

6. Cast iron,

7. Nickel,

8. Cobalt,

9. Magnetite

https://en.wikipedia.org/wiki/Saturation_(magnetic)#/media/File:Magnetization_curves.svg

In this case, we can not put the strongest magnets as the magnetic rotor, and we need some materials that have a certain higher saturation level for the stator part. Otherwise, there is no point in increasing phase currents to get higher torques from the motor.

2.4.3.1.11 Copper wire and Guages

2.4.3.2 About Simulators

Before the design stage, simulating should be done as possible. There are not any 100 present perfect simulators in this world. There are a lot of simulators that are designed for simulating electrical circuits, flow simulating, stress analyzing, thermal stimulating, etc. But there is a limited number of electromagnetic simulators. Among them simulators that can do simulations of dynamic electromagnetics are rare.

The company wanted us to find the best open-sourced electromagnetic simulator. If we could not find that, we had to make one. Since we Cannot trust any simulator at once, we had to compare the results of them. So we divided the work. I searched for commercially available simulators. And my partner searched for open-sourced simulators.

With every simulator, we had to learn that, had to refer user manuals of them. The simulators that we found, weren't common. So it was very hard to find correct user manuals, the correct way of using that each software.

The most important thing is if we didn't configure the simulator software correctly, it still gives some acceptable results. With another design, it may give the wrong outputs.

- Commercial Simulator

However, I found that the best commercially available Finite Element Analysis software (simulator) for electromagnetics is ANSYS Electromagnetics Suite. I chose that according to user reviews of software and referring feedbacks from several communities. With time, I was able to model a PMSM which has a custom housing. It took considerable time for learning the software. At that time my partner found some open-sourced software.

- Open-sourced simulators

Since ANSYS has strong Base and good feedback, we compared results gathered from open-sourced software with ANSYS. Open-sourced software didn't show good progress.

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- Comparison of Softwares

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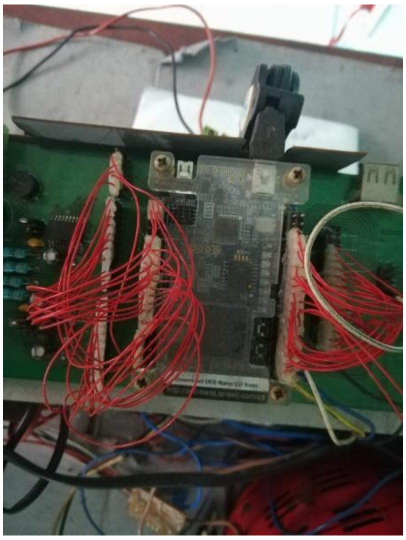
So at this point, we got separated. The supervisor told my partner to make better FEA software and me to take the hardware parts of the project.

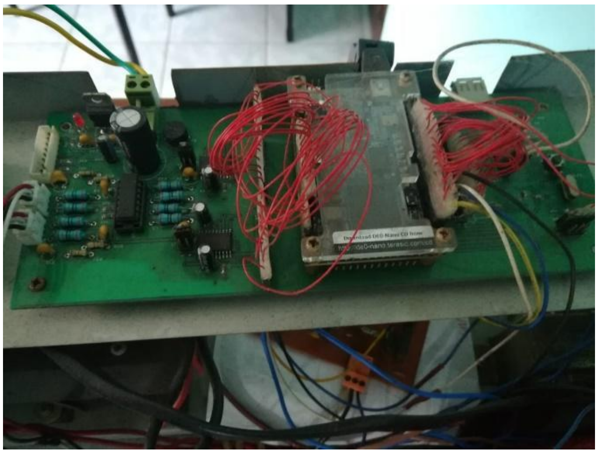
However, we cannot trust any FEA software. So I had to make some motors, and verify simulation results by measuring the torque of them. while making the motors, my partner had to simulate them in the software. Then I taught what I got from the ANSYS to my partner.

2.4.3.3 About Motor Driver

2.4.3.3.1 Old Driver

There was a motor driver that was developed by the company. To operate a servo motor perfectly the servo controller, needs to execute 3 independent control loops. So at least it needs 3 microcontrollers if we implementing the controller algorithm on Microcontrollers. So that’s why the previous designer had implemented the driving algorithm in a DE-NANO FPGA. After implementing perfectly, they have planned to make a motor driver board with including the FPGA chip to the board.





- **Studying about the current state of the Servo controller that developed by the company**

Above three picture shows the exact servo controller that was developed by the company. There are two separate PCBs. One for Power stage and other for interfacing to the FPGA.

We can see a lot of wires coming out from the FPGA to the interfacing board. There were about 4 Power supplies including a huge VARIAC (RED color in the picture).

Altogether it was very bulky. Current sensors were not perfect sensors. So there were huge noises in the sensor signal lines. The next task was to optimize the motor controller after selecting the Best FEA software.

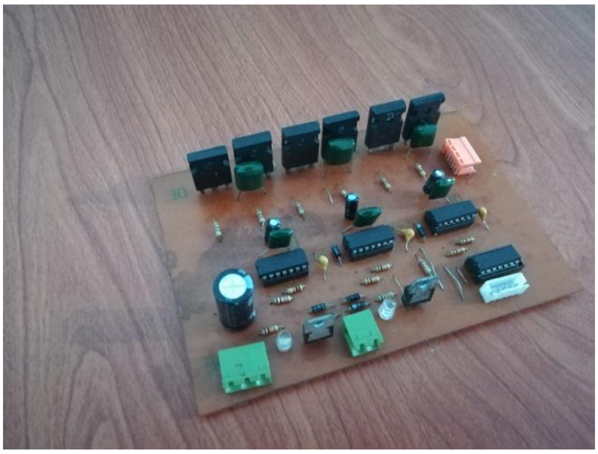
The problems encountered with the current servo driver is given below.

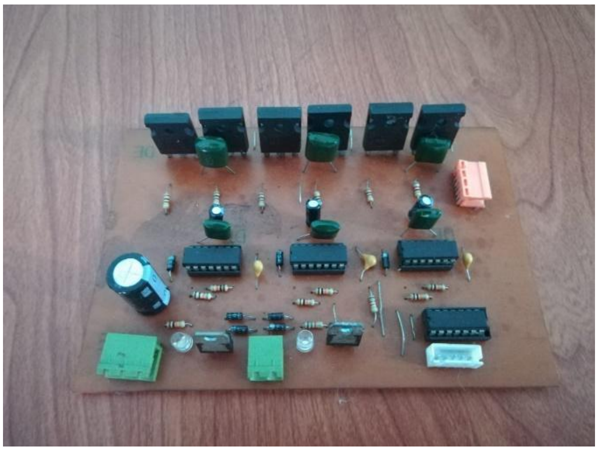
- **Current problems**

According to the technical director, Previous designer and according to experience that we got current motor driver had the following problems.

- Sometimes, MOSFET half-bridge driver ICS were damaged.
- Sometimes MOSFETs (IRFP 250 N) of the driver board was damaged.
- The driver board cannot operate under higher voltages.
- The size of the driver board is too large.
- The driver cannot deliver higher currents.
- The controller and the driver board need power supplies more than one.
- The driver didn't have any regenerative braking hardware.
- It is inconvenient to compress the overall servo driver with the DE NANO FPGA.
- Servo controller which I implemented on the FPGA didn't have a closed velocity loop or closed position loop.
- Some parts of the control loop in the FPGA had some unwanted noise which is hard to eliminate.
- Need to program, every time after powering up.
- Very hard to program the FPGA with the help of an EEPROM.

So first of all, I had to make a new copy of the current driver board (Power Stage). By then, we had only one driver board. If something happens and the driver board is getting damaged, then we should have a backup driver board. After soldering and putting solder in to high current flowing paths, we had to check that power stage. Below pictures are representing That Power stage.





2.4.3.3.2 New Driver

- **Finding the new chip**

While I searching the datasheet of MOSFET driver is, I was suggested a motion-controller IC called TMC 4671-ES by Digi-key. So I immediately informed this to our technical director. So he looked in deep about this new chip. Surprisingly, he satisfied with the IC. It cost around 12 USD s. But the chip is too small to solder here with the company's capabilities. And also that company which is the manufacturer of TMC 4671-ES called TRINAMIC Motion Control had made a breakout Board for educational and development purposes called TMC 4671 BOB. But it cost around 50 USD s. So the company ordered two of those breakout boards while I carry on other things. The manufacturer has implemented FOC on this chip. It is a chip that can do multiple things, such that 3 phase industrial Servo controlling, Stepper motor controlling, simple Dc motor controlling, BLDC motor controlling,..etc.

Since this chip has multiple functions, it has to be configured correctly, before assigning it to a new job. Otherwise wrong signaling to power stage may give a huge disaster. The company is a German Company. Though our FPGA problem was solved, now we had encountered two new main problems.

