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MICROCONTROLLER BASED 808-nm DIODE LASER DESIGN TO BE USED IN BIOMEDICAL APPLICATIONS

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

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T.C.
FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

BİYOMEDİKAL UYGULAMALARDA KULLANILMAK ÜZERE MİKROİŞLEMCİ TABANLI 808-nm DİYOT LAZER TASARIMI

KEVSER YILDIRIM

YÜKSEK LİSANS TEZİ
BİYOMEDİKAL MÜHENDİSLİĞİ PROGRAMI

DANIŞMAN
YRD. DOÇ. DR. H. ÖZGÜR TABAKOĞLU

İSTANBUL, TEMMUZ / 2015

To my dear family,

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July 2015 Kevser YILDIRIM

(Engineer)

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ABBREVIATIONS

MCU : Microcontroller unit
LED : Light emitting diode
EMF : Electromotive force
PWM : Pulse width modulation
CCM : Continuous conduction mode
DCM : Discontinuous conduction mode
PCB : Printed circuit board

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SUMMARY

MICROCONTROLLER BASED 808-nm DIODE LASER DESİGN AND ITS BIOMEDICAL APPLICATIONS

Kevser Yıldırım

Biomedical Engineering Programme

MSc Thesis

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

Providing constant current to laser diodes is crucial to ensure proper and safe operation of the lasers. Switching converters are mostly used as reliable and efficient drivers to drive diode lasers. In this study, design of a microcontroller based, and buck configured switching regulator was aimed to drive 3W-808nm laser diode. The configured system is capable of supplying current to the laser diode between 0-5A allowing the user to adjust the output current, so the optical power. In addition, the regulator assures stability of the output current through proportional-integral control algorithm operated by MSP430 microcontroller unit in case of any unintentional current spike in the system.

808nm has many application fields in biomedical, i.e.dermatology, endodontics, photodynamic therapy, tissue welding. The built 3W-808nm diode laser module will be used in researches to contribute to those fields.

Keywords: diode laser, biomedical, MSP430, PI, laser driver, buck converter

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ÖZET

MİKROİŞLEMCİ TABANLI 808-nm DİYOT LAZER TASARIMI VE BİYOMEDİKAL UYGULAMALARI

Kevser YILDIRIM

Biyomedikal Mühendisliği Programı

Yüksek Lisans

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

Lazer diyodun sabit akım ile beslenmesi diyodun güvenli ve düzgün bir şekilde çalıştırılmasında hayati bir önem taşımaktadır. Güvenilir ve verimli lazer diyot sürücü devreleri olarak en çok anahtarlamalı DC-DC dönüştürücüler tercih edilmektedir. Bu çalışmada da 808-nm dalgaboyunda, maksimum 3-W gücünde ışık yayan bir lazer diyodu sürmek amacıyla MSP430 mikrokontrolör tabanlı, buck topolojisine sahip anahtarlamalı regülatör devresinin tasarımı amaçlanmıştır. Dizaynı gerçekleştirilen sistem ile 0-5A arasında lazer diyodun akımı, dolayısıyla; 0-3W arasında lazerin çıkış gücü kullanıcı tarafından ayarlanabilmektedir. Buna ek olarak MSP430 kontrol ünitesi tarafından çalıştırılan PI-kontrol algoritması sayesinde lazer diyodun akımı, beklenmedik değişikliklere karşı sabit tutulabilmektedir.

808-nm diyot lazerin biyomedikal alanında pek çok uygulaması bulunmaktadır, dermatoloji, fotodinamik terapi, endodonti gibi. Bu çalışmada tasarlanan sistem de bu alanlarda yapılacak bilimsel araştırmalarda kullanılacaktır.

Anahtar kelimeler: diyot lazer, MSP430, biyomedikal, PI, lazer sürücüsü, buck dönüştürücü

FATİH ÜNİVERSİTESİ -BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

CHAPTER 1

INTRODUCTION

1.1 Literature Survey

Lasers have large and continuously spreading application field in medicine. Versatility of the laser light has led up this wide range application field [1]. Now lasers are frequently used in diagnosis, treatment and therapy.

