T.C.
FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

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DİDEM DİRMİLLİ

MSc THESIS
BIOMEDICAL ENGINEERING PROGRAMME

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THESIS ADVISOR
ASSIST. PROF. DR. H. ÖZGÜR TABAKOĞLU

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**FATİH ÜNİVESİTESİ**
**BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ**

# MİKROİŞLEMCİ TABANLI 3W-1470NM DİYOT LAZER SÜRÜCÜ DEVRESİ TASARIMI VE MEDİKAL UYGULAMASI

**DİDEM DİRMİLLİ**

**YÜKSEK LİSANS TEZİ**
**BİYOMEDİKAL MÜHENDİSLİĞİ PROGRAMI**

**DANIŞMAN**
**YRD. DOÇ. DR. H. ÖZGÜR TABAKOĞLU**

**İSTANBUL, MAYIS / 2015**

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**FATIH UNIVERSITY**

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**Didem DİRMİLLİ**, a **MSc** student of Fatih University **Institute of Biomedical Engineering** student ID 520113011, successfully defended the thesis entitled "**MICROCONTROLLER BASED 3W-1470NM DIODE LASER DRIVER DESIGN AND MEDICAL APPLICATION**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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**Director**

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**Date of Defense : 23 July 2015**

***To my fiance and lovely parents,***

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May 2015 Didem DİRMİLLİ

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## LIST OF SYMBOLS

| | |
|---|---|
| $V$ | Voltage |
| $I$ | Current |
| $L$ | Inductor |
| $C_{OUT}$ | Output Capacitor |
| $I_C$ | Capacitor Current |
| $I_L$ | Inductor Current |
| $I_{DC}$ | Direct Current |
| $I_{PEAK}$ | Peak Current |
| $\Delta$ | Delta Function |
| $I_{AC}$ | Alternating Current |
| $I_{TROUGH}$ | Trough Current |
| $I_O$ | Output Current |
| $r$ | Current Ripple Ratio |
| $V_{AC}$ | Alternating Voltage |
| $V_{DC}$ | Direct Voltage |
| $R$ | Resistor |
| $C$ | Capacitor |
| $I_D$ | Drain Current |
| $R_{DS}$ | Mosfet's On Resistance |
| $V_D$ | Diode Forward Voltage |
| $I_{RP}$ | Ripple Current |
| $V_{IN}$ | Input Voltage |
| $V_O$ | Output Voltage |
| $V_{SW}$ | Switching Voltage |
| $f_{SW}$ | Switching Frequency |
| $D$ | Duty Cycle |
| $R_{SENSE}$ | Sense Resistor |
| $K_P$ | Proportional Coefficient |
| $K_I$ | Integral Coefficient |

## ABBREVIATIONS

A/D : Analog/Digital
AC : Alternating Current
ADC : Analog to Digital Conversion
AMD : Age-related Macular Degeneration
CCM : Continuous Conduction Mode
CD : Compact Disc
DC : Direct Current
DCM : Discontinuous Conduction Mode
DVD : Digital Video Disc
Laser : Light Amplification by Stimulated Emission of Radiation
LASIK : Laser-Assisted in Situ Keratomileusis
LCD : Liquid Crystal Display
LPF : Low Pass Filter
Mosfet : Metal Oxide Silicon Field Effect Transistor
PDT : Photo Dynamic Therapy
PI : Proportional-Intragration
PWM : Pulse Width Modulation
RMS : Root Mean Square
SMPS : Switch Mode Power Supply
TACCR : TimerA Capture-Compare Register
UV : Ultra Violet

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## SUMMARY

## MICROCONTROLLER BASED 3W- 1470NM DIODE LASER DRIVER DESIGN AND MEDICAL APPLICATION

Didem DİRMİLLİ

Biomedical Engineering Programme

MSc. Thesis

Advisor: Assist. Prof. Dr. H. Özgür TABAKOĞLU

In recent years, the lasers often manifest successful results in all areas of life. The new laser diode wavelength 1470nm is started to use in biomedical applications and also successful results has been shown in coagulation, vaporization and tissue removal areas.

Looking at the studies in the literature, the success of UV laser light has been demonstrated in laser tissue welding. Because of the fact that, 1470nm is also in the range of UV laser, the impact of that laser in laser tissue welding has made sensation.

In this study, 1470nm laser diode with output power of 3W is designed and manufactured. The driver circuit is designed in buck converter topology that provides the current required to operate of diode laser. Control of the diode current is done by the microprocessor unit by using PI software. In addition to this, the PWM signal that provide to operate the buck converter driver circuit is generated by the same unit. The user interface part includes 4x20 LCD that provides to see the diode current and potatntiometer which enable to set the diode current in amperes and adjust operating duration in seconds. After completion of necessary checks of designed laser driver circuit and making sure that the application works accurately and efficienly, it is going to use in the field of laser tissue interaction.

**Keywords:** 1470nm diode laser, laser tissue interaction, buck topology laser driver

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# ÖZET

## MİKROİŞLEMCİ TABANLI 3W- 1470NM DİYOT LAZER SÜRÜCÜ DEVRESİ TASARIMI VE MEDİKAL UYGULAMASI

Didem DİRMİLLİ

Biyomedikal Mühendisliği Programı

Yüksek Lisans Tezi

Danışman: Yrd. Doç. Dr. H. Özgür TABAKOĞLU

Lazerlerin hayatın her alanında sıklıkla karşımıza çıktığı son yıllarda, biyomedikal alanda yeni sayılabilecek olan 1470nm diyot lazerin koagülasyon(pıhtılaştırma), vaporizasyon(buharlaştırma) ve doku kesip alma konularında başarılı etkiler ortaya koyduğu görülmüştür.

Literatürdeki araştırmalara bakıldığında, lazerle doku kaynağı konusunda genellikle UV lazerlerin başarı göstermiş olması, 1470nm lazerin bu konudaki etkisini araştırma konusunda merak uyandırmıştır.

Bu çalışmada 3W çıkış gücüne sahip 1470nm diyot lazerin sürücü devresi tasarlanıp üretimi gerçekleştirilmiştir. Sürücü devresi alçaltıcı dönüştürücü topolojisinde tasarlanmış olup, diyot lazerin çalışması için gerekli olan akımı sağlamaktadır. Diyot çalışma akımının kontrolü mikroişlemci kullanılarak PI kontrol yazılımı ile sağlanmıştır. Ayrıca alçaltıcı dönüştürücünün çalışmasını sağlayan PWM sinyali de mikroişlemci tarafından üretilmektedir. 4x20 LCD ve potansiyometre kullanılarak oluşturulan arayüz kullanıcaya lazerin akım değerini ve çalışma süresini değiştirme imkanı sunularak, LCD' den bu değerlerin görülmesi sağlanmıştır. Tasarlanan lazer sürücü devresinin gerekli kontrolleri tamamlanarak sorunsuz bir şekilde çalıştığından emin olunduktan sonra lazer doku kaynağı alanındaki uygulamalarda kullanılması amaçlanmıştır.

**Anahtar kelimeler:** 1470nm diyot lazer, lazer doku kaynağı, alçaltıcı dönüştürücü lazer sürücü

# CHAPTER 1

# INTRODUCTION

## 1.1 Literature Review

Looking at the studies in the literature, it is seen that several lasers in different wavelengths have been used on laser tissue welding by the researches. One of the research group Alimova et.all performed their research on the healing process of guinea pig skin which has 4 incisions with 1cm long and 2mm deep on the back of each them. To control the healing process, one of the incision sutured with nylon, and rest of 3 closed with laser welding. For welding, 1455nm continuous wave fiber laser and 1560nm femto second pulsed fiber laser are used. At the end of 40-day healing period, they are observed that laser tissue welded skin looked like normal skin[1].

Tabakoğlu et. all used 980nm diode laser for their study to investigate two different application methods on dorsal skin of Wistar rats. By performing this study, they aimed to show the effects of high power and low power applications of same energy level 980nm diode laser on skin tissue[2]. According to another study by Tabakoğlu and Özer, they searched the effects of 3 different laser wavelengths which are 809nm, 980nm, 1070nm in tissue welding and got different results. They conclude that wavelengths should be chosen according to the specific welding purpose[3].

Fried and Walsh made 2cm long, full-thickness incisions on the backs of guinea pigs for welding. They used Nd:YAG laser for welding the some of wounds and others closed with sutures. In this study, the tensile strength and the wound healing process are observed[4].

Oz et all. examined the effects of two different lasers that are the thulmium-holmium-chromium THC:YAG (2,150 nm) and argon ion (488-514 nm) on the gallbladder cystic duct. The aim of this research was to define suitable parameters for tissue welding[5].

Considering the application that related to 1470nm diode laser, Havel et. all compared coagulative tissue effects of 2 different lasers wavelength; 1470 and 940 nm in treatment of hyperplastic inferior nasal turbinates. As a result of this study, 1470nm laser application showed similar tissue reduction using less total energy with reduced scab formation and improved healing postoperatively[6].