One was, A new power stage that is compatible with the motion controller chip has to be designed. Another main problem is documentation, tutorial, user manuals that are rare for that motion controller chip. I couldn't find any tutorial on the internet at that time, Cause it is the newest chip which is needed to work with hardware level.

Another thing is the manufacturer has issued a programmer and an open-sourced software to work with their chips. That programmer is too much in cost and also that software they provided cannot program (cannot configure) the motion controller chip without that programmer. So I had to use another communication interface of the motion controller IC. Somehow I ended up with a working servo Driver at the last.

From here I am presenting the designing process of the servo motor driver.

- **The design process in brief...**

1. Find the correct power supply for the TMC 4671 BOB.
2. Make and test a distributive board for the TMC 4671 BOB.
3. Fix the fault of the distributive board.
4. Try to Communicate with the TMC 4671 chip with the available resources.
5. Make suitable communication hardware, test it and use it to communicate with the chip.
6. After successful communication, try to make PWM signals at the outputs of the motion controller IC.
7. Start the power stage designing, Design current sensing, encoder interfaces
8. Drawing schematics and layouts.
9. Solder the components
10. Check half-bridges of the power stage
11. Make correct PWM signals and break before make times

12. Open-loop operations

13. Make new power supply for the motor

14. Closing the torque /current loop

15. Closing the velocity loop

16. Closing the position loop.

- **Design and implementation of the Driver board**

"*TMCUPS10A70V-Eval*" driver board was available for the TMC4671-BOB_V1.2 module. The requirement of this project is driving a servo motor. 3-half bridges, MOSFET drivers and current sensors were enough for this stage. Since the "*TMCUPS10A70V-Eval*" was designed for stepper motors as well, the board contained 4 half bridges, temperature sensors also were included for protection purposes and the board was expensive, this driver board was not used in this design. Instead, new driver board was designed using schematics of "*TMCUPS10A70V-Eval*". Following blocks were removed from the "*TMCUPS10A70V-Eval*" design. (Refer the module datasheet [1]-*TMCUPS10A70V-Eval*)

Bridge Idle State
Ident EEPROM
Boost convertor for MOSFET driving supply
One half bridge and MOSFET driver
Temperature sensing
3.3V Power Supply
Ext 2.5V Voltage Reference

In the new design of the driver, first consideration was to replace MOSFETs which have better characteristics than the "*TMCUPS10A70V-Eval*" design. BSC030M08M was the MOSFET used in "*TMCUPS10A70V-Eval*" design. New MOSFET for the design was chosen depending on following specifications.

Symbol	Parameter	Condition
$V_{GS(th)}$	Gate threshold Voltage	Should be minimum
C_{iss}	Input Capacitance	Should be minimum at considered voltage
C_{oss}	Output Capacitance	
C_{rss}	Reverse Transfer Capacitance	
$t_{d(on)}$	Turn-on Delay Time	Should be minimum
$t_{d(off)}$	Turn-off Delay Time	
t_r	Rise Time	
t_f	Fall Time	
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	Should be minimum
Q_{gs}	Gate-to-Source Charge	Should be minimum

And also, safe operating area graph has to be checked. MOSFET which has the maximum holding current at specified voltage (12V in this case) is suitable for the design. Table 5 shows the comparison between parameters mentioned in Table 4, in different MOSFETS.

Parameter	BSC030N08NS5	Condition
$V_{GS(th)}$	3.8V	$V_{DS} = V_{GS}, I_D = 95\ \mu A$
C_{iss}	5600 pF	$V_{GS} = 0V, V_{DS} = 40V, f = 1MHz$
C_{oss}	910 pF	$V_{GS} = 0V, V_{DS} = 40V, f = 1MHz$
C_{rss}	56 pF	$V_{GS} = 0V, V_{DS} = 40V, f = 1MHz$
$t_{d(on)}$	20ns	$V_{DD} = 40V, V_{GS} = 10V, I_D = 50A,\ R_{G,ext} = 3\Omega$
$t_{d(off)}$	43ns	$V_{DD} = 40V, V_{GS} = 10V, I_D = 50A,\ R_{G,ext} = 3\Omega$
t_r	12ns	$V_{DD} = 40V, V_{GS} = 10V, I_D = 50A,\ R_{G,ext} = 3\Omega$
t_f	13ns	$V_{DD} = 40V, V_{GS} = 10V, I_D = 50A,\ R_{G,ext} = 3\Omega$
	3.0 $m\Omega$	$V_{GS} = 10V, I_D = 50A$

$R_{DS(on)}$	4.5 $m\Omega$	$V_{GS} = 10V, I_D = 50A$
Q_{gs}	20 nC	$V_{DD} = 40V, I_D = 50A, V_{GS} = 0V\ to\ 10V$
Parameter	**IRFP250**	**Condition**
$V_{GS(th)}$	4.0V	$V_{DS} = V_{GS}, I_D = 250\ \mu A$
C_{iss}	2000 pF	$V_{GS} = 0V, V_{DS} = 25V, f = 1MHz$
C_{oss}	800 pF	$V_{GS} = 0V, V_{DS} = 25V, f = 1MHz$
C_{rss}	300 pF	$V_{GS} = 0V, V_{DS} = 25V, f = 1MHz$
$t_{d(on)}$	30 ns	$V_{Ds} = 0.8x\ Rated\ BV_{DSS}, V_{GS} = 10V, I_D = 30A,\ I_{G(ref)} = 1.5\ mA$
$t_{d(off)}$	100 ns	
t_r	180 ns	
t_f	120 ns	
Q_{gs}	12 nC	
$R_{DS(on)}$	0.085 Ω	$V_{GS} = 10V, I_D = 17A$
Parameter	**NVB082N65S3F**	**Condition**
$V_{GS(th)}$	5.0V	$V_{DS} = V_{GS}, I_D = 4\ mA$
C_{iss}	3410 pF	$V_{GS} = 0V, V_{DS} = 400V, f = 1MHz$
C_{oss}	70 pF	
C_{rss}	10 pF	
$t_{d(on)}$	31 ns	$V_{DD} = 400V, V_{GS} = 10V, I_D = 20A,\ R_G = 4.7\Omega$
$t_{d(off)}$	76 ns	
t_r	29 ns	
t_f	16 ns	
$R_{DS(on)}$	82 $m\Omega$	$V_{GS} = 10V, I_D = 20A$
Q_{gs}	24 nC	$V_{DS} = 400V, I_D = 20A, V_{GS} = 10V$

Parameter	IRF640NS	Condition
$V_{GS(th)}$	4.0 V	$V_{DS} = V_{GS}, I_D = 250\ \mu A$
C_{iss}	1160 pF	$V_{GS} = 0V, V_{DS} = 25V, f = 1.0MHz$

C_{oss}	185 pF	
C_{rss}	53 pF	
$t_{d(on)}$	10 ns	$V_{DD} = 100V, I_D = 11A,\ R_G = 2.5\Omega,\ R_D = 9.0\Omega$
$t_{d(off)}$	23 ns	
t_r	19 ns	
t_f	5.5 ns	
$R_{DS(on)}$	0.15Ω	$V_{GS} = 10V, I_D = 11A$
Q_{gs}	11 nC	$V_{DS} = 160V, I_D = 11A, V_{GS} = 10V$