Application of laser to the medical area started with a dermatological application which was removing tattoos [2]. Then it was started to be used in ophthalmology which is now one of the biggest usage field of lasers [3]. With developing technology new laser types rose up. This resulted in new application areas of laser in medicine i.e. medical imaging, cancer treatment, therapy with biostimulation, tissue welding etc.

Within one year of invention of first laser a diode laser was designed. Then new types of diode lasers were emerged at different wavelengths, outputs by the time. Today they are very common since they are compact, easy to design, user friendly, reliable and have long life time.

1.2 Purpose of The Thesis

The purpose of this study was design and implementation of a diode laser module which has adjustable output power, also capable to provide constant current to the laser diode. The system is MSP430 mcu based, and buck configured switching regulator aiming drive of 3W-808nm laser diode.

In Chapter 2 some theoretical information about generation mechanism of laser light, laser diodes, laser diode drivers, PI-controllers are given and biomedical applications of diode lasers were mentioned. In Chapter 3 design steps of the buck configured driver were described, and the duties of the microcontroller were explained. In Chapter 4 results of the built-system were demonstrated and discussed.

CHAPTER 2

DIODE LASER BASICS AND THEIR APPLICATIONS IN BIOMEDICAL

2.1 Fundamentals of Laser

Laser is the acronym word for light amplification by stimulated emission. Monochromaticity, coherency and collimation are properties of the laser light that make the laser sources different from other type of light sources.

2.1.1 Proporties of Laser Light

2.1.1.1 Monochromaticity

In ideal conditions, all the photons that form the laser light have same wavelength, thus the same energy. In practical, even though all the photons are not at the same wavelength, the bandwidth of the generated laser light is very narrow around a central wavelength. Bandwidth of a typical laser light is much narrower than a typical led or any other light source.

2.1.1.2 Coherency

The laser light has a unique property that it consists of light waves that are in same phase making the laser light coherent. Generating in-phase light waves, so the coherent light, is achieved by stimulated emission. As it is shown in Figure 2.1 being in-phase of the photons amplifies the output signal of laser, so increasing the output power of the laser.

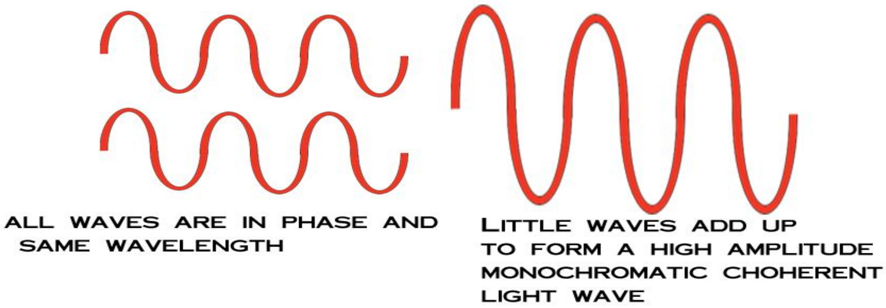

Figure 2.1 Coherent waves [4]

2.1.1.3 Collimation

The photons in the optical cavity will be reflected back and forth by the mirrors placed at both terminals of the laser cavity. These multiple reflections will eliminate the photons that travelling directions’ are not parallel to the cavity walls while allowing to pass the photons travelling in the same direction with cavity walls and perpendicular to the mirrors. This will result in a highly directional beam at the output which means collimated.

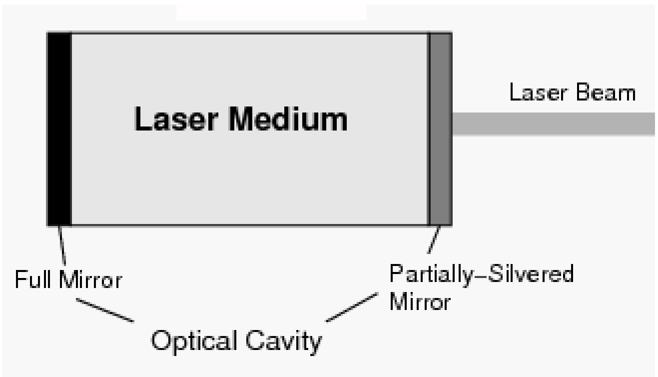

Figure 2.2 Optical cavity and mirrors of the laser system [5]

2.1.2 Generation of Laser Light

Some physical phenomenons will be explained to understand generation mechanism of the laser beam better.

