MIDDLE EAST TECHNICAL UNIVERSITY
Electrical & Electronics Engineering Summer

Practice Report

EE 400

Student Name: Huzeyfe Hintoğlu

Student ID: 2093920

Company:

TUBITAK Defense Industries Research and Development Institute

Company Division:

Electronic Hardware Design Group

Location of the Company:

Elmadag/ANKARA

Summer Practice Dates:

25.06.2018 – 20.07.2018

Responsible Engineer in Summer Practice: Ali Yılmazkoçlar

Signature:

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1. Description of the Company

1.1. Company Name

TUBITAK Defense Industry Research and Development Institute (TÜBİTAK Sage)

1.2. Company Location

Lalahan District,06800, Ankara / TURKEY

Phone: +90 (312) 590 90 00

E-Mail: sage@tubitak.gov.tr

URL Address: http://www.sage.tubitak.gov.tr/en

1.3. General Information About the Company

TUBITAK Sage established in 1972 in the name of Guided Vehicles Technology and Measurement Center (GATÖM) in Besevler, ANKARA and is a served until 1993.
The name was changed to the Ballistic Research Institute in 1983.
Finally, in 1988, it received the name of the Defense Industry Research and Development Institute (SAGE) and started to operate with its current structure at Lalahan Site which is 30 km away from the city center of ANKARA.

TUBITAK Sage specializes in different areas. The main working area of the company is defense industry technologies and carries out researches in related areas. The Institute is aiming to be pioneer in defense industry technologies in Turkey. Recently, they gave special interest on missile production, design manufacturing and test. They have built dozens of Turkish made missiles and munition. For example, Göktuğ missile, SOM, Bozdoğan and Gözdoğan missiles are designed and manufactured by TUBITAK Sage. Now, they are working on new missiles and projects. Some of the projects are kept confidential for security considerations. With the experiences they gain from the previous projects, they are planning to build different kinds of missiles for Turkey.

The main function of SAGE institute is to perform research and development activities for defense systems including engineering and prototype production, starting with their fundamental research and conceptual design. Most of the projects are performed in coordination with other Turkish defense industry companies such as ASELSAN, TAI and other TUBITAK institutes. In the beginning of institute history, SAGE only performs research and there are no products which were produced by TUBITAK Sage. However, nowadays the institute also produce missiles and missiles control systems besides research about defense systems. The mission of the institute is to provide and value-added technology, product and services through R&D to defense industry. Its vision is to make Turkey independent in Defense Technologies. [1]

1.4. Organizational Structure of the Company

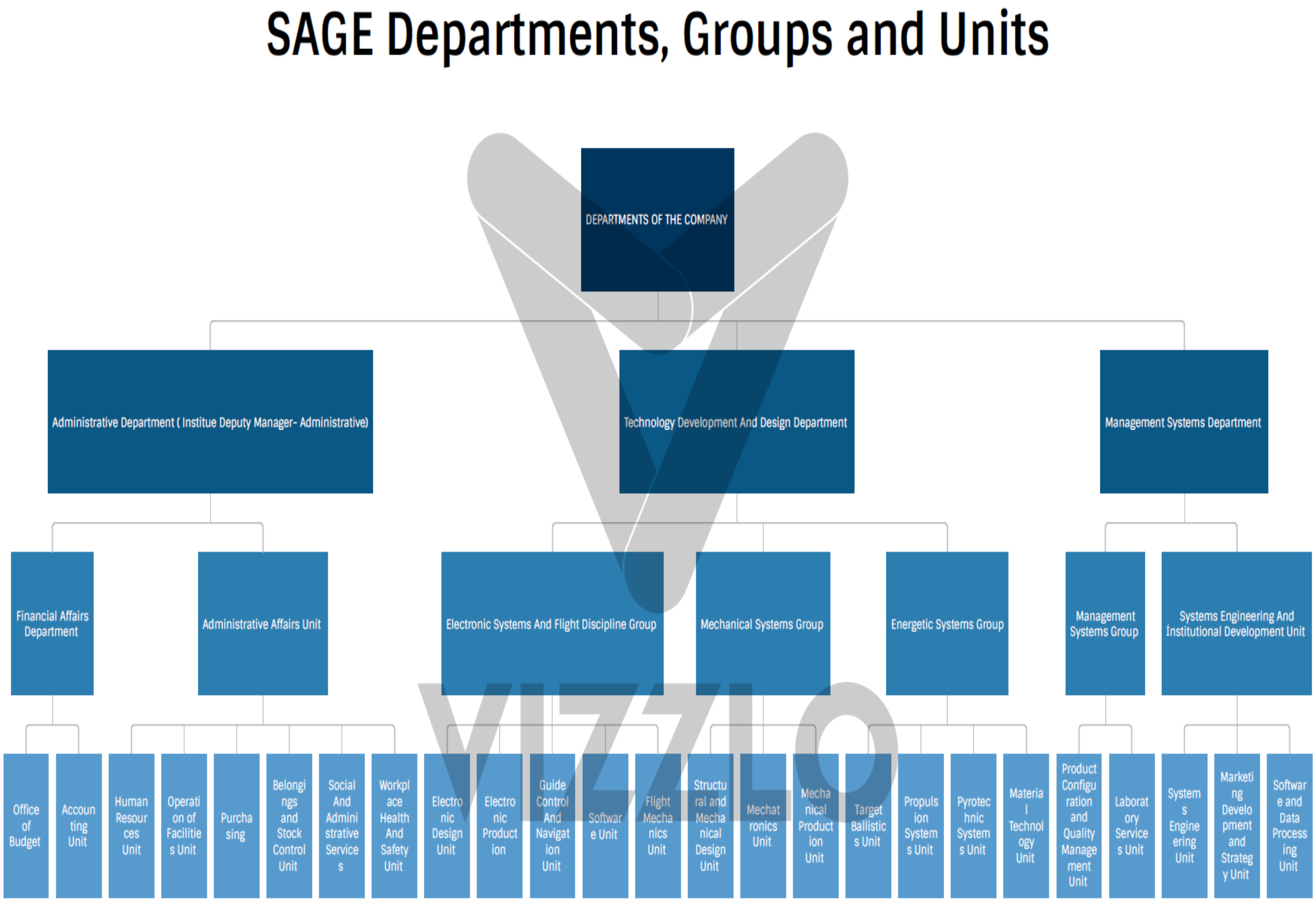


Figure 1: Organization Schematic

TUBITAK Sage is a governmental organization. Because of this, Turkish Ministry of Science and Technology is at the top of the organization. There are many subgroups in the company working for different purposes. My subgroup is the Electronic Hardware Design Unit, which is mainly working on the Designs of Hardware Systems. In Figure 1, the organization schematic is illustrated.