Where,

V_{DD} : Positive gate drive supply

R_D : Drain resistance

R_G : Gate resistance

f : Frequency

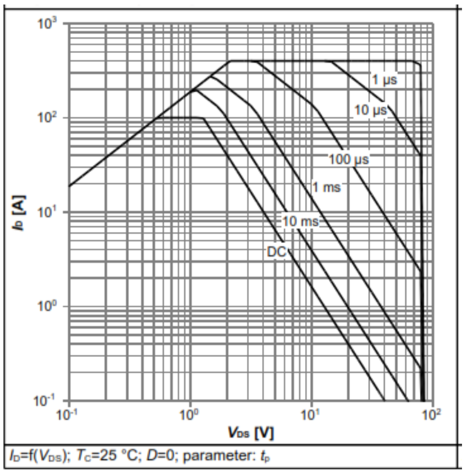
V_{DS} : Drain-to-Source voltage

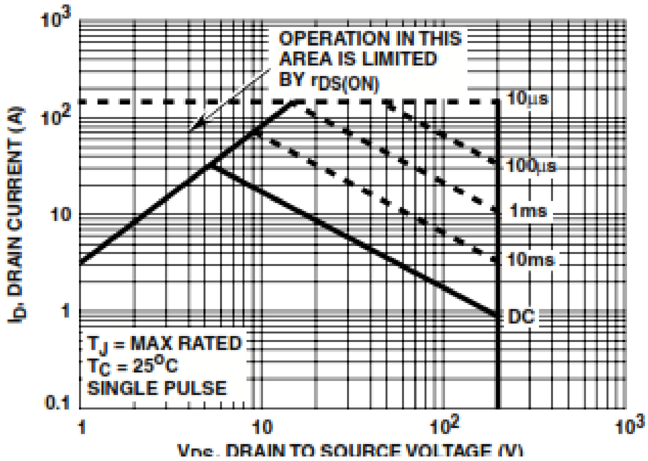
V_{GS} : Gate-to-Source voltage

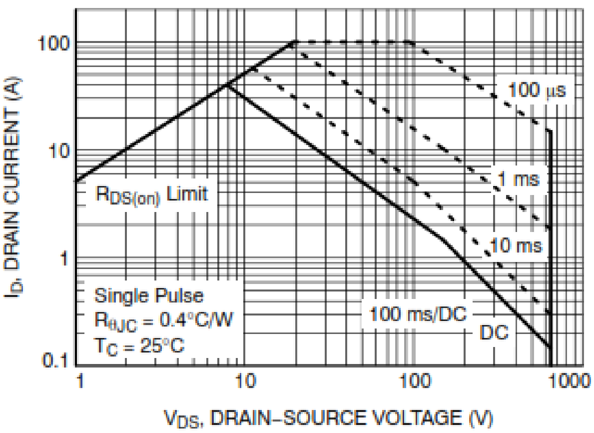
I_D : Continuous drain current

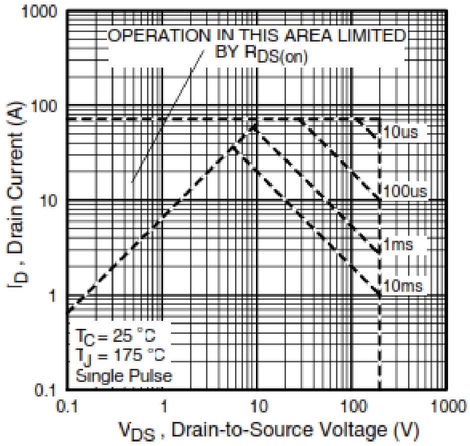
$I_{G(ref)}$: Reference Gate current

$Rated\ BV_{DSS}$: Rated Drain-to-Source Breakdown voltage









2.5 Projects Carried Out

2.5.1 Servo Motor

By then, the company had made a motor (motor Ver. 1). The technical officer had made some equipment for making the motor. They gave me that equipment. The first motors are bridge typed motors. Ver.4, and Ver.5 are segmented typed motors.

In the bridged type, the stator part is a single part look like a flower. Someone can make windings with the help of another tool and insert them into the stator. Then he can insert that stator which has coils on it, to the housing of the motor. So it is easy to make windings with the help of the provided tool.

In the segmented type, the stator is an accumulation of several parts(Segments). There, the designer can make windings on the part itself without the help of a third-party tool.

For the four motors that were made by me, I had to make windings, coat them with Shellac (varnish), smooth stator parts, assemble the motor, wiring and design the parts with solid works.

Stator parts and housing parts were metal parts. So the technical officer made them for me with the help of the CNC Milling machine.

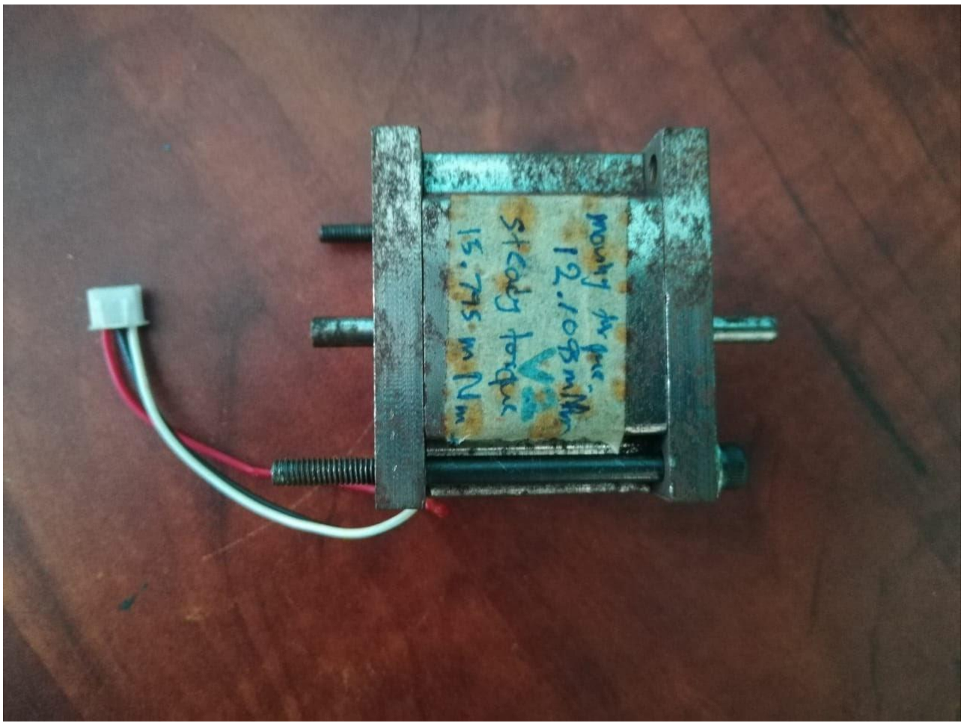
2.5.1.1 Motor v1

The company has made a motor (motor v 1), by following a dissected YASKAWA servo motor. But that motor didn't rotate. The rotor has got stuck. Instead of dissecting the motor the technical director asked me to design the motor Ver. 2. We assumed that bearings of the motor had damaged somehow.

2.5.1.2 Motor v2

The technical director had found servo motors with a plastic core (stator). So the second version of the motor has a plastic core instead of a conductive one. And the housing is made of Iron. There are 100 turns per winding. And the gauge of the copper wire is 33. The rotor is a Neodymium 48,2 poles cylindrical magnet.

- **Final motor**

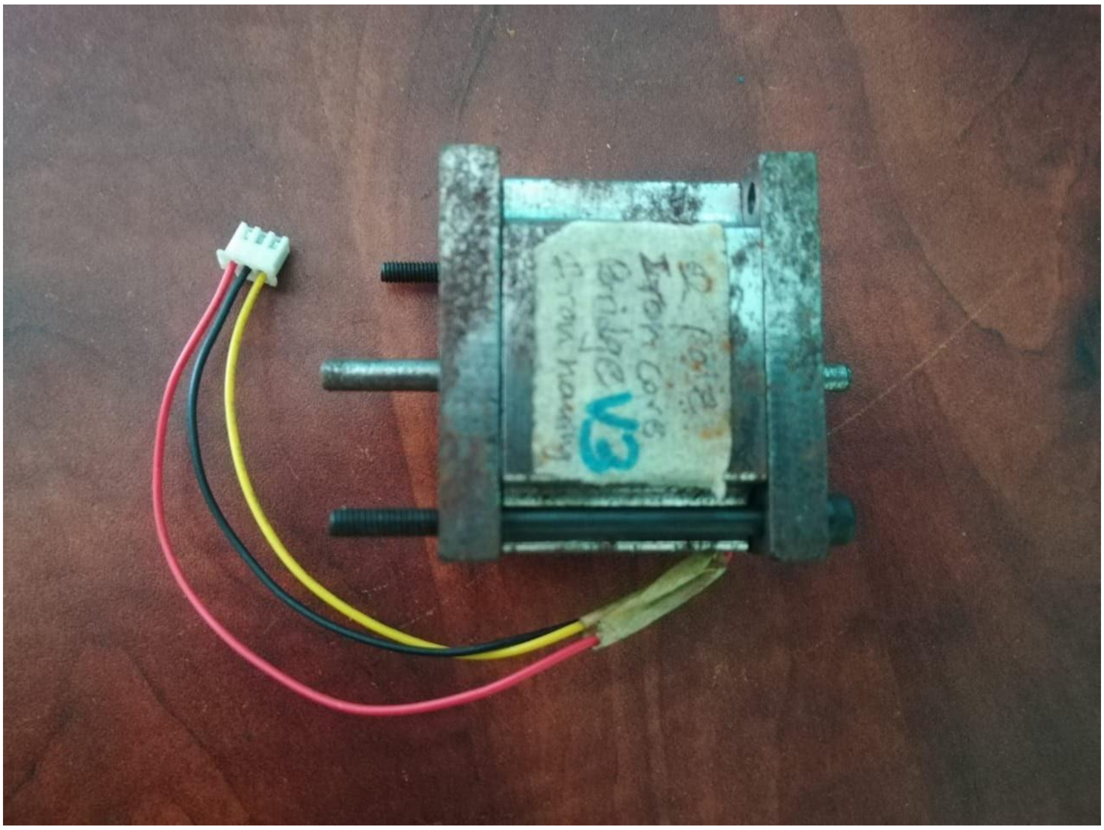


- **Designing process**
- **Simulation results**
- **Actual throughput**

2.5.1.3 Motor v3

The next version has the same dimensions and the same shapes for the stator. But the material of the inner part of the stator is different. The inner part is made of iron. Other parameters are the same with the motor Ver. 2. No of slots is 9 for this motor.