Another study by Sroka et.all determined the impacts of different lasers on vaporization, coagulation, ablation and sealing. For this aim, porcine kidney model is used and coagulation rim, ablation volume and degree of sealing are determined. 2 different diode laser wavelengths ( 980 nm, 1470 nm; c.w. mode), Ho:YAG laser (2100 nm; pulsed) and the KTP laser ( 532 nm; c.w. mode) lights applied on the surface of the perfused ex-vivo porcine kidney model. As a conclusion; they showed that being related with laser power, varied degree of ablation, coagulation and also carbonisation could be induced. In addition to this, they revealed if the power applied to the tissue exceeds a certain thresold, laser induced tissue removal could be achieved[7].

## 1.2 Purpose of the Thesis

Laser refers to the 'Light Amplification by Stimulated Emission of Radiation' which is a device that emits intense beam of coherent light. It is used in many areas such as; communication, medicine, industry, military. The reason of being so valuable of lasers in every field is the characteristics of the light that is produced by them.

Lasers emit coherent beam of light in the range of visible, ultraviolet and infrared wavelength regions. They give narrow beam of radiation that provide to focus on a small point and transmit high energy to that point. Since they are so powerful, even cutting applications they are used. These properties make lasers essential for using in many areas of medical diagnosis and treatment and biomedical application such as; photodynamic therapy, laser tissue welding, photocoagulation etc.

In this study, because of the fact that it is a new laser wavelength which is started to use in biomedical applications and is still under research that on which application area is more effective, the 1470nm diode laser has been chosen.

The aim of this study is to design the driver circuit of 3W-1470nm diode laser that operates in continuous mode, secondly, researching the efficiency of this laser in the area of laser tissue welding. In more detail, the driver circuit will be designed in buck converter structure by using the MSP430G2553 microchip and some other electronic components. This designed circuit will allow user to adjust the output optical power respect to the duty cycle- current.

## CHAPTER 2

## DIODE LASER

Laser stands for 'Light Amplification by Stimulated Emission of Radiation' which is a device that is used in many areas such as; optical communications, in space exploration, barcode scanner and medical applications[8].

The main features of lasers light are being monochromatic, coherent, and highly collimated. Also this device produces intense beam of light. To explain each term briefly; the wavelength of laser light that define the emission region of light , is extremely pure when compared to other sources of light, which indicates being monochromatic, and all of the photons that form the laser beam have a constant phase relationship in between. This characteristic called as coherence [8].

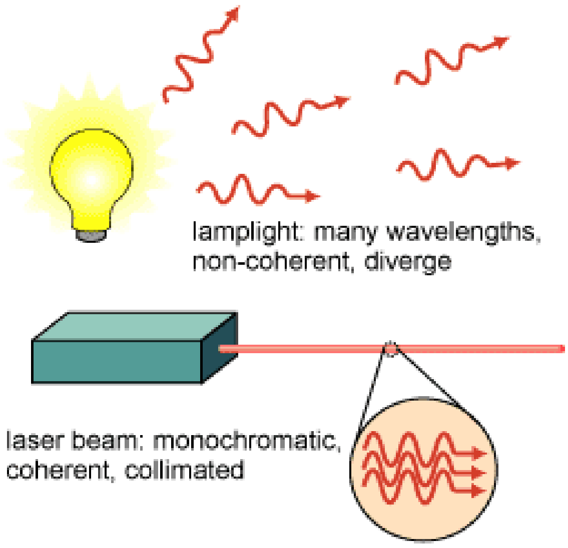


Figure 2.1 Laser Light [9]

Another feature of laser light is to have low divergence. This means the beam radius does not change over the distances so it is said that collimated beam of light. Because of these properties, lasers are used in a wide variety of applications in all fields of life[8].

## 2.1 Working Principle of Diode Laser

The three main component parts of the laser are amplifying medium, resonator and pumping which are shown below [10].

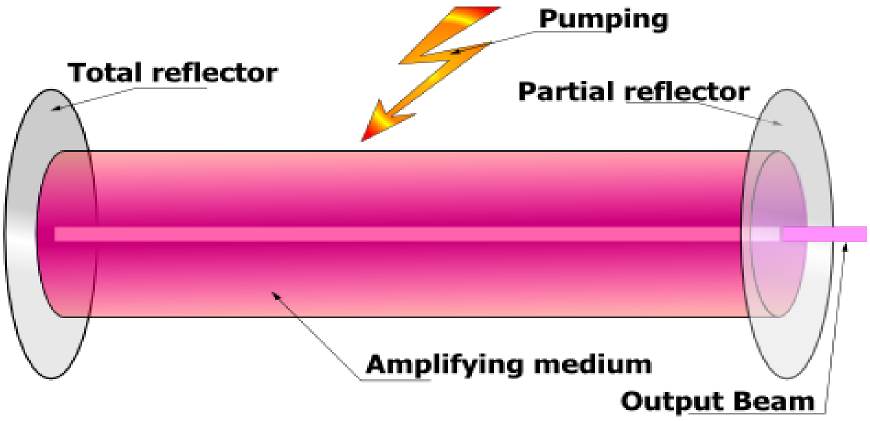


Figure 2.2 Laser Schematic [10]

In this configuration the task of pumping mechanism (either electrical or optical energy) is to provide energy to an active material for producing population inversion that means higher electron population in the upper energy level compared to the lower energy level in active material[8].

In general, there are two types of emission; spontaneous emission and stimulated emission. As the name suggests, stimulated emission constitutes the laser light.

When an electron is in an excited energy state, as the nature of it, it decays to a lower level in time by releasing energy in the form of photon. This emitted photon is in random direction and random phase. This process is called as “spontaneous emission” [8].

The stimulated emission is important process that constitutes the one of the major parts of the laser principle. There is an electron in E2 energy level and normally it should decay to E1 energy level in some time by emitting a photon which is a random direction as stated before. But if a photon which has energy equals to the difference between E2 ad E1 stimulate the electron to decay lower energy level, in this manner the emitted photon will be in the same direction, at exactly the same wavelength, and the same phase as the stimulating photon. This is called “stimulated emission”. Absorption, spontaneous emission, and stimulated emission are shown in figure 2.3 [8].

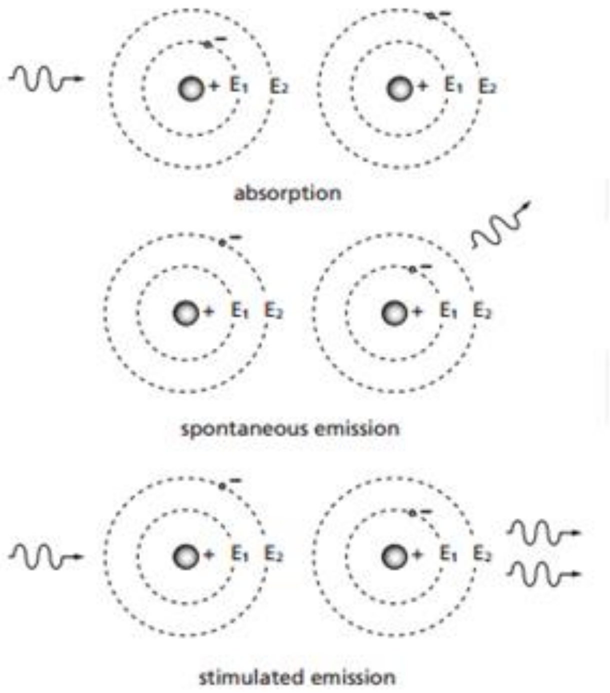


Figure 2.3 Stimulated and spontaneous emission[8]

The light amplification part of the laser is done by the mirrors that are oriented at two terminals of the laser medium. The mirrors main characteristic is one of them reflects all of the lights and the other reflects some of light and emits the rest. By going forth and back between these two mirrors, photons stimulate many electrons that result in increased emission of photons with same wavelength. Finally these photons leak from the mirror which has gap to emit the lights[11].

## 2.2 Usage Areas of Lasers

### 2.2.1 Industrial Applications of Lasers

Today lasers have broad usage areas in industry to perform important tasks. Use of lasers in all industries from automobile to mining sectors became popular since it is making easier the tasks.

To be listed briefly; lasers generally used to measure distance, cutting, welding and drilling in industry. For example; the surveyors use lasers to measure distances. Since laser light travels constant speed , they sent laser light to a reflector at a point that want to measure, by determining the reflection time get the distance between laser and reflector. Also astronauts uses the same manner to measure the distance between Earth and Moon. For laser cutting applications very powerful lasers are used that can also focuse in very small area and produces huge heat to cut the metarial. For this purpose generally Excimer and Carbon Dioxide lasers are prefered. Another example is to determine the drilling direction the lasers is used in mining industry. Also automobile spark plugs, portable batteries and such items are welded by lasers. For production of copper wires laser drill is used[13]. Finally, in supermarkets everbody can see lasers as barcode scanner for identifying the products[14].

### 2.2.2 Environmental Applications of Lasers

Laser technologies is used for environmental application to identify the environmental toxins in smoke and by using lasers it can be checked the amount of photochemical in smog and ozone. Also for supervising wastewater purification it is benefitted from lasers[12].