1.5. Employees of the Company

SAGE is a research and development company that State dependent. According to the data obtained from human resources there are 780 workers and 560 engineers work in SAGE.

The distribution of employees is illustrated in Table 1.

Distributions of Engineers	
Electrical & Electronics Engineer	%20
Computer Engineer	%10
Mechanical Engineer	%45
Other Researcher	%10
Technicians	%10
Support Staff	%5
Total	**%100**

Table 1: The distribution of staff

Since the company is mainly based on research & development (R&D), they support the high level of education. Therefore, employees can have their further education while they are working for the company. This results in more qualified R&D. The education level of researchers in TUBITAK Sage is shown in Table 2.

Education Levels of Researchers	
Undergraduate	%40
Graduate	%30
Ph.D.	%10
Other	%20
Total	**%100**

Table 2: The distribution of education levels of employees

2. Introduction

I have done my second summer practice in TÜBİTAK Sage. My internship is lasted in one month (20 Work Day). Before the summer practice, I was very curious and excited because I was about to meet with experienced engineers and works in defense industry where I would maybe work in the future. Therefore, I was very optimistic in entire period of my internship progress. I preferred to perform my internship in TÜBİTAK Sage as they develop missiles and conduct research about defense industry. Since defense industry contains lots of high class technology and being a part of this kind of a unique work is significantly valuable.

I was involved in the Electronic Hardware Design subgroup regard of my request. Since I would like to know what design engineers actually do in hardware field specifically, I have understood I have chosen the right group for my internship period. I also was lucky to work with lots of successful engineers who are mainly interested in power electronics and control area. They were very kind while sharing their experiences to me. I mainly interested in power converters and motor driver controllers.

First, I worked on designing a Buck Converter. My main purpose was building up a converter according to defined parameters. Secondly, I worked on BLDC motor controller circuits. I was asked to design and analyze controller for a motor used in an actual project of Sage. I do it so by using Matlab and Simulink.

During the internship, there were also some instructive trainings for interns that helped us to understand which projects are being conducted in the company and how they proceed in projects.

In general, during my internship I improved my designing skills in simulation programs, i.e. LTSpice, Matlab and Simulink. The working principles of converters and controllers were my main area of interest. In this report, the experiences I have had in my internship period are explained in detail.

3. Project 1: Buck Converter Design

My first project is designing a synchronous buck converter. I was familiar with SMPS technology from my previous internship. I have designed Flyback Converter before. Therefore, I have started first by making some researches on Synchronous Buck Converter working principle and design.

3.1. Buck Converter Topology

The synchronous buck converter is used to step a voltage down from a higher voltage to a lower voltage. Synchronous buck converters are very popular in industry today and provide high efficiency solutions for a wide range of applications.

A synchronous buck converter produces a regulated voltage that is lower than its input voltage and can deliver high current while minimizing power loss. As shown in Figure 1, the synchronous buck converter is comprised of two power MOSFETs, an output inductor, and input and output capacitors. [2]

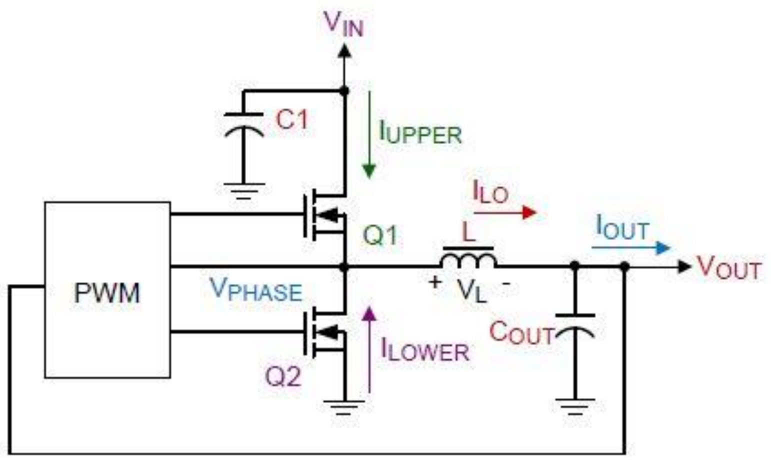


Figure 2: Basics of Synchronous Buck Converter

Q1, the high side MOSFET, is connected directly to the input voltage of the circuit. When Q1 turns on, I_{Upper} is supplied to the load through Q1. During this time the current through the inductor increases (charging L) and Q2 is off. When Q1 turns off, Q2 turns on and I_{Lower} is supplied to the load through Q2. During this time, the inductor current decreases (discharging L). Figure 3 shows the basic waveforms for the synchronous buck converter in continuous conduction mode.

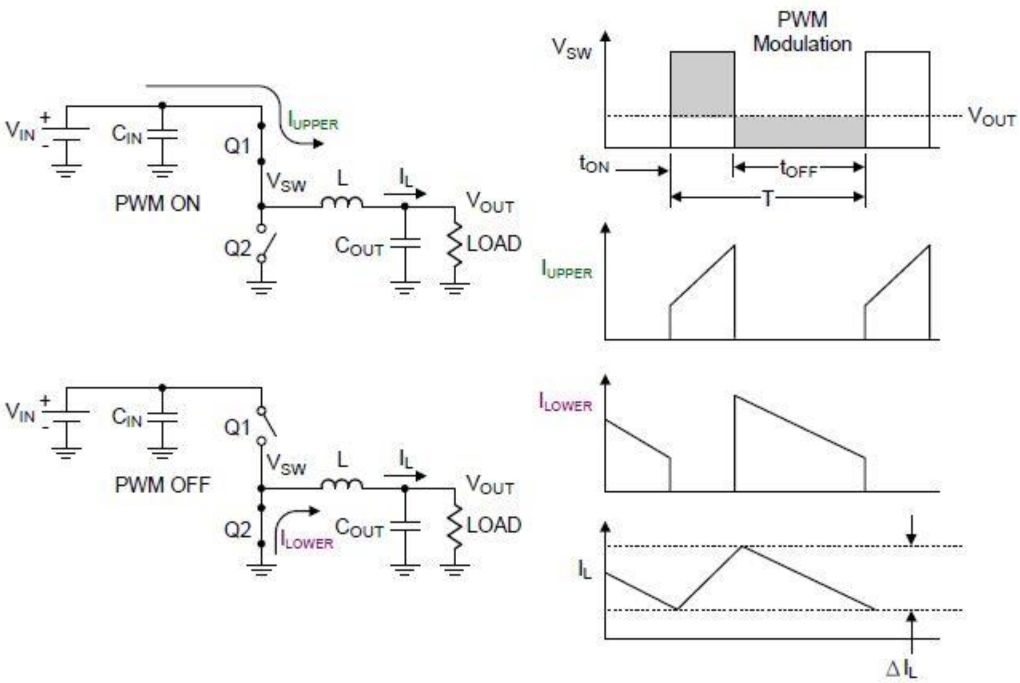


Figure 3: Synchronous Buck Converter Waveforms

Generally, an engineer’s aim is to drive the upper and lower MOSFETs according to customers need. By doing so, required voltage and current values can be obtained. Therefore, a controller must be used in order to drive MOSFETs properly regarding output voltage i.e. if the voltage is lower than expected, controller drives upper MOSFET with higher duty cycle and vice versa for other case.