- **Final motor**



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- **Simulation results**
- **Actual throughput**

2.5.1.4 Motor v4

Motor Ver. 4 has a segmented core. The housing is made of Aluminum. The stator has 9 columns which are an Assembly of 5 iron plates. That means each column has 5 layers of iron. Other parameters like no of turns per coil, wire gauge, clearances, the rotor, are the same.

Final Motor

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Simulation results

Actual throughput

2.5.1.5 Motor v5

Since previously designed motors didn't give acceptable results, this time we decided to change the no of poles of the permanent magnetic rotor. But we didn't have any other magnets which have larger no of poles. We had a dissected YASKAWA servo motor. So I designed stator and housing to match with that magnetic rotor taken from the dissected motor.

Since the rotor became smaller than previous rotors, I had to scale down everything except clearance between rotor and stator. Finally, we had the smallest motor so far.

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Simulation results

Actual throughput

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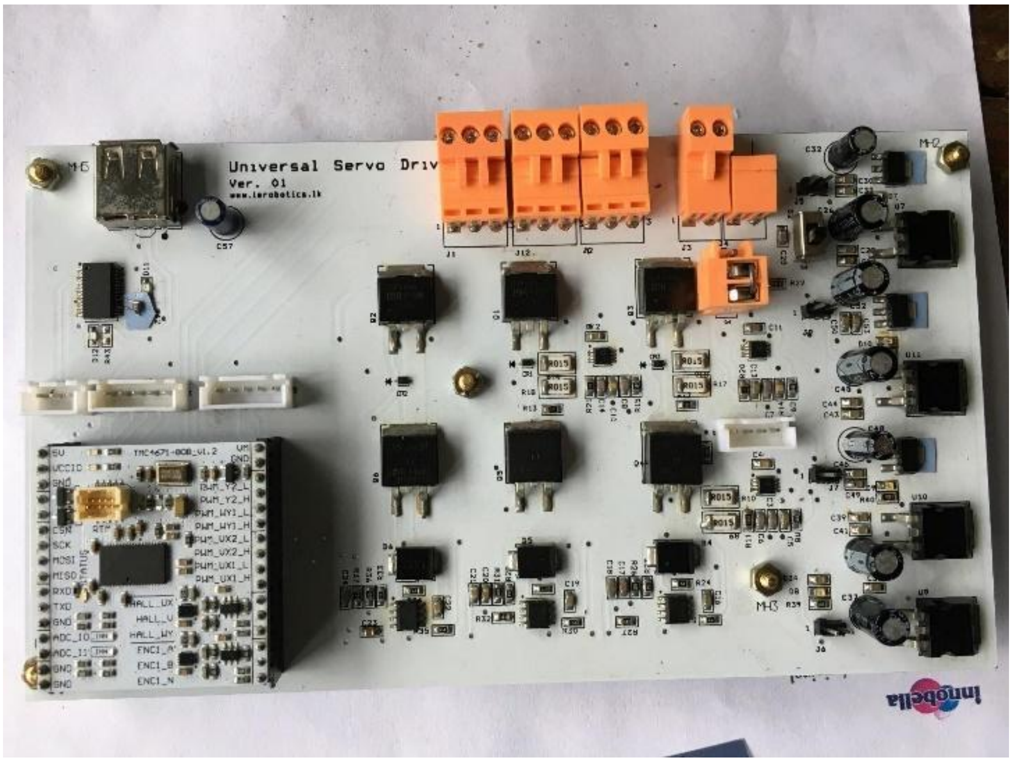
2.5.1.6 Motor v6

Since Motor v5 was a good discovery, we knew that we were going in the correct direction. Though the Verification process didn't give exact measurements compared to simulation output, the characteristics were correct. So the next stage of Motor designing is to make the stator which is a type of segmented, with lamination steels.

The main advantage of the stator core which is made of lamination steel (electrical Steel) over a stator core which is made of solid iron is the reduction of eddy effects. Because of that motor will not heat up compared to previous designs resulting in a lower current consumption than previous motors. So I had planned to design the 6th version of the servo motor, with lamination steel (Electrical steels). But the time was not enough for that designing. So with the knowledge that we were gathered and hand-over to the company, the next designer will design and make that.

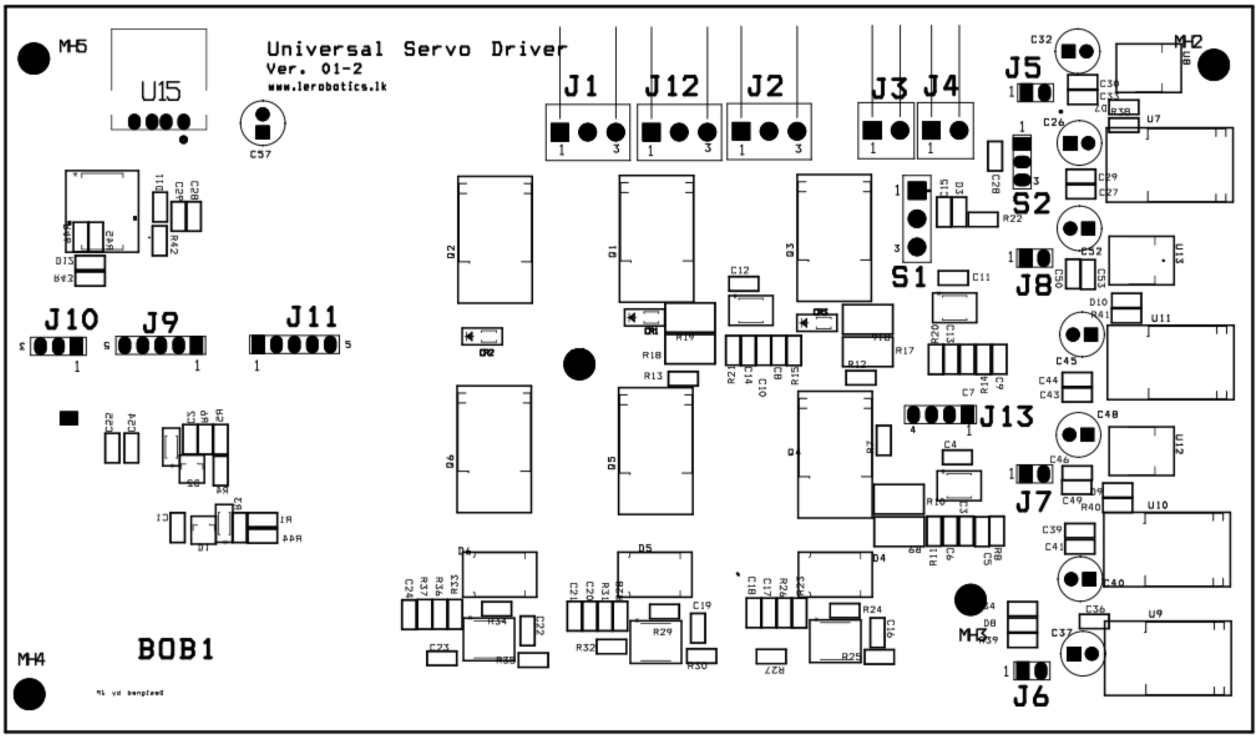
2.5.2 Universal Servo Driver



Universal servo driver board was designed to drive a three-phase AC synchronous motor with higher efficiency and accuracy while solving the issues that occurred in previous versions which were used multi-microcontroller and FPGA DE0 Nano board as the processing unit. In previous versions, the driver boards contained expensive FET drivers and whenever a failure occurs in the PCB, these drivers get damaged and it costs both time and money. In version 01 which was a multi-microcontroller system, could not achieve expected speed due to the communication delays occur when communicating between microcontrollers. And the main problem in version 02 was the algorithmic synchronization issues rise from FPGAs. To address these issues both processing unit and the driver board were redesigned with TMC4671-BOB_V1.2 modules which contain TMC4671-ES chip. The design process of the driver is explained in this Section.

2.5.2.1 Inputs and outputs of the driver board

This section describes all the input and outputs of the design.