### 2.2.3 Lasers in Communication

Because of the fact that fiber optic cables has nearly 100,000 times greater bandwidth than normal copper wire, it is popular in communication sector. Since laser light has huge transmiting capacity and high speed for carrying data via fiber optics, they are used as the light source of the optical communcation[12].

### 2.2.4 Lasers in Research

For researches like physics, chemistry, biology and medicine, lasers are one of the most important tools that is used to:

- Register ultra fast chemical processes such as the bonding between atoms to form molecules,
- Study the process when cells split, or a virus enters into s cell,
- Manipulating  molecules down to extremely low temperatures,

- Transfer as much energy as possible to different materials in a short time to obtain different types of emissions[12].

### 2.2.5 Lasers in Medicine

Over the past half century, lasers are used to perform important tasks such as; ablation, coagulation and vaporization in almost every field of medicine. Also it has wide application areas in biomedical researches.

Such features as; being coherent and powerful, able to focusing on a small point, giving high power density distinguishes the lasers from other light sources. These properties make lasers essential and popular in many areas of medical treatment and diagnosis. The usage areas of lasers in medicine are detailed listed and explained below[12].

#### 2.2.5.1 Lasers Repair Skin and Eyes

Lasers were used in ophthalmology and dermatology for many years. Leon Goldman showed that how to remove port wine stains and melanomas with ruby lasers in 1961.

Nowadays, applications like tattoo removal, birthmark removal and hair removal are widely done by lasers in dermatology. In deciding which type of laser and which wavelength of light will be used, the type of lesions and the main absorber in it are considered. Also the type of patient's skin is efficient determining the wavelength of laser.

In order to treat the detached retinas argon lasers are used by ophtalmologists. The green light which is emitted by argon laser is absorbed by hemoglobin; for this reason argon lasers are also used to stop bleeding blood vessels.

UV light emitting excimer lasers are preferred by both dermatologists and ophtalmologists for several applications. For example; LASIK application which means reshaping of corneas, and removing spots and wrinkles from the face are performed with excimer lasers[12].

#### 2.2.5.2 Lasers in Imaging

Just as many other diseases, in cancer detection lasers have a major role for imaging. For example; in mammography, instead of traditional x-ray imaging, laser-based systems are started to use. Using x-rays reveal a challenge: being able to detect the cancer cells high intensity x-ray beams are needed, but when the intensity of the x-ray is increased the risk of being cancer also increase[12].

#### 2.2.5.3 PDT

In a photodynamic therapy, the natural dyes which called as photosentisizers are used to dye the selected cells. These photosentisizers feature is being light-activated drug and collected by more cancer cells than normal ones. After injection of these drugs to the patient, under laser light photosensitizers are activated and produce a toxic reaction that destroys the tumor without damaging the healthy cells[12,15].

#### 2.2.5.4 Other Applications of Lasers in Medicine

Urologists can treat urethral strictures, benign warts, urinary stones, bladder obstructions, and enlarged prostates with lasers.

For precision cutting and endoscopic guidance into the brain the lasers are used by neurosurgeons.

Veterinarians make use of lasers for endoscopic procedures, photocoagulation of tumors, excision, and photodynamic therapy.

Dentists use lasers for removing lesions, teeth whitening, drilling cavities, gum disease, and tooth decay[12].

# CHAPTER 3

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## SMPS- BUCK CONVERTER

A switching-mode power supply is an electronic device that is composed of low loss components such as capacitors, inductors, and transformers and the use of switches. Since the switch is very fast between on and off state, it dissipates very little power and total power loss can be considered as minimal between conversion, so it is said that high efficient electronic device[17].

Since the switching regulator reveals many advantages like higher power conversion efficiency compared to linear regulators, smaller size (it is working with high frequency, so it reduces the size of the components), lighter weight and increased design flexibility, it has high popularity[18].

There are four types of switching converter:

- Buck Converter: decreases a DC voltage to a lower DC voltage.
- Boost Converter: increases the input voltage to the desired output voltage level.
- Buck-Boost Converter: the output voltage is either greater than or less than the input voltage.
- Flyback Converter: that includes electrical isolation by the help of transformer and the output voltage can be less than or greater than the input.

Before explain the SMPS basics, it can be a good point to start from the law of inductance which is one of the main parts of the configuration.

### 3.1 Law of Inductance

According to Ohm's law, if an inductor wired to a voltage source, a current will flow through that inductor and electrical energy is stored in the form of magnetic field in the coil. The most important point is that the current will be time-varying regardless of the voltage. More precisely, even if the voltage is constant, the current will be time-varying.

The fundamental equation that defines the relationship between the voltage and current in an inductor is given below:

$$V = L \times \frac{di}{dt} \tag{3.1}$$

From this equations we can understand that the inductance has two important characteristics:

**1)**To induce a voltage across an inductor, it is needed to time varying current. The current level remains unchanged when DC flows to the inductor, so no inducted voltage is produced[18].

**2)** An inductor opposes any change in the value of current flowing through it. A current flowing in an inductor can not change value instantly (in zero time). To change the current abruptly, the infinite voltage is required.

**Note:** Unlike the current flowing in the inductor, the voltage across it can change suddenly (in zero time). The principles of inductance are shown in the light of given characteristics in above in Figure 3.1.[17].

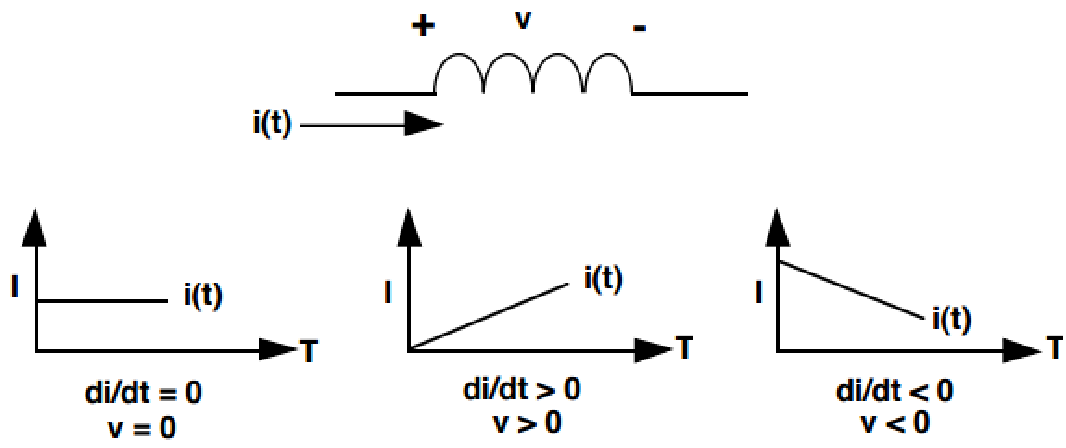


Figure 3.1 Inductor voltage/current relationship[17]

di/dt term is the significant parameter that enable us to evaluate the changing in current with time. To identify di/dt term, slope of the current versus time plot at any given point can be used. For reviewing given graphs above, when it is applied constant current, zero di/dt value is obtained which is shown in the first plot(on the left), and also there is no voltage across the inductor. The second graph(in the middle) shows that, a current increasing with time gives a positive di/dt value and resulting in a voltage greater than zero. The reverse process is given in the third plot(on the right). A current that decreasing with time has negative di/dt value, and also the voltage is negative across the inductor. It should be noted that, the constant voltage across the inductor results in a linear current ramp[17].

## 3.2 Buck Converter

Buck converter is the most basic SMPS topology which widely used throughout the industry to convert a higher input voltage into a lower output voltage levels.

## 3.3 Working Principle of Buck Converter

As it is stated in the name, the main idea of the buck topology switching power supply is the switching approach. Under favour of storing energy capability of inductor, by quickly switching the input of inductor/capacitor circut between the source voltage and ground, conversion of higher input voltage to a lower output voltage is obtained[19,21]. Basic buck converter topology including inductor, diode, switch and capacitor is given in figure below.