3.2. Project Description

Requirements are as follows:

- Synchronous Buck Converter
- Input: 12 ±3V
- Output: 1V with %3 tolerance
- Stable even circuit draws 20A of impulsive current
- External typed MOSFET controller IC
- 20mS rise time from 0V to 1V

3.3. Design Process

In order to meet the needs, I started searching on controller IC. I have found LTC3854 controller IC of Linear Technology, which is now a part of Analog Devices, as a suitable controller for my project. Then, I mainly read and analyze the datasheet of this controller to understand every single detail use of IC as I am instructed by my responsible engineer. Later on, I decided to use a typical application of IC with suitable circuit components on LTSpice. The circuit schematic is shown in Figure 4.

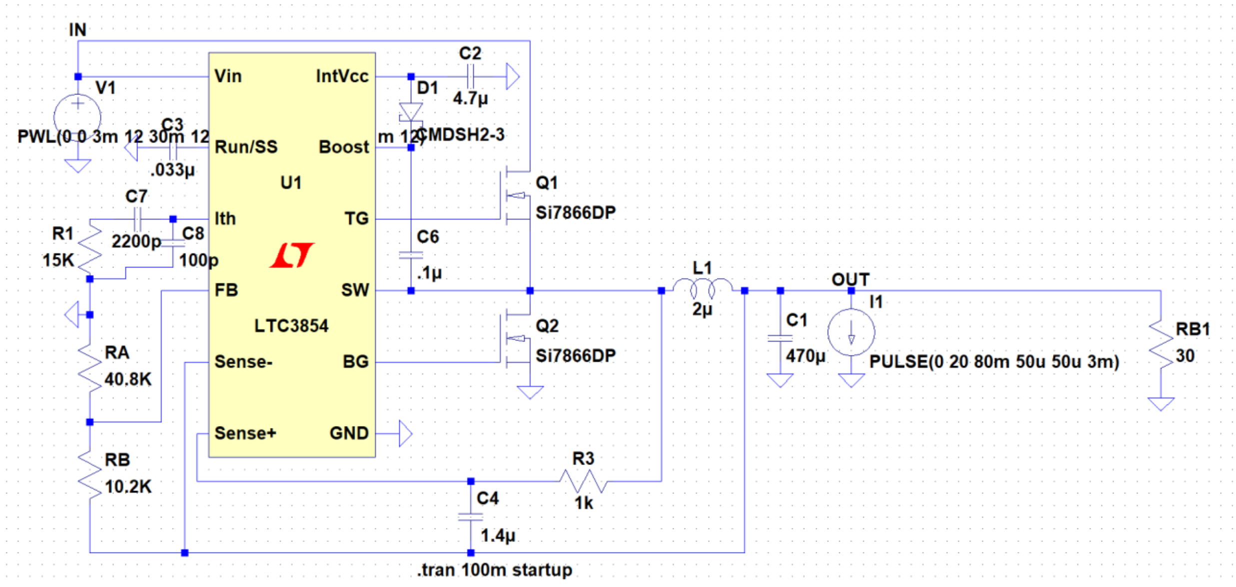


Figure 4: Typical application of Synchronous Buck Converter with controller IC LTC3854

The controller’s working principle is very simple. It includes an error amplifier as a reference for feedback purposes. FB pin is used for this purpose as it takes output voltage for this. Then, it is given as input to error amplifier. Also, the output voltage is sensed by Sense± pins from the capacitor voltage of C4 in Figure 4. They are the inputs for differential current comparator inside the IC. Run/SS pin is crucial for soft start of the circuit. TG and BG pins are used to drive the MOSFETs on the top and bottom respectively. The other uses of pins are written in the datasheet. More information about the IC can be simply learned from the datasheet [3].

3.4. Simulations

At first stage, I was struggling with the problem that the output voltage cannot be fixed on 1V when I apply 20A of impulsive current is drawn. After changing the output capacitor and inductor values which are the main components that should be considered first in order to keep the voltage to required value, I was able to fix the voltage to the 1V even though 20A current is drawn. The waveform of output voltage and current is shown in Figure 5.

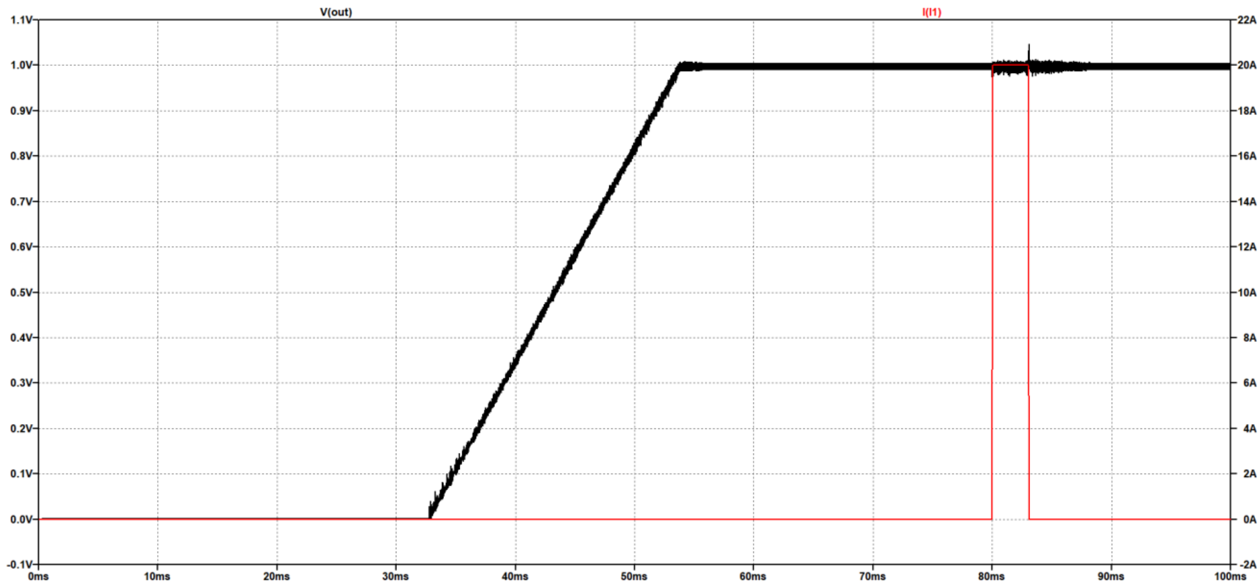


Figure 5: Output Voltage and Current Waveforms of Synchronous Buck Converter

As seen in Figure 5, output voltage is fixed to 1V even though there is a 20A of impulsive current. This is achieved by controller IC by arranging the duty cycle of MOSFETs with respect to output voltage. Since it draws more current than expected, upper MOSFET's duty cycle is a bit lowered and it goes on until output is fixed to the desired value as shown in Figure 6. Then, duty cycle goes back to previous value to fix the output voltage to 1V.