I/O	Description	Pin Description	
U15	USB connector		
J10	UART interface	1	GND
		2	TxD
		3	RxD
J9	SPI interface	1	GND
		2	MISO
		3	MOSI
		4	SCK
		5	CSN
J11	Encoder interface	1	5V
		2	A

		3	B
		4	N
		5	GND
J1	Step input (24 V)	1	24V
		2	Step input
		3	GND
J12	Direction input (24 V)	1	24V
		2	Direction input
		3	GND
J2	Phase current out	1	U
		2	V
		3	W
J3	Power input for FETs	1	24V
		2	GND
J4	Power input for FET drivers, ICs and TMC module	1	GND
		2	24V
J13	Current sensing interface	1	Total current
		2	U
		3	V
		4	GND
J5-J8	Input power debugging pins	1	GND
		2	5V/12V/3.3V/5V

S1	Switch to supply power for MOSFETs	
S2	Switch to supply power for other units	

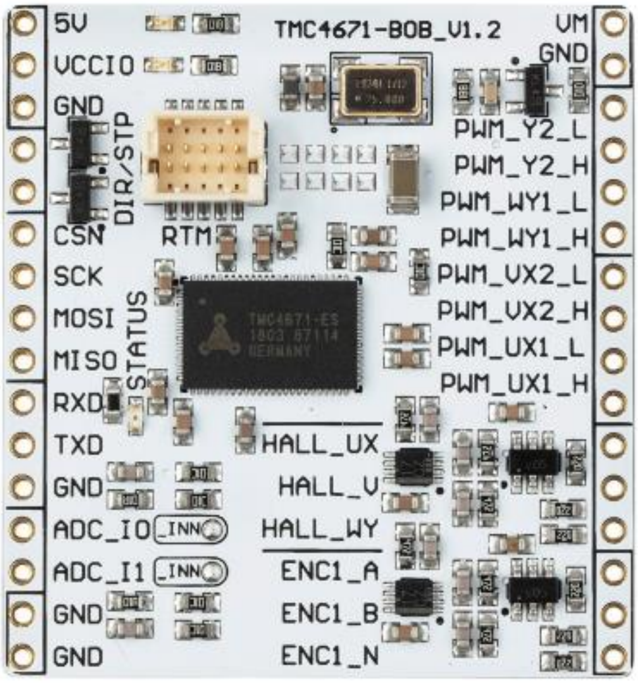
2.5.2.2 Design Process of the Universal Servo Driver Controller part (Module)

In order to overcome algorithmic issues rising from multi-microcontroller and FPGA based servo drivers designed earlier, an IC which executes the FOC algorithm having step and direction inputs (like an industrial servo drivers) was needed. TMC4671-BOB_V1.2 module was found to be compatible with these requirements. Due to the practical issues rising while soldering TMC4671-ES chip (having TQFP package), the Breakout Board (BOB) was used in the design. Since this module does not have internal regulators, 3.3V and 5V external power supply requires from the module.

2.5.2.2.1 TMC 4671-BOB_v1.2 Module Description

The module is designed to drive DC, stepper and 3-phase AC motors. This module is composed of 32 pins. The top view of the module is shown in below figure.

According to the Figure , I/O pins are divided into several groups. Table given below shows respective pins and tasks of each pin.



Pin number	Signal	Description
1	+5V	Power Supply pins for the module
2	VCCIO (3.3V)	
3	GND	
4	STP	Step and Direction input signals
5	DIR	
6	CSN	SPI interface
7	SCK	
8	MOSI	
9	MISO	
10	RXD	UART interface

11	TXD	
12	GND	
13	ADC_I0	ADC pins
14	ADC_I1	
15	GND	Ground pins
16	GND	
17	VM	Voltage sensing (Capable of sensing 0 to 80V)
18	GND	
19	PWM_Y2_L	PWM output for FETs
20	PWM_Y2_H	
21	PWM_WY1_L	
22	PWM_WY1_H	
23	PWM_VX2_L	
24	PWM_VX2_H	
25	PWM_UX1_L	
26	PWM_UX1_H	
27	HALL_UX	Hall sensor inputs
28	HALL_V	
29	HALL_WY	
30	ENC1_A	Encoder signal inputs
31	ENC1_B	
32	ENC1_N	

Since the module was designed to control stepper motors as well, the module can drive up to 4 half-bridges. Therefore, 8 pins are allocated to output four sets of PWM signals.

It essential to analyze expected logic levels and behaviour of TMC4671-BOB_V1.2 I/O pins and TMC4671-ES I/O pins.Below Table shows comparison of expected logic levels in each port.

2.5.2.2.2 Description about Inputs and Outputs

Pins	Voltage levels of TMC4671-BOB_V1.2	Voltage levels of TMC4671-ES
Power pins (1,2,3)	5V, 3.3V, GND	5V, 3.3V, GND
DIR/ STP (4,5)	3.3V	3.3V
SPI interface (6-9)	3.3V	3.3V
UART interface (10-12)	3.3V	3.3V
ADC (13,14)	3.3V	3.3V
Voltage sense (17,18)	0-80V	0-3.3V
PWM ports (19-26)	3.3V	3.3V
Hall Sensor input (27-29)	5V	3.3V

Encoder input (30-32)	5V	3.3V

2.5.2.2.2.1 Power Supply Section

In the power section there are three pins namely, 3.3V, 5V and GND. In order to supply power to the module, 3.3V, 5V and GND should be supplied to respective pins in the power supply section. Two blue color LEDs on the module should light up if the power supply process is successful.

2.5.2.2.2.2 Step/Direction Interface

This can be used to control the target position of the motor. This can be enabled by setting the STEP_WIDTH (S32) register to a proper step width.

2.5.2.2.2.3 UART Interface

The basic UART protocol uses in the module is a 5-byte protocol. The interface is composed with three pins (GND, RxD, TxD). The transmission bit sequence is composed with one start bit, one byte of data, one stop bit and no parity bits. In the protocol, 5 bytes of data need to be transmitted within one second. These 5 bytes of data can be in a structure as shown in this Figure .

<table>
<tr><th colspan="6">40 BIT DATAGRAM (UART) to TMC4671</th></tr>
<tr><td colspan="2">8 BIT ADDR BYTE#5</td><td>MSB DATA BYTE#4</td><td>DATA BYTE#3</td><td>DATA BYTE#2</td><td>LSB DATA BYTE#1</td></tr>
<tr><td>WRnRD</td><td>7 BIT ADDR</td><td colspan="4">32 DATA</td></tr>
</table>

The MSB is the first byte which should transfer first. In the MSB, the 7^{th} bit indicates whether the user writes to the module or the user reads from the module. If the user writes to the module, the 7^{th} bit of MSB should be set to 1 or if writes to the module, 7^{th} bit should be 0. Rest 7 bits of the MSB represents the register address, the user wants to write or read. If the user writes to the module, rest 4 Bytes should be the desired value which needed to write. Then other data bytes will be transmitted from 4-0 sequentially. The maximum data rate allows by the module is 3Mbps and the default value is 9600 bps.

2.5.2.2.2.4 ADC engine

The interface has sigma-delta modulators. The FOC engine require offset corrected ADC values, scaled into the FOC engine's 16-bit fixed point representation. The integrated offset compensator maps raw ADC samples of current measurement channels to 16-bit two's complement values. The off set is compensated by subtraction, the offset is represented as an unsigned value. The sampled raw ADC values can be accessed through ADC_RAW_DATA (0x02) register and it is important to identify offset and scaling factors during system setup phase.

2.5.2.2.2.5 PWM engine

The PWM engine takes care of converting voltage vectors to pulse width modulated control signals. The base resolution of the PWM is 12-bit internally mapped to 16-bit range. The minimum PWM increment is 20 ns due to the symmetrical PWM with 100 MHz counter frequency. This requires couple of parameter settings.

- PWM Polarities (control by PWM_POLARITIES (0x17) register)
- PWM Frequency (control by PWM_MAXCNT (0x18) register)