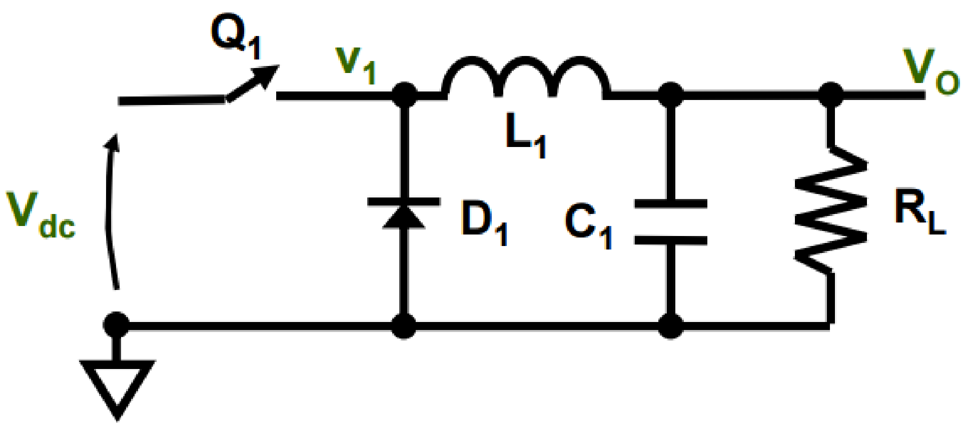


Figure 3.2 Basic buck converter circuit[19]

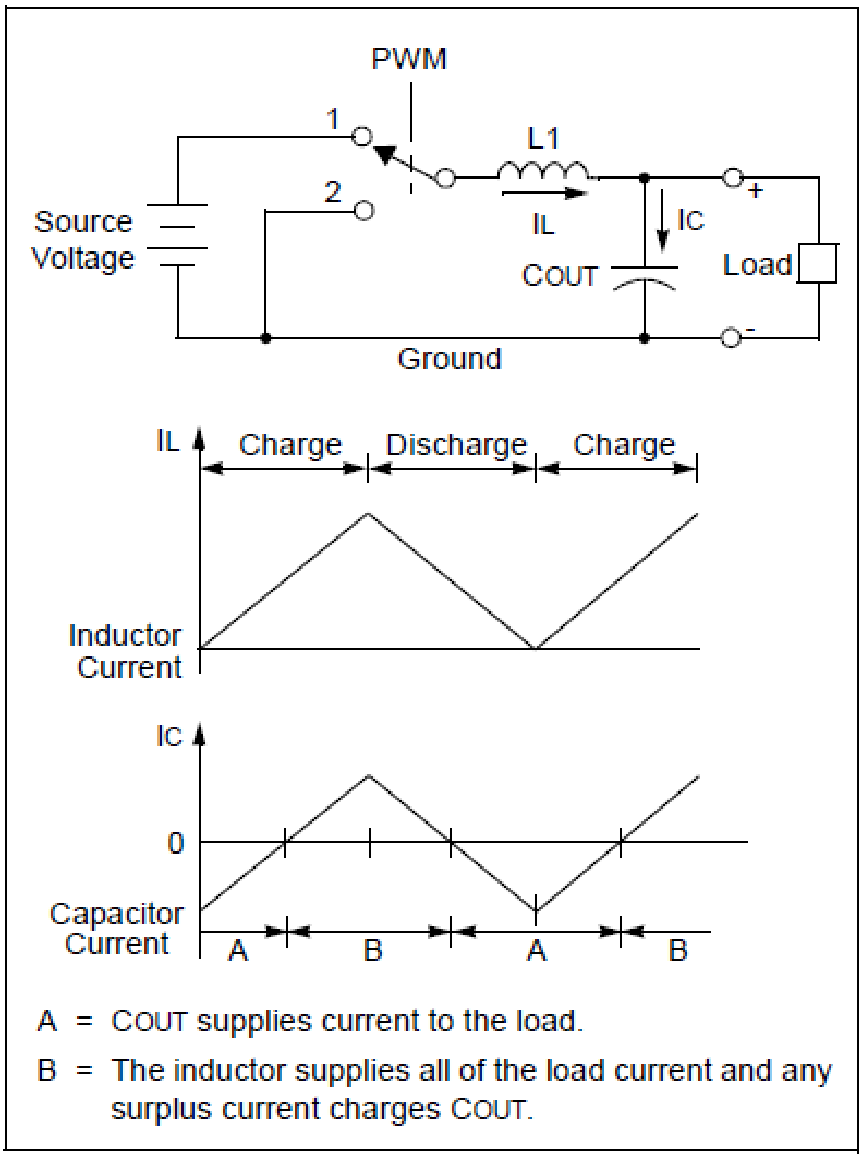


Figure 3.3 Buck topology switch cycle [21]

As it is seen from figure 3.3; there is two positon of the switch and the switch perform its task with PWM pulses. While the PWM switch is in position 1, the inductor L1 is wired to the source voltage, the charging phase of the source is started, and a current flows ($I_L$) through the inductor, to the load and $C_{OUT}$. In this way, the inductor stores part of energy in the form of magnetic field. When the switch position changed from 1 to 2, the discharging phase is started, the magnetic field around the inductor collapses, the current continues to flow through the load. Now the diode is forward biased, so the current that is supplied by inductor completes its path over the diode. From the inductor current graph of figure 3.3 it is seen that, when $I_L$ drops to zero, the new charge-discharge cycle starts by switching PWM button to position 1. In every switching cycle the inductor current increase and decrease linearly over the course of a cycle. The task of capacitor ($C_{OUT}$) in the LC network is smoothing $I_L$ that flows to the load. In capacitor current graph part B shows that, when inductor current($I_L$) is greater than the load current, load is supplied by inductor current and any surplus current charges the output capacitor($C_{OUT}$). The part A of the capacitor graph illustrate that, if inductor current can not supply required amount of current to the load, the capacitor current reverses and make addition to inductor current to supply the amount of current that is the difference between inductor current and required load current. When describing the procedure of the switch control in a switching power supply design, the charge time and total switching time should be determined. According to this, the duty cycle term can be calculated as charging time over the total switching time[20,21].

## 3.4 Buck Converter Operation Modes

There is 2 different modes of operation for buck converter that are continuous conduction mode(CCM) and discontinuous conduction mode(DCM). In a discontinuous conduction mode, the inductor current drops to zero for a portion of the switching cycle. It starts at zero, increasing up to reach a peak value and returns to zero during each cycle of switching period. However, in a continuous conduction mode, the inductor current flows continuously during the whole cycles of switching period and does not drop to zero[26]. In the waveform of resulting inductor current AC and DC components are included. The DC component defines the average current flow during the cycle. The AC component is results of the switching action and it has a triangular shape waveform that super-imposed on the DC component. Since reducing the charge storing requirements of $C_{OUT}$ by flowing to the output continuously, the continuous current design is more favourable[20-21].

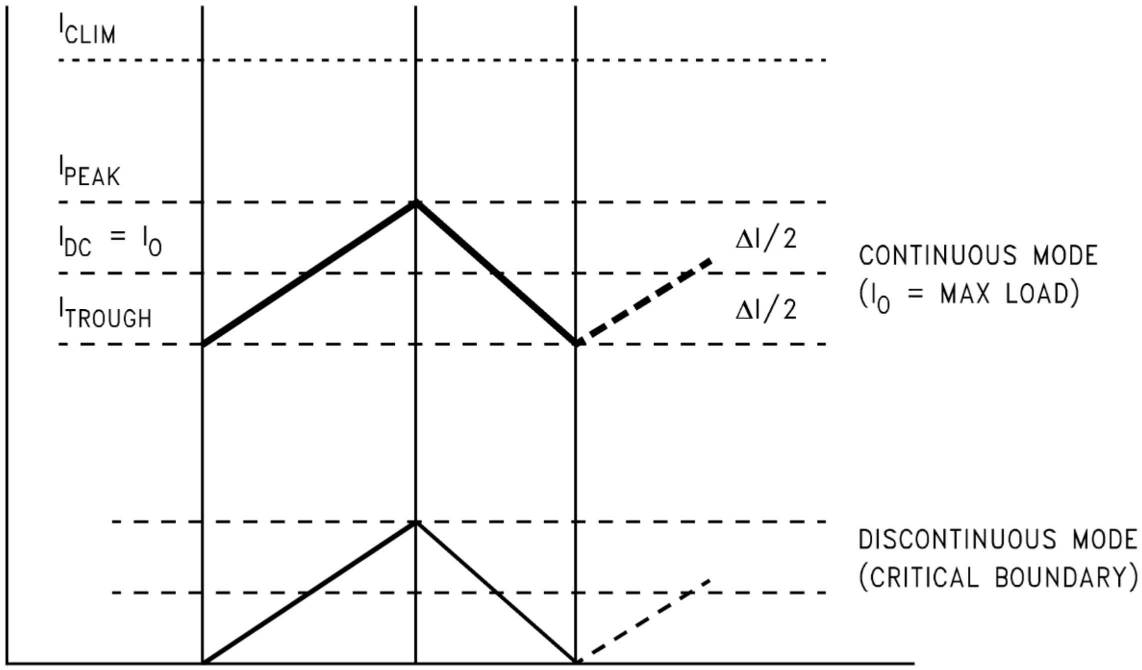


Figure 3.4 Inductor current waveform [26]

The detailed interpretation of the inductor current waveform is given below:

**1.** $I_{DC}$

- is the geometrical center of the AC component,
- is the average of the total inductor current,
- is the current which flows into the load

**2.** $I_{PEAK}$ is $I_{DC} + \Delta I/2$, and it determines the peak value that the core must withstand without saturating.

**3.** $I_{TROUGH}$ is $I_{DC} - \Delta I/2$ and determines the constant residual level of current/energy in the inductor.

**4.** The AC component of the current is calculated as:

$$I_{AC} = \Delta I = I_{PEAK} - I_{TROUGH} \tag{3.2}$$

**5.** The DC component is the load current, $I_{DC} = I_O$ where $I_O$ is the maximum rated load.

**6.** ‘r' is defined as the ratio of the AC to DC components (current ripple ratio) evaluated at maximum load, $I_O$. By definition 'r' is a constant for a given application (as it is calculated only at maximum load), and it is calculated only for continuous conduction mode.

$$r = \frac{\Delta I}{Io} \tag{3.3}$$

A high inductance reduces ΔI and results in lower ‘r' (and lower RMS current in the output capacitor), but may result in a very large and impractical inductor[26].