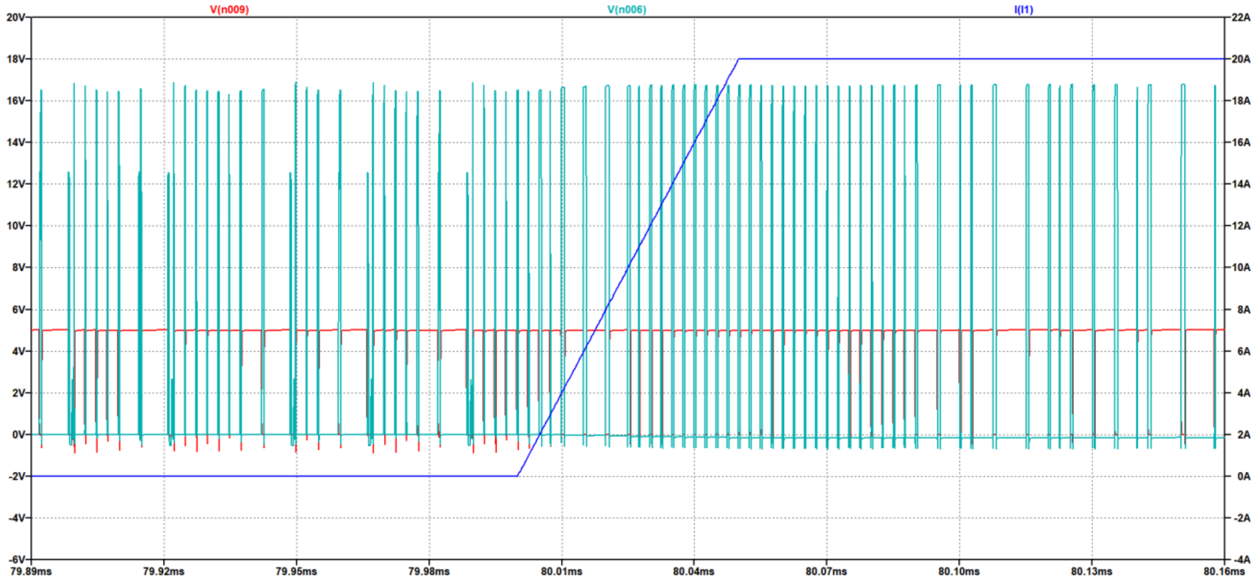


Figure 6: Duty cycles of upper and lower MOSFETs when the output current is 20A

It is also tried that when the output is drawing a constant current of 4A and there is still a 20A impulsive current durability requirement has met or not.

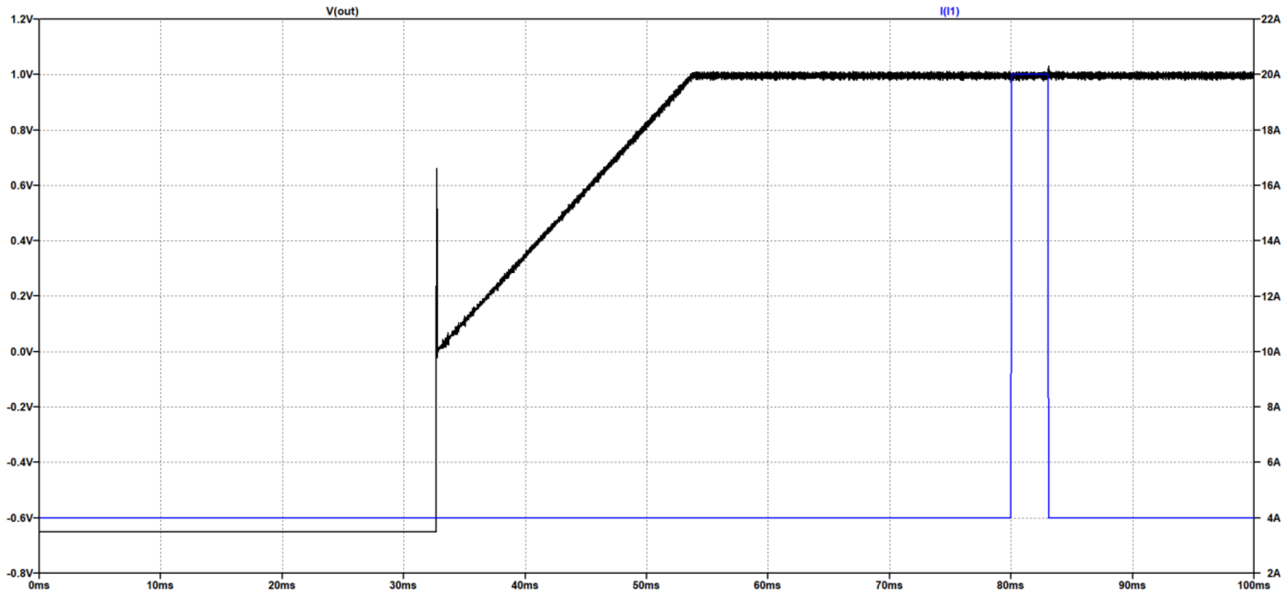


Figure 6: Output Voltage and Current Waveforms of Synchronous Buck Converter with 4A constant current and 20A impulsive current

It can be seen from Figure 6 that output is suddenly changed a bit at first. However, it is then stabilized by the Soft Start property of controller.

Furthermore, the components are chosen according to the required voltage and current values of the branches. For example, the MOSFETs are chosen with respect to their current capability and gate driving capability. Schottky diode is chosen to keep the difference of 5 V which is the threshold values of MOSFETs. If it is not chosen true, there might be problems of driving MOSFETs because V_{GS} value for upper MOSFET wouldn't be more than 5V.

As a result, it is understood that the designed Synchronous Buck Converter is working properly after several tries of different current values. After completing first project, I have started to work on my second project.

4. Project 2: Control of BLDC Motor

In my second project, I asked my supervisor to design a motor controller. Then, we decided on designing and analyzing a Brushless DC Motor(BLDC) on Simulink. Before going deep into the project, I have done some research on BLDC motor current and position controlling in order to learn fundamentals of BLDC motor control.