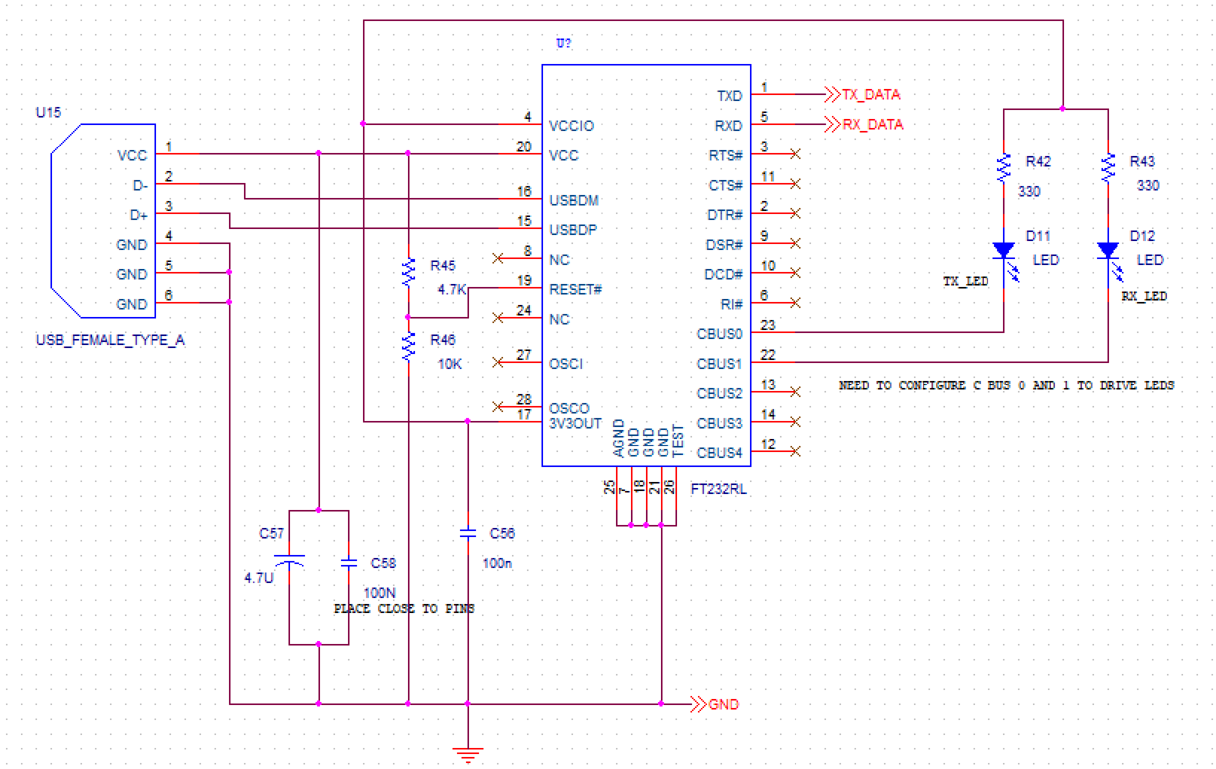
2.5.2.2.2.6 RTMI (Real-Time Monitoring Interface) Connector

The RTMI connector is used to connect to *Trinamic's RTMI adapter* for live monitoring and tuning of the TMC4671 control loops at control loop sampling frequency. A connecting cable comes with the USB-2-RTMI adapter. Below Figure shows the pinout of the adapter.

Left	Signal	Right	Signal
1	+3.3V	2	n.c.
3	DBG_SPI_nSCS	4	DBG_SPI_TRG
5	DBG_SPI_SCK	6	GND
7	DBG_SPI_MOSI	8	GND
9	DBG_SPI_MISO	10	GND

2.5.2.2.3 Designed Circuitries

2.5.2.2.3.1 UART Interface



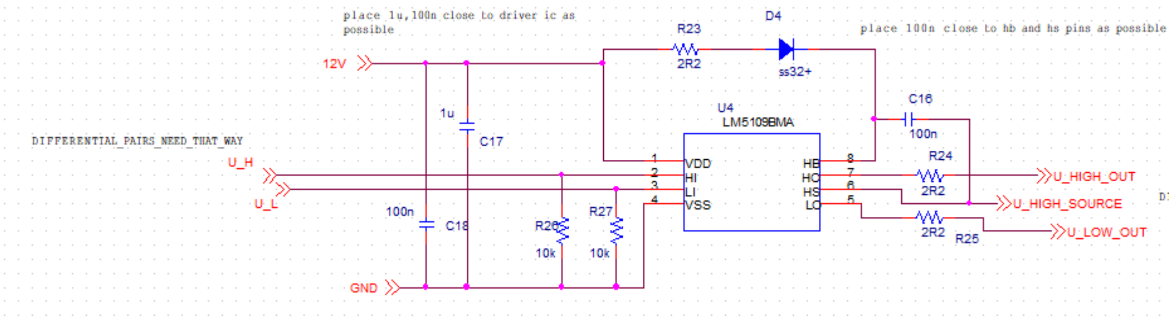
Initially, UART communication was established. This process required external hardware to be implemented. The schematic of the hardware is shown in Figure given above. The design used FT232RL USB to serial convertor. First, the FT232RL chip need to be configured before using, otherwise, the communication process will not be successful. To configure the chip, "*FT_Prog*" software given by the chip manufacturer was used. Since there is not enough space in this report, I'm not going to give that process.

After configuring the chip, any serial terminal available in PC can be used to communicate with the module. The "*Termite*" software was used in this case. First, the communication settings need to be set in "*Termite*" software. Which are,

Number of start bits	: 01
Number of data bits	: 08
Number of stop bits	: 01
Number of parity bits	: 00
Baud rate	: 9600

Then communication can be done between PC and the module. Register addresses and data bytes must be sent accordingly.

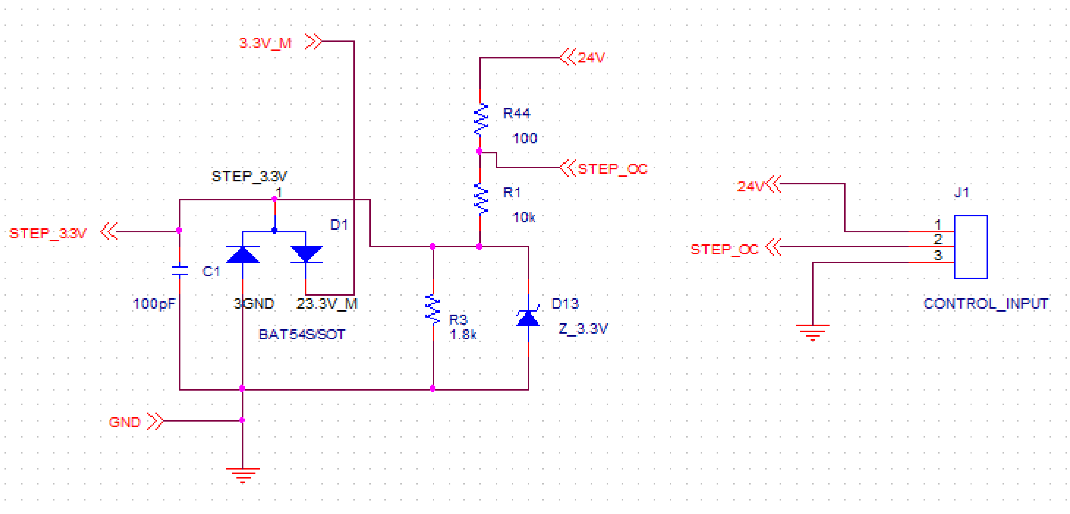
2.5.2.2.3.2 MOSFET Half Bridge Driver

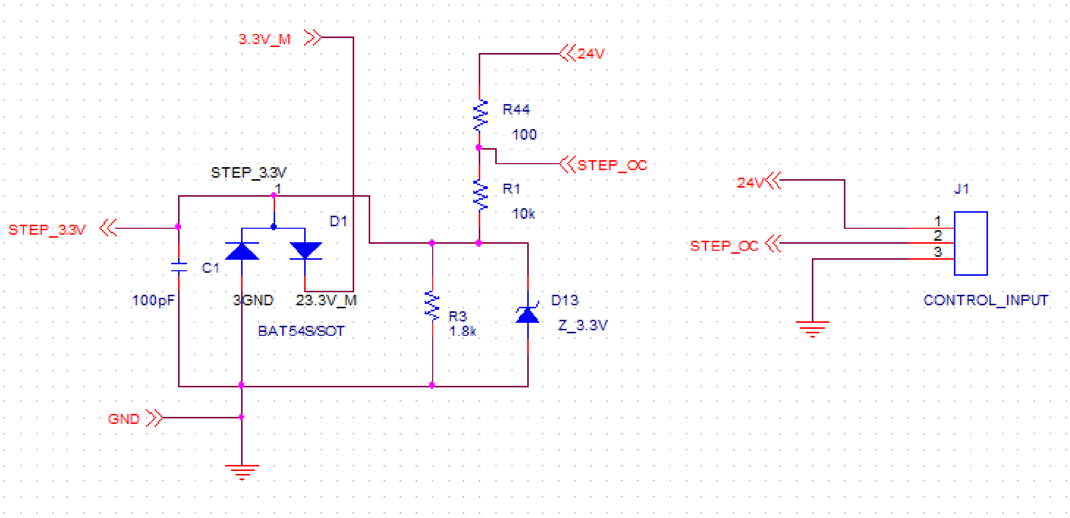


According to datasheet, $V_{GS(th)}$ for the IRF640NS MOSFET should be 4.0V. Therefore, for MOSFET to turn on, voltage greater than or equals to 4.0V should be supplied. Since $R_{DS(on)}$ is very low and the Gate is a capacitive load, R24 and R25 resisters (refer above Figure) were needed. And, R23, D4 and C16 need to be calculated. LM5109B MOSFET driver which was used in "*TMCUPS10A70V-Eval*" design was used as the MOSFET driver for the new design. Calculation takes heavy space.So there not here.

2.5.2.2.3.3 Step/direction interface

This interface consists of some protection mechanism and voltage divider circuit. Same circuitry is used for both step and direction inputs.