2.1.2.1 Interaction Types Between An Atom and A Photon

Spontaneous Absorption

The transition of an electron from lower energy state to higher energy state is called as spontaneous absorption.

Spontaneous Emission

Returning of an excited electron to the lower state emitting photon is called as spontaneous emission.

Stimulated Emission

Photon emission can also be stimulated by an incoming photon. Energy of the incoming photon should be very close to the difference between ground and excited energy states of the stimulated atom. When this condition is satsified the emitted photons and incoming photons will be in-phase, having same frequency, resulting in light amplification. This is the physical priniciple that working mechanism of light amplifiers, thus lasers, depends on [6]. All these 3 phenomenons could be seen below.

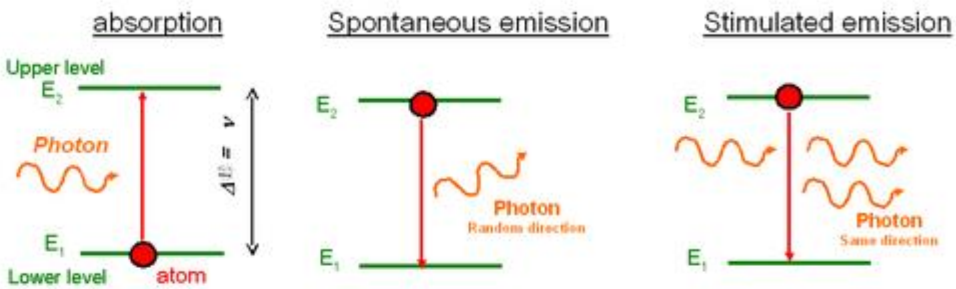

Figure 2.3 Interaction types between an atom and a photon [7]

An electron transmitted to the excited state by absorbing energy stays at the excited energy level for 10^{-7}seconds then returns to the metastable state and stays here for longer time 10^{-3} seconds resulting in more electrons existing in the excited state than electrons existing in the ground state. This phenomenon is called population inversion which is critical in generation of laser light [8]. Population inversion assures that number of the photons passing from metastable state to the ground level with stimulated emission is higher than the number of the photons spontaneously absorbed. This results in more photons in the laser medium.

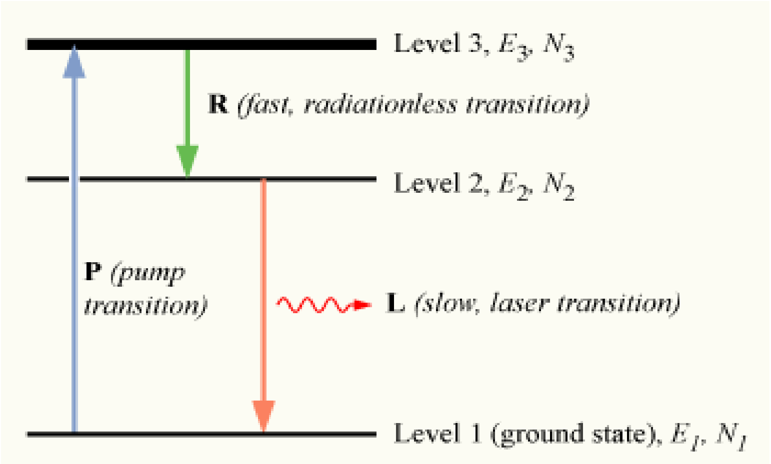

Figure 2.4 Population inversion [9]

2.1.2.2 Basic Configuration of Lasers

A typical laser system should basically have three parts as in Figure 2.5 to generate laser light which are amplifying medium, highly reflecting mirrors placed at both ends of the amplifying medium with one of them partially transmitting, and pumping mechanism to energise the amplifying medium [10].