4.1. Fundamentals of BLDC Motor Control

In controlling a BLDC motor, it is first needed to design a current controller in order to control the torque of motor which is directly related to current. Then, this motor driver is integrated with a position controller in a closed loop feedback system. More detailed information on working principle of BLDC Motor control is provided in the following section.

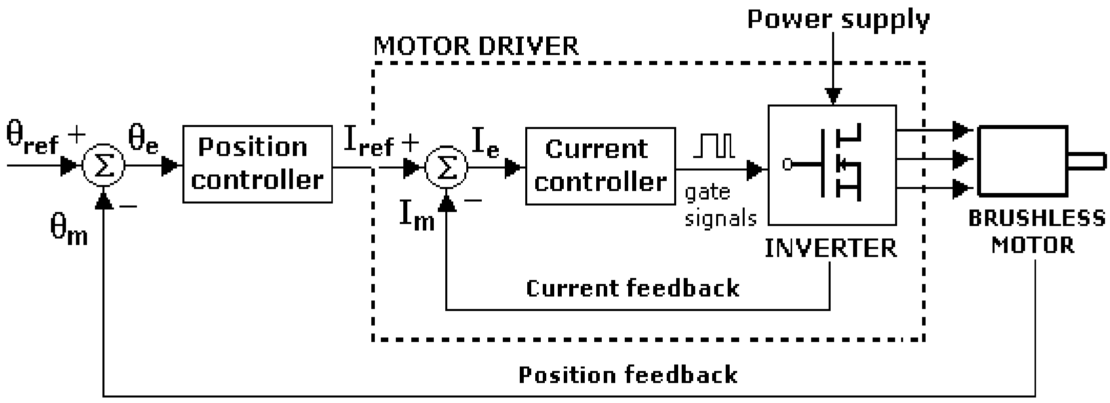


Figure 7: Overall control system

Motor driver, enclosed by the dashed lines in the Figure 7, functions as an inner control loop. A torque mode driver controls the motor torque by controlling the current in the motor. In a permanent magnet motor, torque is proportional to current. This relationship is called the torque constant. A current command signal is supplied to the driver, which in turn produces a current in the motor, which in turn produces torque. A resistive or Hall effect current sensor provides a feedback signal. The current feedback signal is differentiated with the command signal. The current controller continues to produce additional current by controlling the power switches of the motor phases. Outer loop is the position control loop. It controls the motor position in a similar closed loop configuration. The addition of a position control loop requires the addition of a position sensor such as an encoder. [4]

Position controller is using position error to produce its output, current command signal for the motor driver circuit. In addition to position error signal, motor speed and motor position data can also be used in some controller algorithms.

Motor driver performs the two functions simultaneously. It performs the commutation of the motor. Commutation is the procedure of exciting different motor phases according to the instantaneous rotor position to provide a unidirectional motor torque. Because the brushless motor does not possess brushes to perform the commutation itself mechanically like a brush type dc motor. Second function of the driver is to control the motor current in +/-10A range according to the +/-10V analog current command signal coming from the position controller.

4.2. Project Description

Requirements are as follows:

- Current Controller up to 20A
- I-PD Controller for position control
- 180˚ Step Command
- %10 Maximum Overshoot
- 30mS Rise Time
- 50mS Settling Time

4.3. Current Controller Design

The brushless motor, which is used in this work, BMS-0723 is manufactured by KOLLMORGEN Inland Motor. The datasheet of BLDC motor is given in Appendix section.

Motor torque is the motor current multiplied by the torque sensitivity K_t of the motor.

$$T_m = K_t . i \tag{4.1}$$

where,

T_m = Motor torque (N-m)

i = Motor current (Amp)

K_t = Torque sensitivity (N-m/Amp)

The motor mechanical equation, also known as the shaft equation is;

$$T_m = J\frac{dw}{dt} + Bw + T_L \tag{4.2}$$

where,
T_m = Motor torque (N-m)
T_L = Load torque or disturbance torque (N-m)
w = Motor speed (rad/sec)
J = Inertia (kg-m^2)
B = Viscous damping ($\frac{Nm}{rad/\sec}$)

Substituting $w = \frac{d\theta}{dt}$, Eq. (4.2) becomes

$$T_m = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_L \tag{4.3}$$

where,
θ = Motor position (rad)
Combining Eq. (4.1) and Eq. (4.3),

$$K_t.i = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_L \tag{4.4}$$

Converting Eq. (4.4) into the s domain, transfer function between motor current and motor output position is obtained as shown below

$$\frac{\theta(s)}{i(s)} = \frac{K_t}{Js^2 + Bs}$$

This transfer function is used in modelling of the BLDC motor on Simulink. The corresponding values, i.e. K_t, J, B are chosen from the datasheet and applied to the Simulink model of current controller.

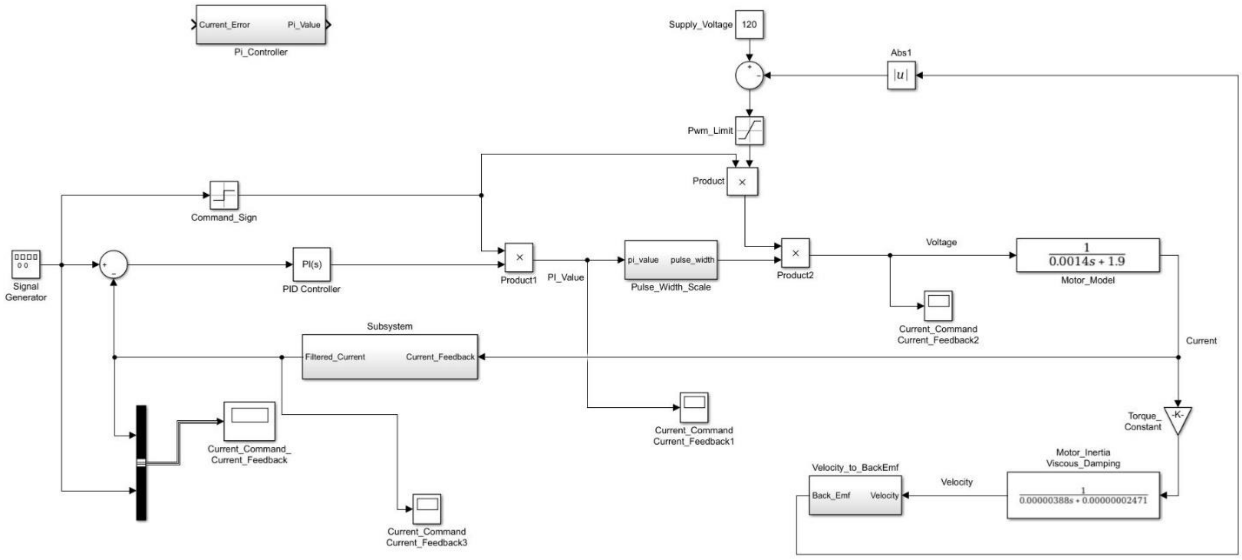


Figure 8: Simulink Model of Current Controller designed

PI controller is used in the system since generally PI controllers are used in current control mechanism as I have researched. Kp and K_I are chosen by trial-error method. In this case, Kp=10 and K_I=1000.