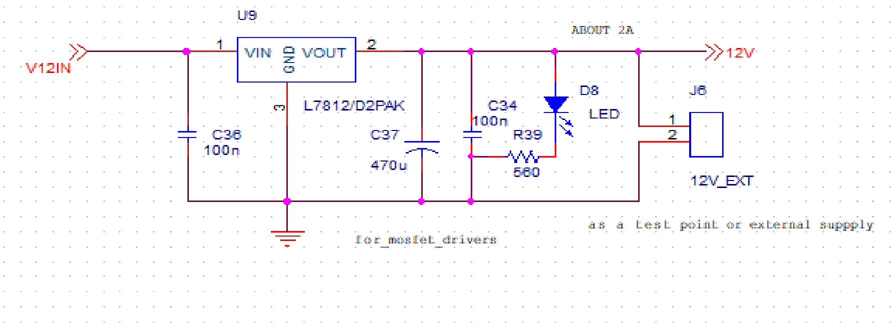


2.5.2.2.3.4 Power Supply

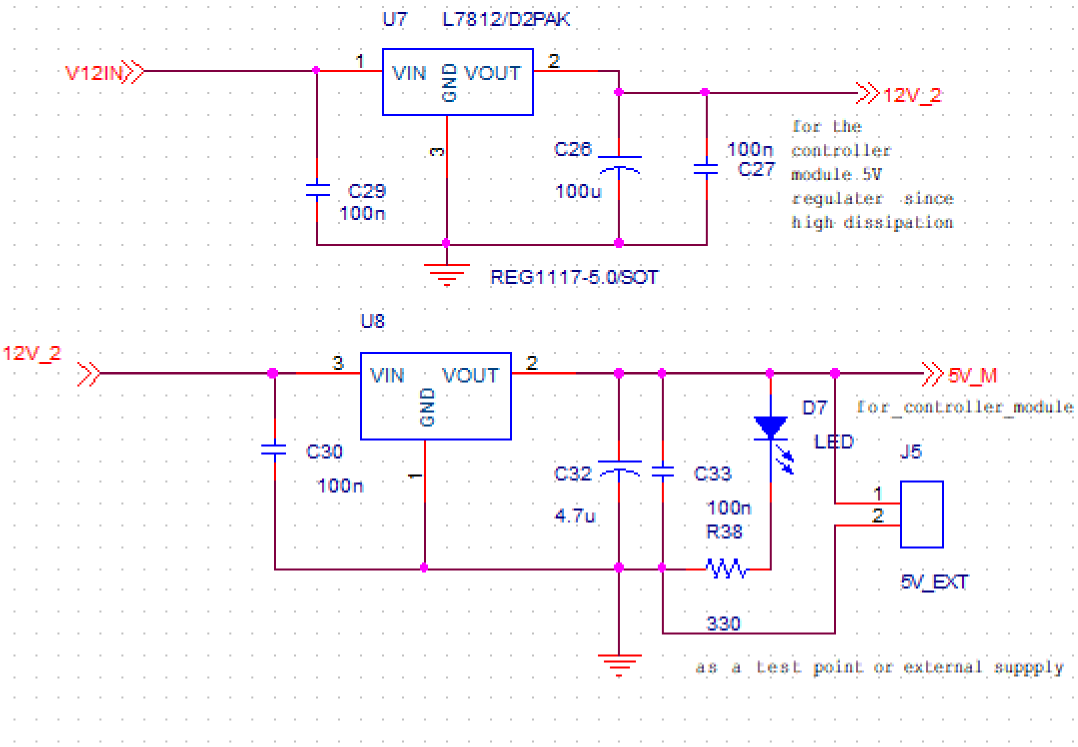
12V, 5V and 3.3V were generated for following purposes.

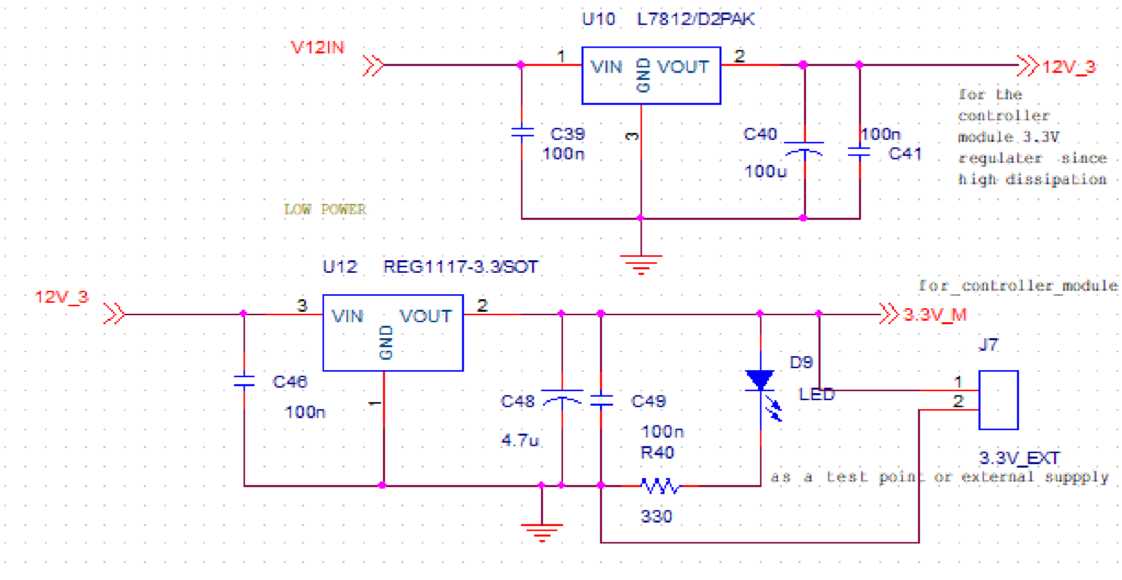
- 12V for MOSFET drivers
- 5V, 3.3V supply for TMC4671-BOB_V1.2 module
- 5V for current sensors

Therefore, 4 separate power supply blocks were included to the design. The design was used L7812CD2T, AMS1117 5.0, AMS1117 3.3 regulators. Every power supply block has two separate pins for debugging purpose. Below figures shows schematics of 12V, 5V and 3.3V supplies respectively. 18 V was given as the input for the driver board. The design uses separate



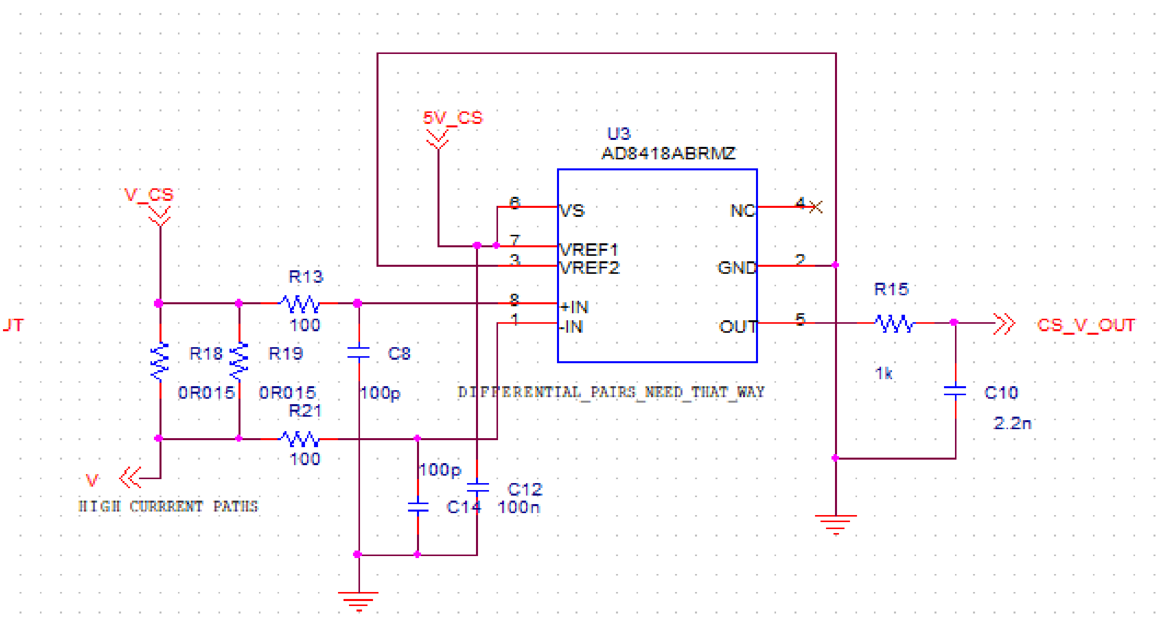
18V supply and a 24 supply, for powering up the circuit and the other for powering up ICs and the module., one for powering up MOSFETs respectively.