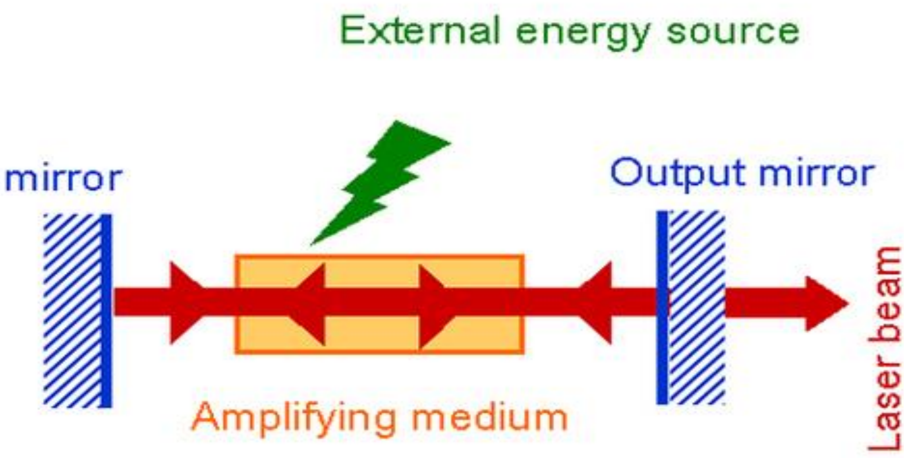

Figure 2.5 Basic configuration of a laser [11]

Amplifying medium can be solid, liquid or gas. The atoms in amplifying medium are excited to upper energy state electrically, or optically by the pumping mechanism. After few nanoseconds, the excited atoms will return to lower energy state by emitting photons. The emitted photons will reflect back and forth between the mirrors through the optical cavity. Striking of an emitted photon to another atom at the excited state will stimulate this atom to emit another photon having same energy and phase, and moving in same direction with it. This will lead to higher number of photons so increased intensity of laser light. One of the mirrors reflects all the photons while the other reflects most of the photons and transmits small portion of them to form laser beam at the output. Travelling of the photons back and forth between the mirrors will allow just the photons to pass out that are in same direction with cavity ensuring collimated output while preventing photons to pass out that are travelling in a different direction from the cavity [12].

2.2 Diode Lasers

2.2.1 Physics of Laser Diodes

A laser diode is differentiated version of a light emitting diode. Thus, firstly physics of an LED should be understood to understand physics of a laser diode.

An LED is a p-n junction diode made from a crystal of semiconductor emitting light. One side of it is p doped material containing positive charge carriers (holes) while the other side is n-doped material contains negative charge carriers (excess electrons) as it is shown in Figure 2.6. In equilibrum there is a potential barrier between p and n-doped materials. When an external potential applied which is higher than threshold voltage level for LED, charge carriers start to flow into the junction. The electrons and holes recombine in the junction causing release of photons thus emitting light. The wavelength of the photon so color of light depends on bandgap energy of the p and n-doped materials.

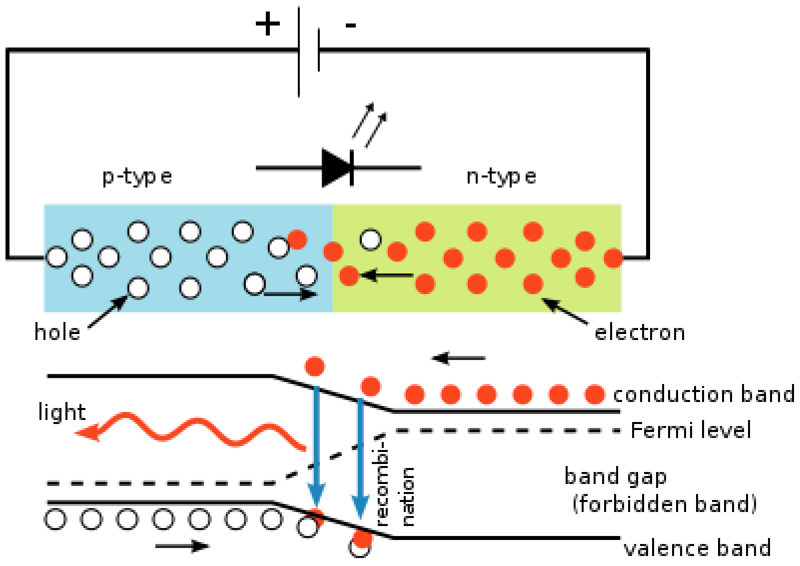

Figure 2.6 Formation of light in a LED [13]

An LED must have two features to be a laser diode. There must be optical cavity and stimulated emission at the satisfactory level. Increasing current through the diode increases density of electron hole pairs in the junction region creating population inversion which is needed for stimulated emission. The optical cavity is achieved by cleaving the crystal planes that are parallel. The optical cavity provides multiple reflections of photons so increases light density.