Command sign is used to arrange the rotating directions. When the Command Sign is positive, motor rotates in + direction and vice versa for negative case. Also, there are some limiting factors in order to keep the system in linear region. The system is sometimes forced to stay in linear region. There is a 120 V of supply voltage of the motor. The current control input command and output are shown in Figure 9.

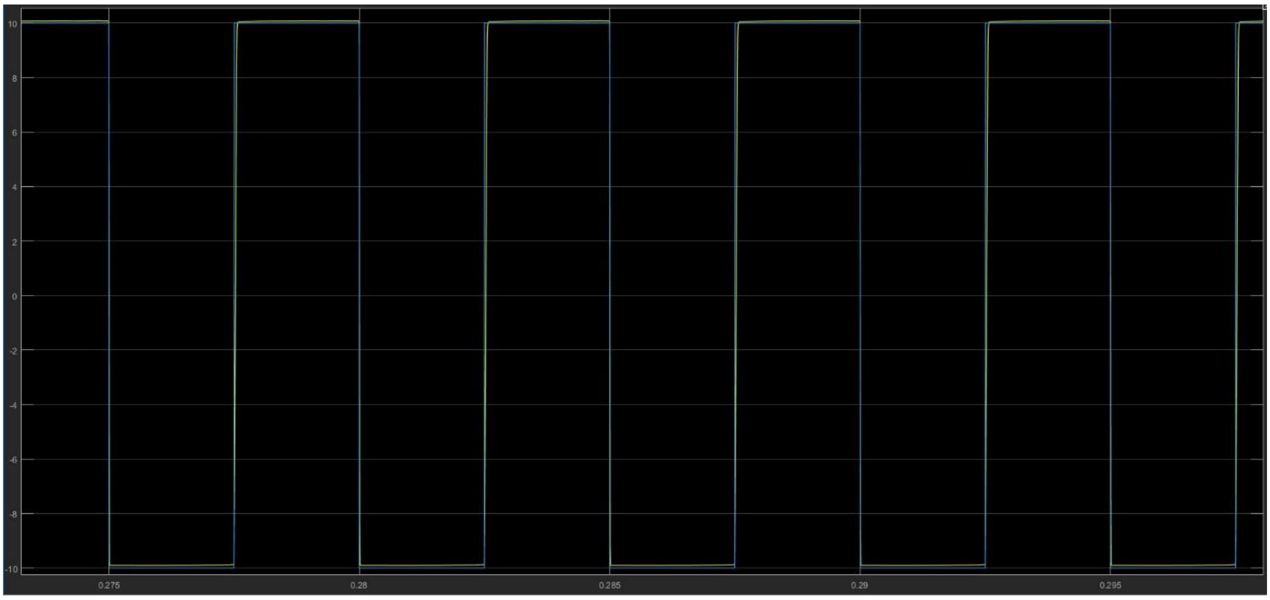


Figure 9: The current controller command and response waveforms respectively

As expected, system works properly. After this process is done, whole system is converted into a subsystem which will be implemented in Position Controller Design as shown in Figure 7.

4.4. Position Controller Design

After implementation of current controller, I needed to design a controller for position controller. Therefore, I have implemented a I-PD controller to the system as show in Figure 10.

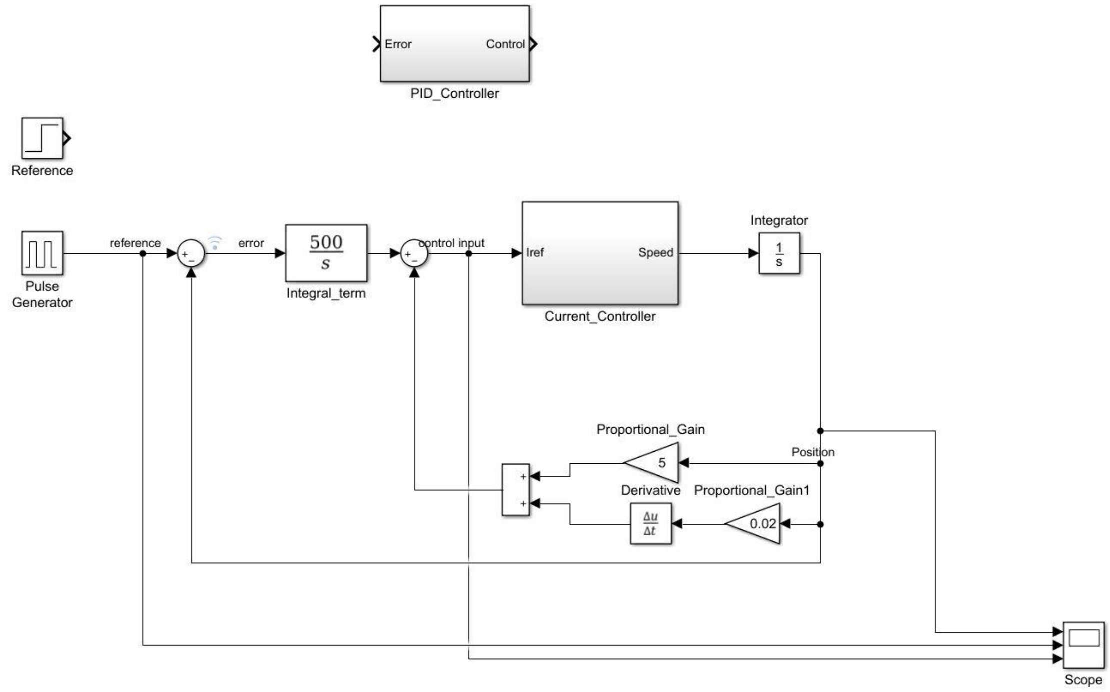


Figure 10: Position Controller with I-PD

The step response of the system is illustrated in Figure 11.