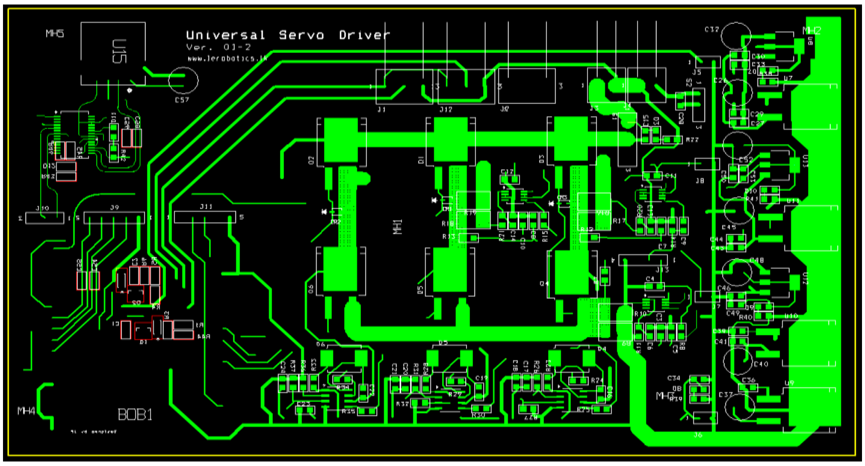
2.5.2.2.3.5 Current Sensing

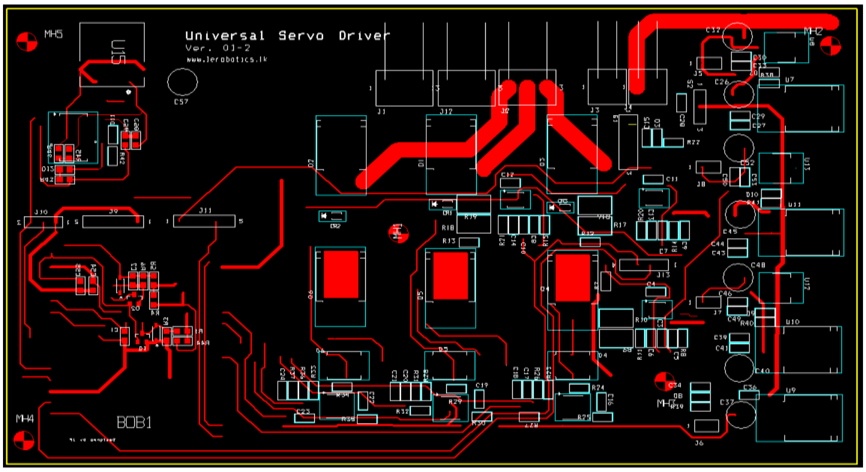
The current sensor used in the design was AD8418A. The sensor has a gain factor of 60. Three current sensors were used to sense the total current and two, phase currents. The schematic of the current sensing block is shown in below figure.

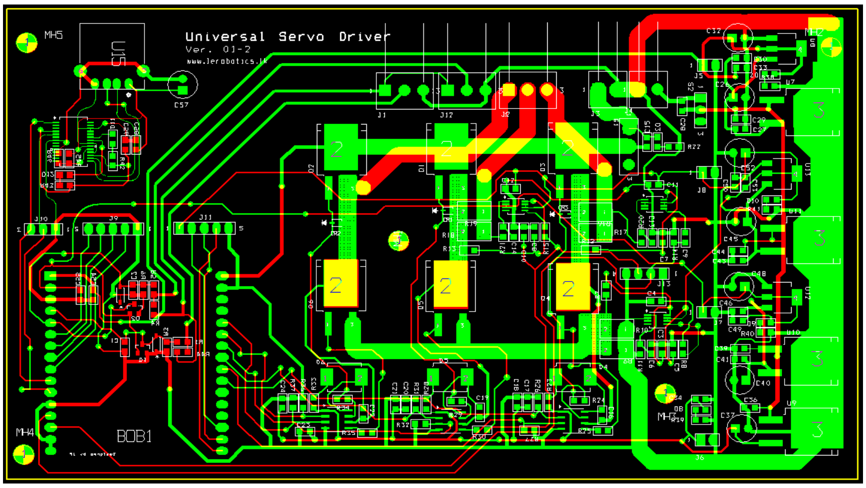


2.5.2.2.4 PCB layouts

The Universal Servo Driver Is a double layered PCB which was designed by me.While designing, I had to consider about Ventilation , Heat Dissipation, High Current Flowing, Differential pairs, High Speed Signal Paths, Optimized grouped Component Placing ,Isolating, noise Reduction and backup plans in case of Accident .Top and bottom sides are given below.







2.5.3 Motor Driver User Interface Software

The motion controller IC TMC 4671 -es need to be reconfigured every time after a power cut because this chip is not from standalone type. So I had to use a simple UART terminal software(in my case termite)for sending datagrams to the chip. Since the inter datagram time gap is 1 second, sending about 12-15 datagrams with such a delay was very time-consuming work.

As a solution for this, I built a software that can search available COM Ports, that can select the required baud rates, that the user can select various options and that can read or write any register with suitable time gaps between datagrams. With this, I was able to easily configure the chip.

At that time I didn't know about C#. I asked the technical director for java programming because I have done Java language for a certain depth. But he told me to do it with C#. With the time I studied C# for necessary level and started to make the software. The reason is to do that job with C# is because the C# is more nearby to the hardware level. Thus we can gain more speed.

Since I was dealing with the hardware stuff, it was not easy. It took me about 5 days to make a perfect Serial Communication interface with finding bugs, errors and correcting it.

Even though I had an idea to use database systems with the software to store the various options, that various registers had, there wasn't enough time for that.

2.5.4 RTMI(Real Time Monitoring Interface)

After closing the 3 control loops, the next task is to fine-tuning of control loops. So to find the best P and I values, we have to monitor the required parameters, to monitor them higher sampling frequency is needed. To get current values, we have to read registers of the motion controller chip, with a higher frequency. But the UART and SPI Slave interfaces have limited speed.

So we won't able to read values via UART or SPI slave interfaces which are previously used for configuring the motion controller.

To solve this, we have to use the high-speed SPI master interface of the motion controller. So compatible hardware is also needed for doing such a thing. By referring RTMI adapter of the TRINAMIC Motion control s, I figured out the hardware for doing that. The main hardware is the ft4222 USB to SPI converter chip.

Then I had to design the schematic and the PCB layout in about 2 days, cause the next PCB order for the china, has scheduled after 2 days. the manufacturer had used only the high-speed SPI master interface of the ft 4222 chip. But in my case, I designed my design with capabilities of operating in quad SPI slave modes, operating in I2C mode and High-Speed SPI Master mode.

So if this design will be rejected for real-time monitoring purposes, Someone can use this item as a USB to I2C converter or someone can use As a USB to SPI Interface.

2.5.4.1.1.1

3.1 Summary of Technical Exposure

Lanka Electronics (Pvt) Ltd is a well-known electronic product manufacturing company and during the 24-weeks of industrial training I was able to get many experiences regarding the electronic product manufacturing as well as Mechanical product manufacturing machines. During my industrial training period I'm went thorough a complete electronic product development cycle. I learned theories about electronic product development cycle in the university. However, this was the first time I went through this product design cycle practically. On the first day my supervisor give a brief introduction about LE Robot arm V2, LE Robot Analyzer PC application and Problems of current implementation, project which I had to complete within my internship and theories required for project. To understand theories they provided research papers, thesis and patent documents. Learn theories by reading research papers and patent document is a very important for engineers. Further, I learned to find theories from patent using free patent database. Then I started my feasibility study. Here I learned about machine learning and machine vision. This was the first time I learned about deep neural network and convolution neural network. Further I learned how to do a feasibility study using alternative designs. Then I started sub-module design stage. Here I made testing PCB using Orcad. For testing PCB I had to design required foot print. Here I learned design footprints using component data sheet. Further I learned assembly programming. This was the first time I wrote algorithms using assembly language. Then I proposed new architecture for LE Robot V3. After that I started main system design. When I design main system I had to collaborate with my team members. Therefore in this stage I learned how to do a design with a team. Further I learned about C# language and Linux command prompt.When designing main PCB I leaned how to design a industrial level PCB. Every personnel in the company assisted the interns wherever it was needed. I never saw any difference between senior employees and interns. That was the culture they had been evolved within the company.

3.2 Weaknesses of the Training Establishment and Possible Suggestions

Electronics and Telecommunication industry is a very large field and it comprises many areas such as Analog Electronics, Digital Electronics, Embedded Designing, Verification, Telecommunications Etc. Lanka electronics is a very good opportunity if you want to procced through the carrier path of a electronic design engineer. But the telecommunication side didn’t cover through the internship. Therefore I learned only one side of my degree. However I’m very satisfied with my electronic product design experience.