# CHAPTER 4

## SYSTEM DESIGN

Our diode laser driver system shown in the Figure 4.1. It has supply voltage of $220V_{AC}$ which is converted to $12V_{DC}$ by power supply unit. The buck topology laser driver decreases $12V_{DC}$ to $2V_{DC}$. This unit can provide 10A current that laser needs. Also the control part of the driver is done by the microcontroller unit. The user interface enables the communication between system and the user.

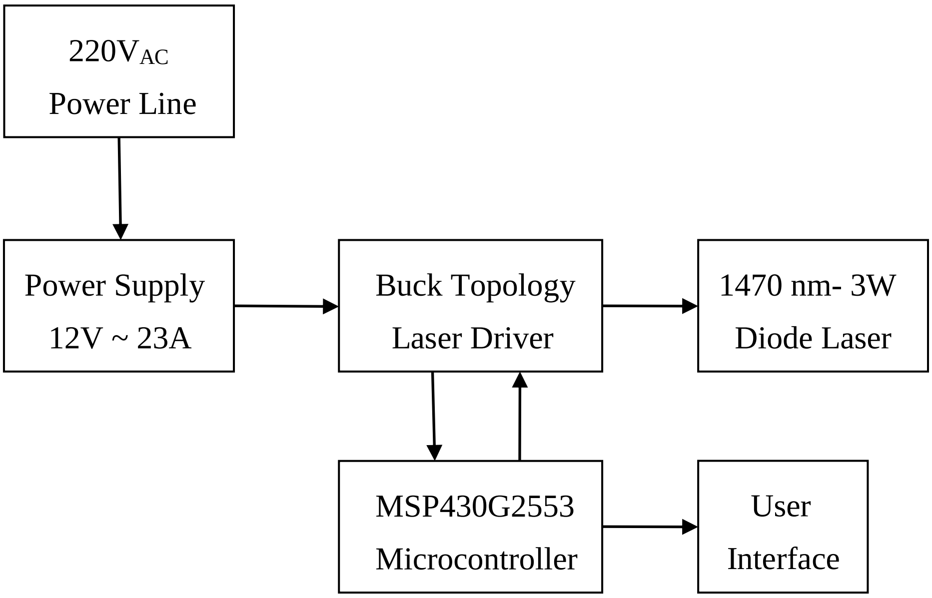


Figure 4.1 Block Diagram of the diode laser system

### 4.1 Power Supply Unit

Power supply unit MS28012 is manufactured by Mervesan Electronics and it supplies 12 $V_{DC}$ voltage and 23A current at maximum load. Also, it has selectable AC input voltage range 110-220 $V_{AC}$ by switch and it includes short circuit and overload protection. This unit is used to energize the buck topology converter, that supplies voltage to the diode laser, because of high output supply current and its reliability[24]

### 4.2 Buck Topology Driver

This is the main part of the driver circuit which supplies 10A current to laser diode in order to generate 1470nm laser light. It has $12V_{DC}$ input voltage which reduced to $2V_{DC}$ at the output. This driver generally composed of high current p-type mosfet, inductor and diode. Because of the lack of high current and high capability inductor in the market, it is winded by us. The PWM pulses are provided by the microcontroller to the mosfet. In figure the buck topology driver circuit shown which drawn with LT Spice.

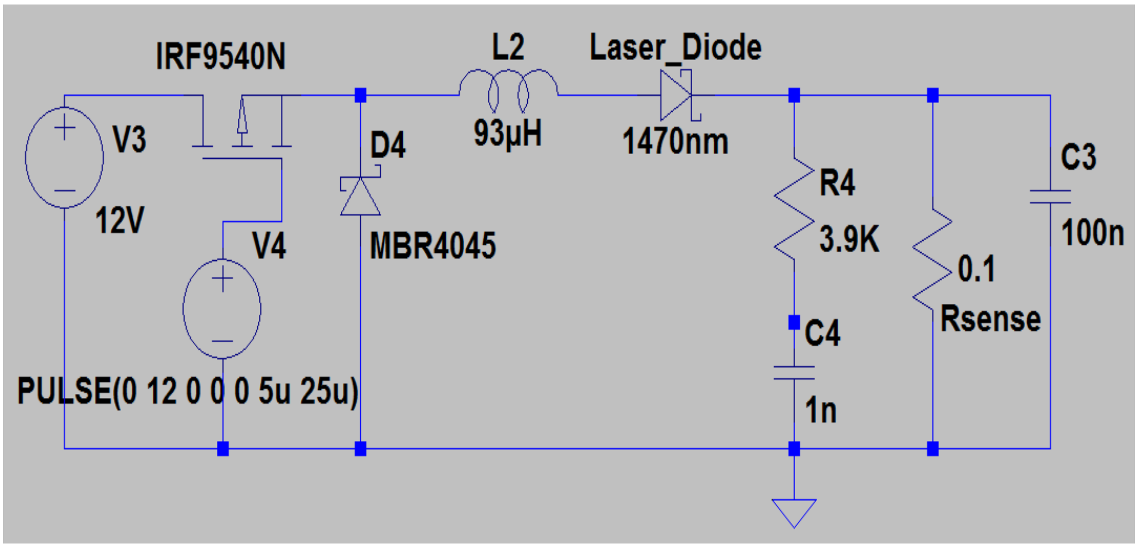


Figure 4.2 LT Spice Drawing of buck topology converter

#### 4.2.1 Driver Components Selection

Designing a buck topology driver requires the selection of 7 componets for operation of it. These components are:

• MOSFET

• Diode

• Inductor L1

• ADC measurement circuit

• Current-sensing resistor $R_{SENSE}$

• The LPF components R2 and C2

#### 4.2.1.1 Mosfet Transistor

The transistor must handle the maximum current output of the laser driver. Therefore, the minimum current rating for the transistor ($I_D$) is determined by the combined peak value of the DC and AC components of the diode laser current waveform.

Since our diode laser operates at 10A average current, our peak current is going to be 10.250A according to our ripple current. And due to the power disspation the $R_{DS}$ value should be minimized.

According to these points we selected the IRF9540N mosfet which manufactured by International Rectifier Company that can carry 23A ,100V with on resistance $R_{DS}$ = 117mΩ. The output characterictics of the mosfet shown in figure[23].

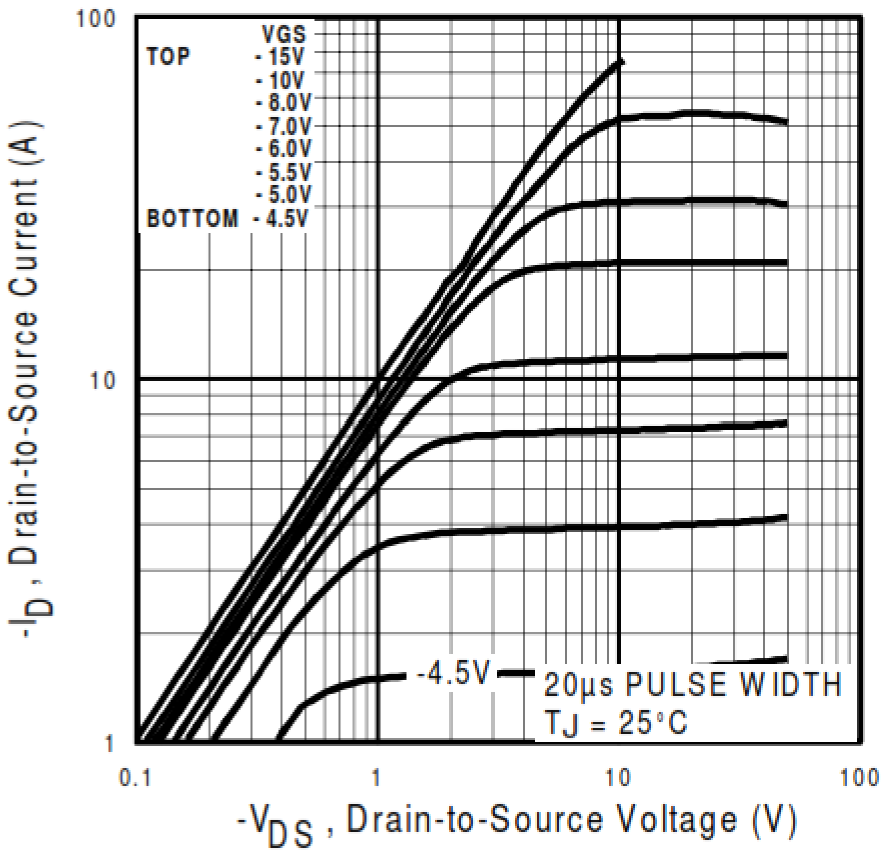


Figure 4.3 Output characterictics of the mosfet[23]

#### 4.2.1.2 Diode Selection

The diode have to carry the inductor current during the discharge phase, so it can stand to 10A for this design. Also its forvard voltage should be minimized due to power disspation. When these two parameters considered, a diode which meets the requirements of the design is the MBR4045 that can carry 40A and $V_D$ =0.6[25].