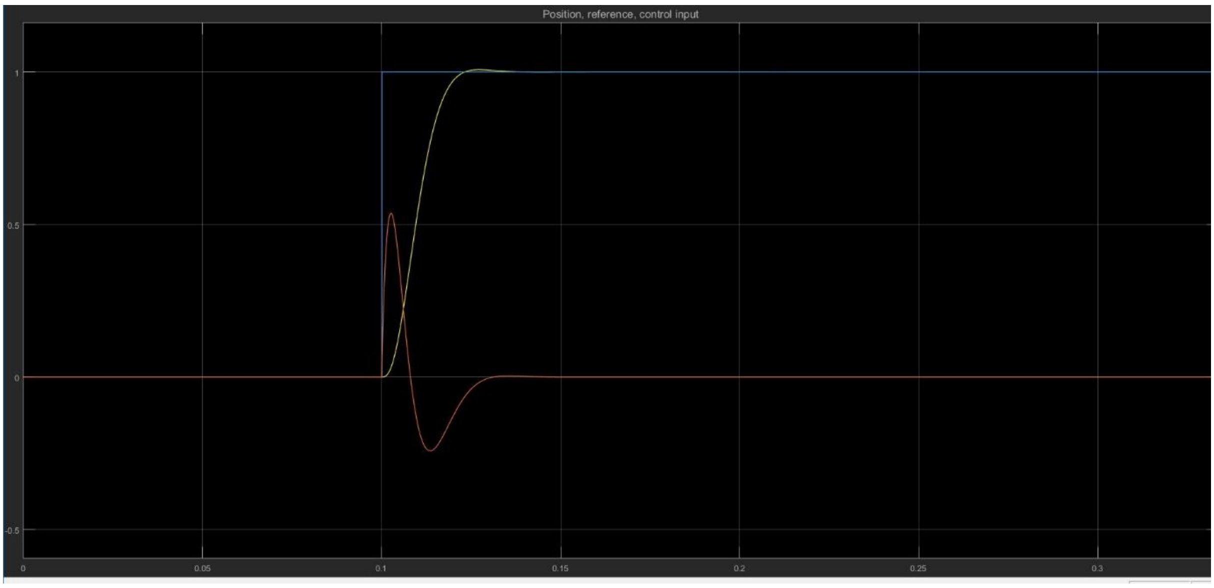


Figure 11: Step Response of the system with I-PD controller

Blue line shows the position command and yellow line shows the position of the motor. The orange line is showing the motor command which is accomplished by I-PD controller. It can be seen from the graph that rise time is 25mS and settling time is 45mS as requested.

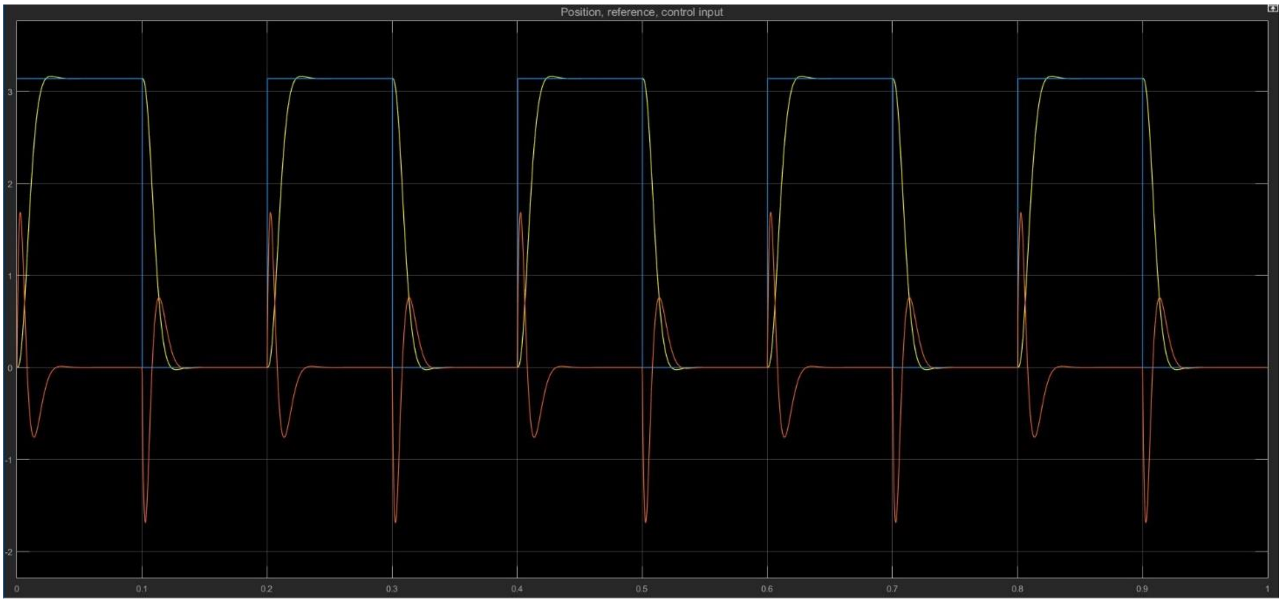


Figure 12: Response of the system with I-PD controller to the pulse input

It is also shown the response of the system to the pulse input in Figure 12. The system is durable to Pulse command as well.

At this point, we finalized the project and my internship process.

5. Conclusion

In my summer practice, I have been a part of TUBITAK Sage for four weeks and it was great opportunity for me to see how things going on work life and what engineers do in defense industry companies. This was my second experience as an engineer and there were plenty of thing happening around for me to observe. I understand the point that I need many practical approaches to learn in order to be a good engineer.

In the first project, I have worked on how to design a SMPS topology converter, especially Buck Converter, which are the main area of interest of Power Electronics subdivision. I worked on this converter with my supervisor engineer. First, I have done lots of researches on Synchronous Buck converter topology and external typed Mosfet controllers. After I have chosen my controller, I tried to model the circuit part by part by making some calculations. Then, I formed the circuit in LTSpice to simulate and analyze the problems and whether it works properly or not. After solving some little problems, I have finalized my circuit.

In the second project, I have designed a BLDC motor driver on Simulink. In order to do so, I first designed a current controller with PI controller to control the current and essentially torque in the BLDC motor. After that, I started working on position controller whose requirements were mentioned before. By using a I-PD controller and lots of research, I was able to design a proper BLDC motor controller.

All in all, this internship was very valuable experience for me. I have observed and learnt a lot about what engineers do in real life. Also, I observed several fields of electrical and electronics engineering. Finally, I think TUBITAK Sage is one of the places that a student should perform a summer practice since I have learnt many things from my supervisor engineers. There was a great atmosphere and I was thankful to them to provide me this opportunity.

I specially thank my supervisor, Mr. Yılmazkoçlar, for his great ability to lead and guide people. He has helped me a lot in my internship period. He is definitely a qualified engineer. Especially in hardware design, he taught me lots of things. He also transferred many practical experiences to me.