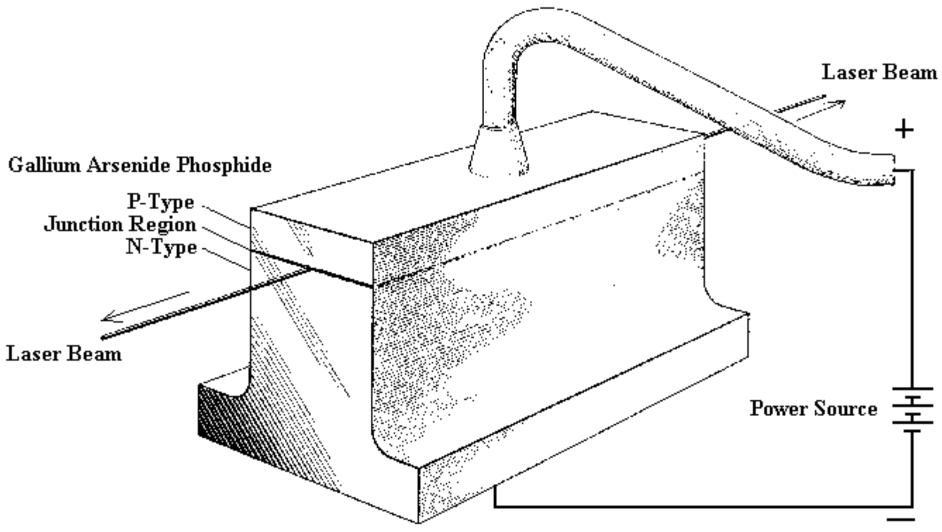

Figure 2.7 The basic diode laser from Scahwlow (1963) [14]

2.2.2 Driving Diode Lasers

A laser diode operating below the threshold current behaves like an LED with spontaneous emission. Above the threshold current level it emits laser light, and its output power is in correlation with operating current level of the laser diode. Since the relation between output power and current through the diode is linear, constant current drivers are used to drive the laser diodes [15]. In case of using constant voltage source, during a run away situation current may increase while the voltage across the diode is the same. Increasing of the current will cause the diode to heat up and because of increasing in temperature the current will again increase. Hence, a constant current driver is needed to prevent excessive current to pass through and destroy the laser diode [16]. An ideal driver provides constant current at the operating level, gives an accurate, linear and noiseless output.

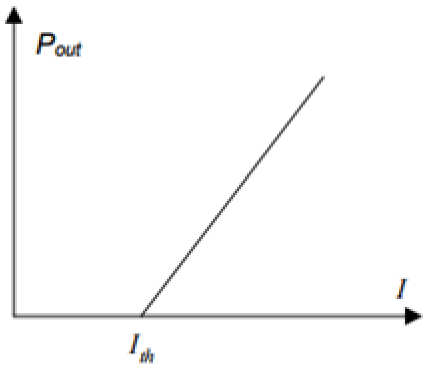

Figure 2.8 Output power from a laser diode versus the applied current [17]

Since laser diodes are current driven devices, and the current is proportional to the output power, providing constant current to the diode is crucial. Supplying constant current could be achieved by linear regulators, or switching regulators. During the operation of diode driving by the linear regulator, the difference between input and output voltage is wasted as heat causing very low efficiency of the system and requiring more heat sink [18].