#### 4.2.1.3 Inductor Selection

When selecting inductor the given factors in below should be determined:

- Switching frequency
- Peak-to-peak AC component ($I_{RP}$)
- Inductance

For this design, the switching frequency determined as 40 kHz . For the ripple current, to obtain more like DC current, we limited the ripple %5 of the average current which means that the r value was calculated as 0.05. The current required for 3W optical output power of diode laser is 10A. Thus, for calculation of peak current, a DC component of 10A and the half of the AC ripple component ($I_{RP}$ = 500mA peak to peak) should be added. Finally we calculated our maximum current as 10.250A (10A+ (500mA/2)). The inductor should carry this amount of current.

As the calculation of required inductance:

From the general equation of inductor:

$$V = L \times \frac{di}{dt} \tag{4.1}$$

We can get this equation during the on time of the mosfet:

$$Vin - Vsw - Vo = L \times \frac{\Delta I}{D/f} \tag{4.2}$$

where $V_{IN}$ is the applied input DC voltage , $V_{SW}$ shows the voltage across the mosfet when it is on state, D indicates the duty cycle and f is the switching frequency in Hz. Since:

$$r = \frac{\Delta I}{Io} \tag{4.3}$$

From equation 4.2 ΔI term is pulled and written in equation 4.3, the new 'r' equation obtained as:

$$r = \frac{(Vin - Vsw - Vo) \text{ x } D}{L \text{ x } f \text{ x } Io} \tag{4.4}$$

For a buck converter, the duty cycle can be calculated with this formula:

$$D = \frac{Vo + VD}{Vin - Vsw - VD} \tag{4.5}$$

Where $V_D$ indicates the forward voltage drop across the diode (0.6V for selected diode MBR4045).

‘r' can be finally written as:

$$r = \frac{(Vin - Vsw - Vo) \text{ x } (Vo + VD)}{(Vin - Vsw + VD) \text{ x } L \text{ x } f \text{ x } Io} \tag{4.6}$$

And L is therefore:

$$L = \frac{(Vin - Vsw - Vo) \text{ x } (Vo + VD)}{(Vin - Vsw + VD) \text{ x } r \text{ x } f \text{ x } Io} \tag{4.7}$$

According to these equations, L is calculated as 93uH with 10A current carrying capacity[26,27,28].

#### 4.2.1.4 ADC Measurement Part

For measurement of current $R_{SENSE}$ resistor is used. The voltage across that resistor is read by ADC unit of microcontroller, and via the software related current value is calculated. To protect the microcontoller pins which are using for reading voltage, diode is used. Thus if the voltage exceeds 3.3V, the current will flow to ground over the reverse polarized diodes. The circuit related with ADC measurement is given below:

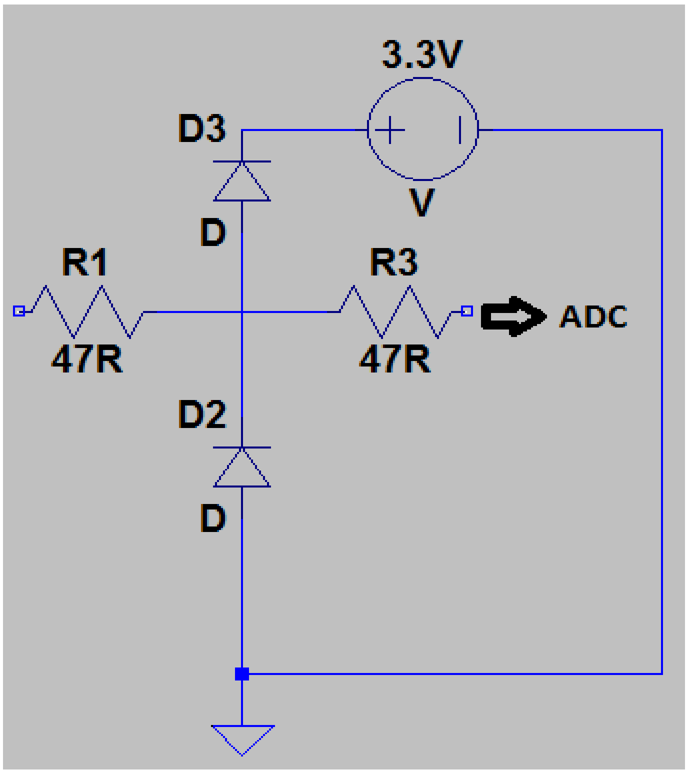


Figure 4.4  ADC Measurement part

#### 4.2.1.5 $R_{SENSE}$ Selection

Resistor $R_{SENSE}$ is used to measure the amount of current flowing into the inductor/laser. But it has two important requirements. It should be large enough to generate a feasible feedback voltage, but it should also be small enough not to dissipate too much power. For this design, 0.1Ω/50W resistor was chosen. It generates 1V for 10A and disspates 10W.

#### 4.2.1.6 LPF Components Selection

Since the switching frequency $f_{SW}$ is known, it is simple to determine R2 and C2 values. Suitable combination of values can be determined from Equation 4.8.

$$fsw = \frac{1}{(2\pi RC)} \tag{4.8}$$

According to the equation 4.8, a value of 1nF for C2 and a value of 3.9k for R2 are choosen to produce a switching frequency of approximately 1kHz.

As a results , our components are shown in the table.

Table 4.1 Selected components

| | |
|---|---|
| Mosfet | IRF9540N -23A / -100V / $R_{DS}$=117mΩ |
| Diode | MBR4045 40A / 45V |
| Inductor | 93uH |
| R2 for LPF | 3.9kΩ |
| C2 for LPF | 1nF |
| $R_{SENSE}$ | 0.1Ω / 50W |

And the buck converter design parameters are listed below.

Table 4.2 Operating parameters

| | |
|---|---|
| Input Voltage, $V_{IN}$ | 12V |
| Output Voltage, $V_O$ | 2V |
| Output Current, $I_O$ | 10A |
| Switching Frequency, $f_{SW}$ | 40kHz |
| Inductor Current Ripple, ΔI | 5% |

## 4.3 Microcontroller Unit

In this unit, MSP430G2553 microcontroller is chosen due to its peripheral features listed below:

- Low Supply-Voltage Range: 1.8V to 3.6V
- Ultra-Low Power Consumption
- Two 16-Bit Timer_A With Three Capture/Compare Registers
- On-Chip Comparator for Analog Signal Compare Function or Slope Analog Digital Cycle Time (A/D) Conversion
- 10-Bit 200-ksps Analog-to-Digital (A/D) Converter With Internal Reference, Sample and-Hold [29]

MSP430G2553 is the most important component, in fact the brain of the driver because it controls the diode current with PWM by the help of PI loop. Also it provides the communication between user and laser driver by user interface.

### 4.3.1 Software Description

The software written in C programming language is compiled in IAR Embedded Workbench program. The main function configures the timerA, LCD and ADC. With TACCR0 and TACCR1 registers, PWM signal has produced that is needed for mosfet operation and TACCR2 is used to trigger ADC. The ADC conversions of the current are done over the ADC circuit that is taking average of 10 voltage samples. For determining setpoint, it is also reading potantiometer. Every 250usec ADC conversion is occured. When the conversion is completed the program goes to interrupt vector, and after finishing to take 10 samples, it calculates average of them. Then PI control algorithm come into play. Also for the safety of laser, the laser can not work without press button that is on the launchpad. When the hand is removed from the button, the laser starts to working and setpoint become able to adjust. How much time that laser works can be determined by the user and should be assigned the value to 'timer_value' parameter. In this control system, the ADC conversion enables to control the amount of measured laser current. The PI controller calculates an error that based on this measured feedback value and the chosen operating current. At the end of the calculations of pi loop, the output value is then used to set the duty cycle for the buck converter. The equations required to execute a PI controller are shown in equations below.

Error = Setpoint – Feedback (4.9)

P_term = $K_P$ * Error (4.10)

i_Temp=(Error_1+Error_2)/2; (4.11)

I_term = $K_I$ * Integral (4.12)

First an error term is calculated. This is simply the difference between the desired system output value (Setpoint) and the actual output value. In this current regulator application, the ADC will provide a sample value corresponding to the actual output current and a setpoint value will be initialized that represents the desired output current.

The proportional term of the controller multiplies the calculated error by a gain value. The proportional term provides a system response that is proportional to the amount of error. If the output current is very near the desired value, the proportional term of the controller will provide very little response to correct the error. If the output current is much greater or much less than the desired output value, then the proportional term of the controller will produce a very big response to correct the large error. The goal is to reduce the error to zero and the PI control algorithm cannot do this with just a proportional term. With only proportional control, the output of the PI controller equation will be zero when the error is zero.

The integral part of the PI controller works by adding last two error and taking average of them. This averaged value, or integrated error, is multiplied by a gain coefficient to produce the integral response of the controller. End of the PI control loop, calculated p_term and ı_term are subtracted from the last value of TACCR1 register which controls the duty cycle of PWM and then assign that new value to the TACCR1 register to adjust new PWM duty cycle.