References

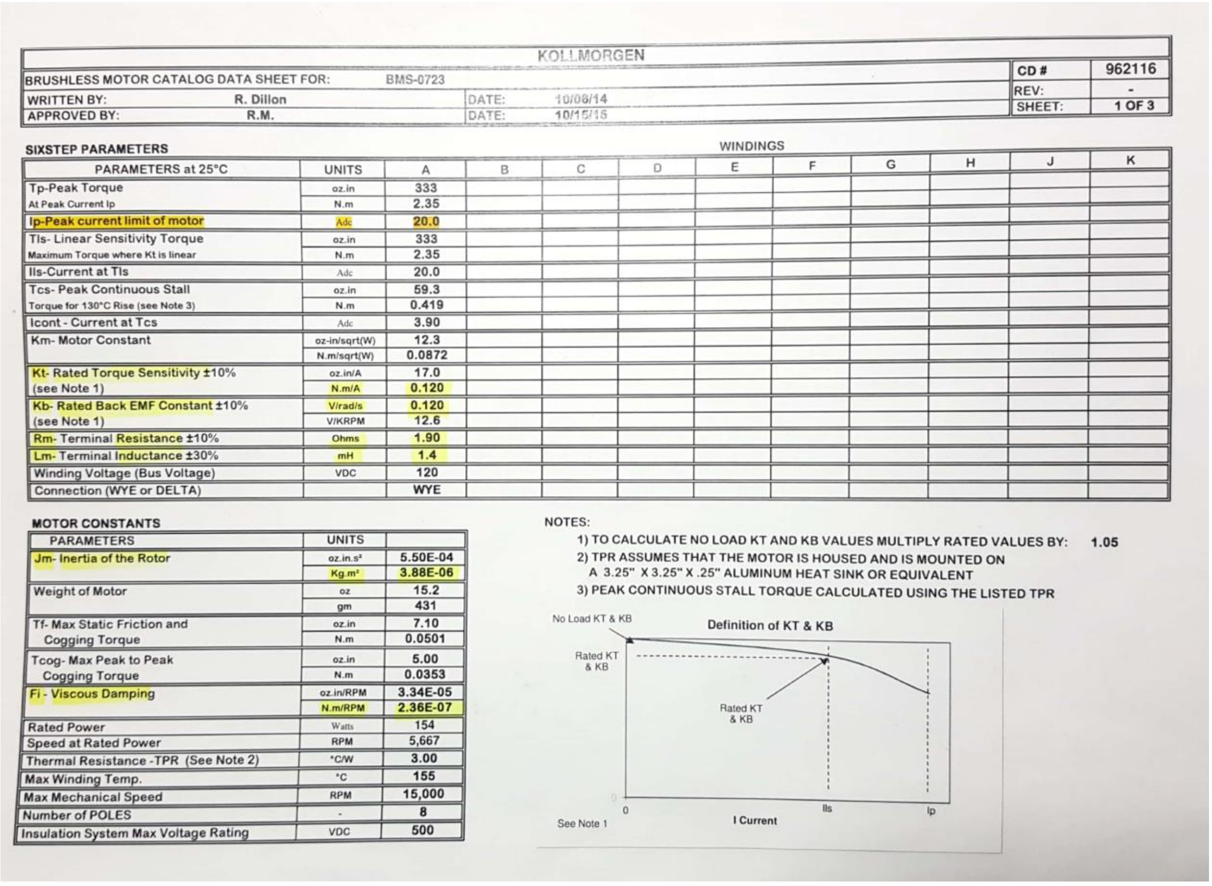
[1] ‘About Us’. Retrieved from http://www.sage.tubitak.gov.tr/en/kurumsal/about-us

[2] Lee, J. (2015). *Basic Calculation of a Buck Converter’s Power Stage*. Richtek Inc.

[3] *LTC3854, Small Footprint, Wide V_{IN} Range Synchronous Step-Down DC/DC Controller*. Linear Technology Inc.

[4] Yılmazkoçlar, Ali. (2002). *BLDC Motor Position Control*. Pg.6. METU

Appendix



KOLLMORGEN

BRUSHLESS MOTOR CATALOG DATA SHEET FOR:	BMS-0723			CD #	962116
WRITTEN BY:	R. Dillon	DATE:	10/08/14	REV:	-
APPROVED BY:	R.M.	DATE:	10/15/15	SHEET:	1 OF 3

SIXSTEP PARAMETERS

WINDINGS

PARAMETERS at 25°C	UNITS	A	B	C	D	E	F	G	H	J	K
Tp-Peak Torque	oz.in	333									
At Peak Current Ip	N.m	2.35									
Ip-Peak current limit of motor	Adc	20.0									
Tls- Linear Sensitivity Torque	oz.in	333									
Maximum Torque where Kt is linear	N.m	2.35									
Ils-Current at Tls	Adc	20.0									
Tcs- Peak Continuous Stall	oz.in	59.3									
Torque for 130°C Rise (see Note 3)	N.m	0.419									
Icont - Current at Tcs	Adc	3.90									
Km- Motor Constant	oz-in/sqrt(W)	12.3									
	N.m/sqrt(W)	0.0872									
Kt- Rated Torque Sensitivity ±10%	oz.in/A	17.0									
(see Note 1)	N.m/A	0.120									
Kb- Rated Back EMF Constant ±10%	V/rad/s	0.120									
(see Note 1)	V/KRPM	12.6									
Rm- Terminal Resistance ±10%	Ohms	1.90									
Lm- Terminal Inductance ±30%	mH	1.4									
Winding Voltage (Bus Voltage)	VDC	120									
Connection (WYE or DELTA)		WYE									

MOTOR CONSTANTS

PARAMETERS	UNITS	
Jm- Inertia of the Rotor	oz.in.s²	5.50E-04
	Kg.m²	3.88E-06
Weight of Motor	oz	15.2
	gm	431
Tf- Max Static Friction and Cogging Torque	oz.in	7.10
	N.m	0.0501
Tcog- Max Peak to Peak Cogging Torque	oz.in	5.00
	N.m	0.0353
Fi - Viscous Damping	oz.in/RPM	3.34E-05
	N.m/RPM	2.36E-07
Rated Power	Watts	154
Speed at Rated Power	RPM	5,667
Thermal Resistance -TPR (See Note 2)	°C/W	3.00
Max Winding Temp.	°C	155
Max Mechanical Speed	RPM	15,000
Number of POLES	-	8
Insulation System Max Voltage Rating	VDC	500

NOTES:

1) TO CALCULATE NO LOAD KT AND KB VALUES MULTIPLY RATED VALUES BY: 1.05

2) TPR ASSUMES THAT THE MOTOR IS HOUSED AND IS MOUNTED ON A 3.25" X 3.25" X .25" ALUMINUM HEAT SINK OR EQUIVALENT

3) PEAK CONTINUOUS STALL TORQUE CALCULATED USING THE LISTED TPR

Figure 13: Kollmorgen BLDC motor Datasheet