## 4.4 User Interface

In this study for user interface it is used 4x20 pins LCD display, button and potantiometer. The current, setpoint value, pulse duration(duty cycle) and error value are shown on the LCD display. User can adjust the working time of laser by assigning the value to related parameter indicated in the software program and the laser pulse duration-duty cycle can be changed via potantiometer by the help of desired output current that concern with the optical output power.

# CHAPTER 5

## RESULTS

In this study, first the simulation of the circuit is done by the LT Spice program. The snapshoot of the circuit and the output graph are shown in below. We used the similar devices in the program to converge it to the real one. In graph the green line shows PWM output, the red one indicates the current on $R_{SENSE}$ resistor.

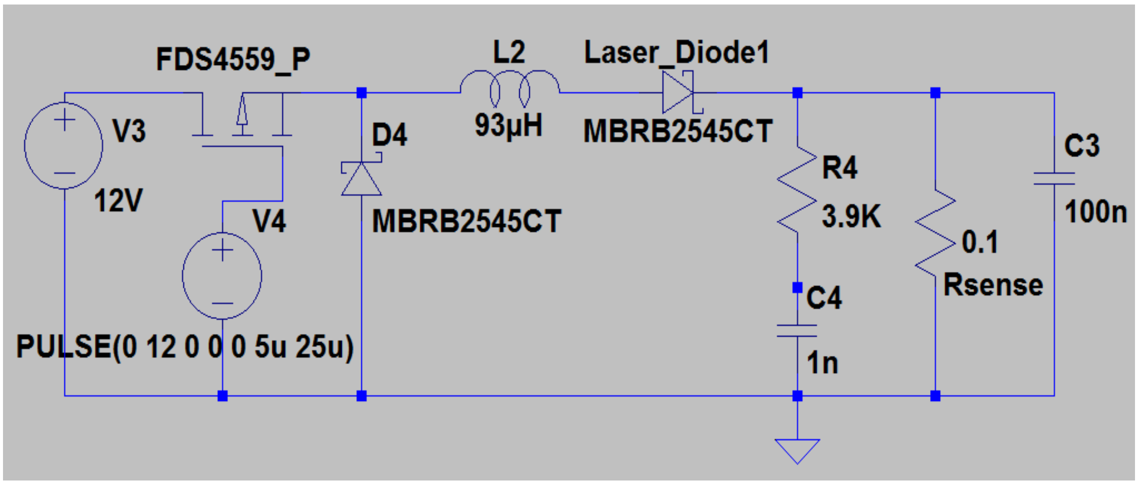


Figure 5.1 LT Spice circuit simulation

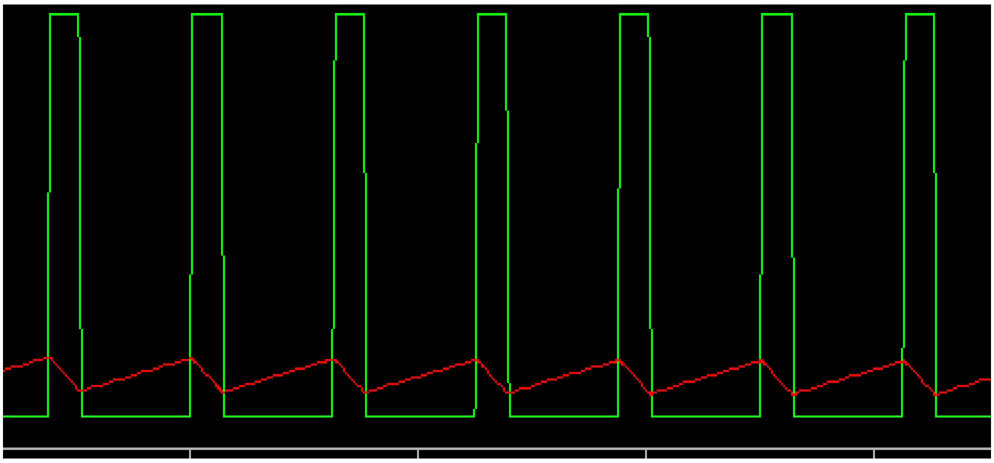

Figure 5.2 LT Spice output graph

Manufactured circuit output current graph is seen in figure 5.3 below. The yellow line indicates the laser current that measured over the $R_{SENSE}$ resistor and the red one shows the PWM pulses. It is seen from the graph that there is 470mV average voltage that refers to 4.7A current. We used mosfet driver to get 12V peak PWM voltage, otherwise the microcontroller could not supply enough current to mosfet gate. Since p-type mosfet is used, the current is ramping up at no-gate charge applied(PWM at 0V) and vice-versa. This is the application part of the circuit. And we prove that the circuit is working precisely.

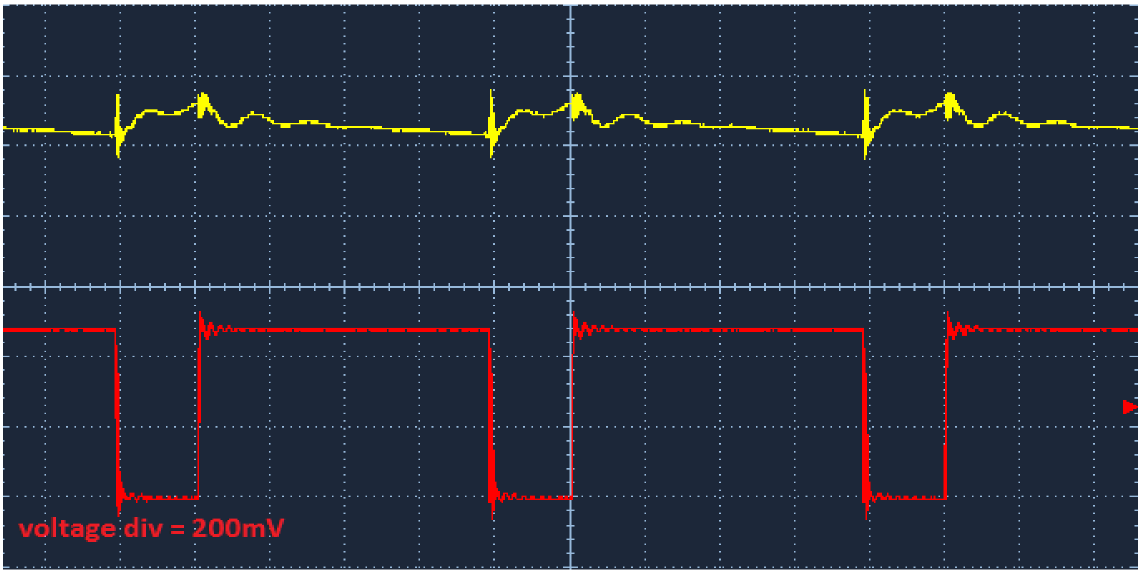


Figure 5.3 Snapshot of osilloscope

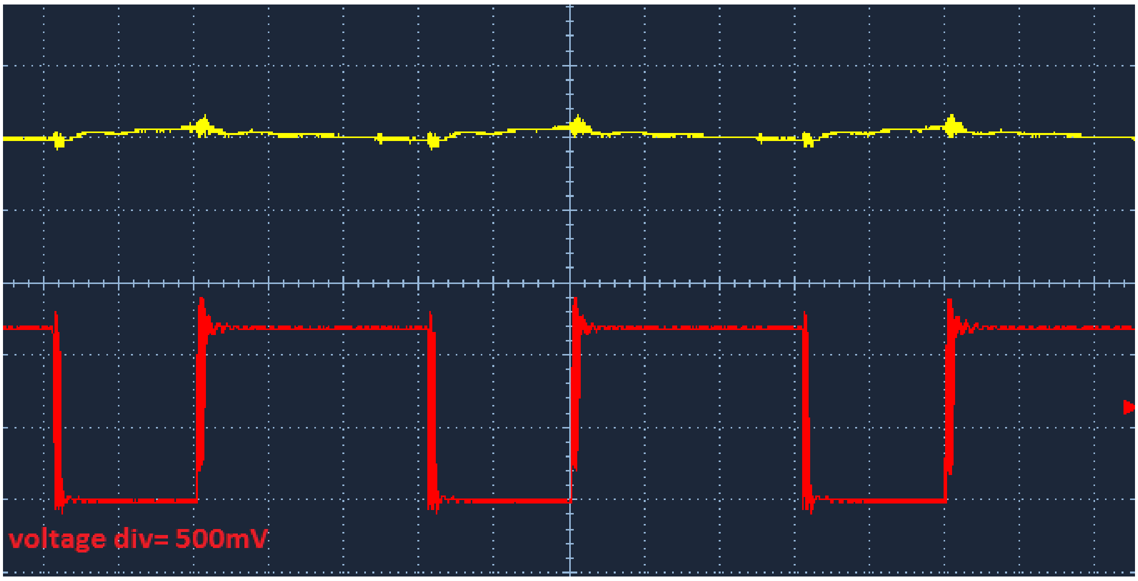


Figure 5.4  10A current output graph

The above graph shows 10A average current with duty cycle of %42.

The optical outputs of the diode laser is measured by optical powermeter. The output powers with respect to current is given in table below.

Table 5.1  Optical outputs of laser

| **Optical Output Value** | **Laser Current** |
|---|---|
| 1.1W | 4.7A |
| 1.6W | 5.9A |
| 2.1W | 7.6A |
| 2.7W | 9.8A |

## DISCUSSION

In this study, the system design and manufacturing steps of a microcontroller based 1470-nm diode laser system are presented.

Diode laser module generates continuous 1470-nm laser light during the lasing process. The power of the laser light measured by using a powermeter is seen in the range of 0 to 3W with respect to the value of applied diode current from 0 to 10 A. Important parameter for the diode laser module to give stable output power is to be pumped with constant current. While the laser is operating, microcontroller unit of the system control the laser current with PI control and by changing the PWM duty cycle in referance to adjusted current. On the laser box, LCD screen is placed to see the operating current, pwm duty cycle, error between the laser current and setpoint value by user. Also user can able to set current thus pwm duty cycle. The main advantage of that buck topology driver circuit is it can supply up to 15A output current at 2V. It means that it can be used for other loads that match with these parameters.

The system designed in this study is for general purpose usage in biomedical applications. In this study we also focused on the effect of 1470nm in laser tissue welding.

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# APPENDICES

## APPENDIX A. MICOCONTROLLER SOFTWARE

This section includes the source code of MSP430G2553 microcontroller used in the controller unit. Code written in C language and compiled with IAR Embedded Workbench program is given below.

```
/* Vref=3.56V
 8 adc clock, 0.1R üzerinden akım okuma
bit2->akim
bit3-> pot
*/
#include <msp430g2553.h>
#include "lcd16.h"
unsigned int ornekler[2]={0};
int Setpoint;
int Error_Value;
int new_ADC_value;
int pwm_duty=0;
float Kp = 0.06;
float Ki=0.012;
float i_Temp=0;
unsigned int a=0;
unsigned int akim_sonuc;
unsigned int pot_sonuc;
unsigned int s;
```

```
unsigned int b=0;
unsigned int e=0;
int Error_1,Error_2;
unsigned int timer_value;
unsigned int tim_value;
int lcd=0;
unsigned int istenen_deger;
unsigned int okunan_akim;
unsigned int Adc_value_pot=0;
unsigned int Adc_value_current=0;

void pwm_duty_change();
void adc_setup();
void integer_yaz(unsigned int,char);
void deger_goster();
void adc_conversion();
void turn_on();
void turn_off();
void timer_config();

void main( void )
{
  WDTCTL = WDTPW + WDTHOLD; // Stop watchdog timer to prevent time out reset
  BCSCTL1 = CALBC1_8MHZ;
  DCOCTL  = CALDCO_8MHZ;
```

```
TACTL = MC_0;

P1OUT=0x00;

P1OUT |=BIT6;

P1SEL &= ~BIT6;

P1DIR |= BIT6+BIT2+BIT4+BIT5+BIT7;

P1DIR &= ~BIT3; // input

P2DIR = 0x0F+BIT6+BIT7;

P2OUT = 0x00;

P2SEL = 0x00;

adc_setup();

lcdinit();

waitlcd(100);

prints("buck converter");

gotoXy(0,1);

waitlcd(100);

prints("current reading");

waitlcd(100);

lcdcmd(0x01);

waitlcd(100);

while(1)

 {

   if((P1IN & BIT3)==0;

 {

  while((P1IN & BIT3)==0)

 {
```

```
  }
    turn_on();
    timer_value=0;
    TA1CTL |= TASSEL_2 + MC_3 + TACLR;
    TA1CCTL0 = CCIE;
    __bis_SR_register(GIE);
    TA1CCR0=4000-1;
    while(timer_value<10000)
    {
    }
    turn_off();
   }
 }
}
#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR(void)
{
   P1OUT |= BIT5;
   ADC10CTL0 &= ~ENC;
   if(a<10)
   {
    Adc_value_pot+= ornekler[0]; //bit5
    Adc_value_current+= ornekler[1]; //bit4
    a++;
   }
```

```
    if(a==10)
     {
       pot_sonuc = (int) (Adc_value_pot/10);  // bit2
       akim_sonuc = (int)(Adc_value_current/10); // bit1
       Adc_value_pot=0;
       Adc_value_current=0;
       a=0;
       pwm_duty_change();}
       ADC10CTL0 &=~ ADC10IFG; //clear interrupt flag
       P1OUT &= ~BIT5;
  }
// Timer A0 interrupt service routine
#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer_A(void)
{
  b++;
  if(b==5)
   {
   P1OUT |= BIT2; //4usec
    adc_conversion();
    P1OUT &= ~BIT2;
    b=0;
    }
}
// Timer A0 interrupt service routine
```

```
#pragma vector=TIMER1_A0_VECTOR
__interrupt void Timer1_A(void)
{
  timer_value++;
}
void turn_on (void)
{
  lcdcmd(0x01);
  P1OUT &=~ BIT6;
  P1SEL |= BIT6;
  TACTL |= TASSEL_2 + MC_3 + TACLR;
  timer_config();
}
void turn_off (void)
{
  P1OUT |= BIT6;
   P1SEL &= ~BIT6;
  TACTL = MC_0;
   TA1CTL = MC_0;
   lcdcmd(0x01);
   gotoXy(0,0);
   prints("laser is off");
   gotoXy(0,1);
   prints("press button P1.3");
   gotoXy(0,2);
```

```
  prints("to turn on the laser");
  gotoXy(0,3);
  prints("Adjust Setpoint to 0");
}
void timer_config(void)
{
 TACCR0= 100-1; // period = 25usec
 TACCR1 = pwm_duty; // duty cycle
 TACCTL1 = OUTMOD_6;
 TACCR2= 96;
 TACCTL2 |= OUTMOD_6;
 TACCTL0 = CCIE;
  __bis_SR_register(GIE);
}
void pwm_duty_change()
{
 P1OUT |=BIT4;
 float iMax= 1000;
 float iMin= -1000;
 float P_term;
 float I_term;
 Error_Value = (pot_sonuc- akim_sonuc);
 P_term = (Kp * Error_Value);
 e++;
 if(e==1)
```

```
{
Error_Value=Error_1;
i_Temp+=Error_1;
}
if(e==2)
{
Error_Value=Error_2;
i_Temp=(Error_1+Error_2)/2;
Error_1=0;
Error_2=0;
e=0;
}
if(i_Temp > iMax)
{i_Temp = iMax;}
else if (i_Temp < iMin)
{i_Temp = iMin;}
I_term =  (Ki * i_Temp);
pwm_duty = (int) (pwm_duty + (P_term+ I_term));
if(pwm_duty < 1)
{
pwm_duty = 1;
}
else if (pwm_duty > 55)
{
pwm_duty = 55;
```

```
}
TACCR1 = pwm_duty;
istenen_deger = (int)(((3.56*pot_sonuc)/1024)*10000);
okunan_akim = (int) (((3.56*akim_sonuc)/1024)*10000);
lcd++;
if(lcd==1000)
{
 deger_goster(istenen_deger,okunan_akim,Error_Value,pwm_duty);
 lcd=0;
 }
 P1OUT &=~BIT4;
 }
 void deger_goster(int ham,int hamm)
 {
  gotoXy(0,0);
  prints("Setpoint = ");
  integer_yaz(istenen_deger,1);
  gotoXy(0,1);
  prints("akim = ");
  integer_yaz(okunan_akim,1);
  gotoXy(0,2);
  prints("Error = ");
  integer_yaz(Error_Value,0);
  gotoXy(0,3);
  prints("pwm = ");
```

```
 integer_yaz(pwm_duty,0);
  }
void adc_setup()
 {
 ADC10CTL0 &= ~ENC;
 ADC10CTL0 = SREF_0 + ADC10SHT_1 +  ADC10ON + ADC10IE;
// 16 ADC CLOCK, 1.5V REF. GERİLİMİ
 ADC10CTL1 = INCH_1+ ADC10SSEL_3 + SHS_3 + CONSEQ_1;
 //SMCLK, TIMER A2 OUTPUT, SEQUENCE OF CHANNEL
 ADC10AE0 |= BIT0+BIT1; // BIT2 AND BIT3 ANALOG PINS
 ADC10DTC1 = 2;
 }
 void integer_yaz(unsigned int deger,char flag)
 {
 lcdData( deger/10000+48);
 lcdData( (deger%10000)/1000+48);
 if(flag==1) lcdData('.');
 lcdData((deger%1000)/100+48);
 lcdData((deger%100)/10+48);
 lcdData((deger)%10+48);
 }
void adc_conversion(void)
{
 ADC10CTL0 &= ~ENC;
 while (ADC10CTL1 & BUSY);
```

```
ADC10SA = (int) ornekler;

ADC10CTL0 |= ENC;

__bis_SR_register(GIE);

}
```

## CURRICULUM VITAE

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