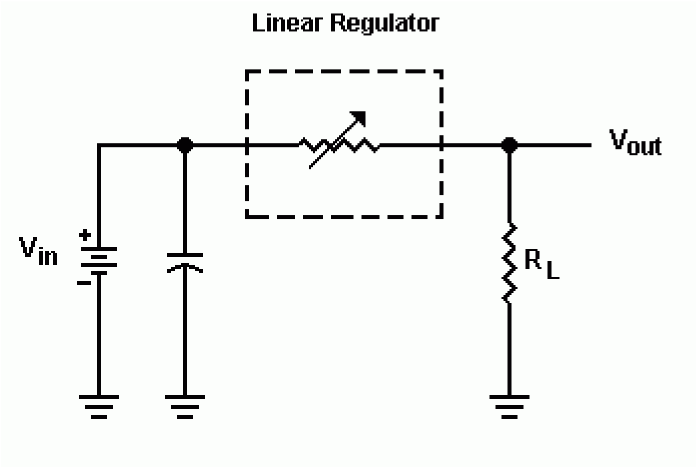

Figure 2.9 Basic configuration of a linear regulator [19]

Another option to regulate current of the laser diode which is more popular, reliable and efficient is switching regulators. Switching regulator name comes from switching on and off of the transistor that is connecting input and output. Energy storing components are used such as inductors to maintain providing current to the load during the off state of the switching transistor [20]. This process provides advantage to the switching regulators in efficiency which is the most important feature of switch mode regulators [21].

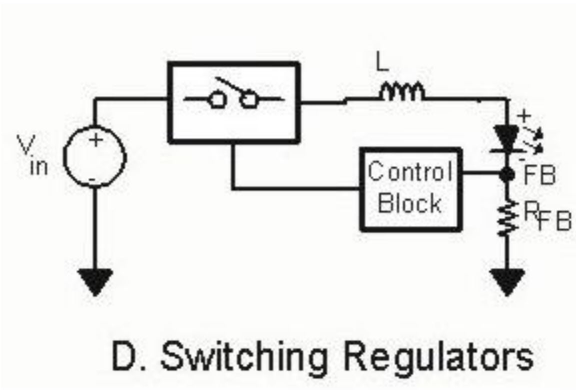

Figure 2.10 A basically configured switching regulator [19]

In this study buck configuration of switching regulator is used which is the most used type in driving light emitting diodes and laser diodes.

2.2.2.1 Buck Drivers

Buck converter is used when the required voltage to drive the load is lower than input voltage. Switching off and on of the transistor by the pwm signal, it generates lower voltage at the output than input voltage. The output voltage level could be varied by changing pwm signal that changes on and off times of the transistor. A circuit schematic is seen in Figure 2.4 that shows a basic buck configured switching regulator.

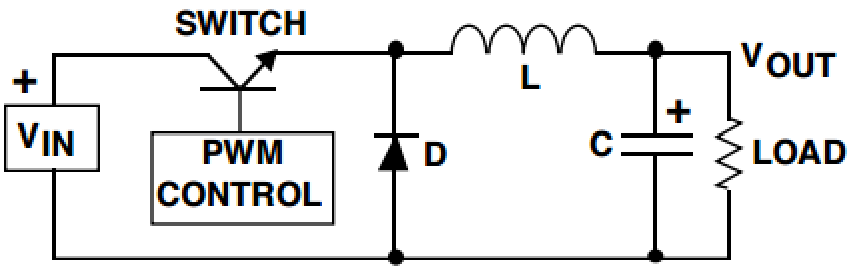

Figure 2.11 Buck converter circuit [22]

There are two operation modes in the buck converter depending on states of the switch.

On Mode of The Operation

When the transistor acts like a closed switch conducting the current, the current flows through the inductor, capacitor and load. The inductor stores energy in its magnetic field with flowing current through it. The current signal of the inductor in shape of a ramp can be seen in Figure 2.14. The capacitor charges with the current during on mode. The diode is reverse biased so doesn't play a role in this stage.

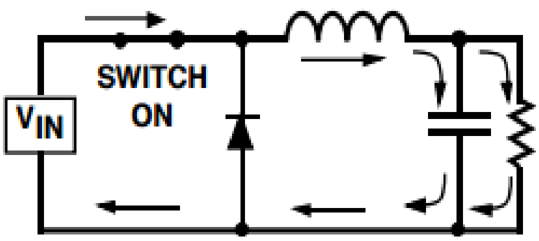

Figure 2.12 Current flow in a buck converter during On-Mode operation [22]

Off Mode of the Operation

When the transistor is not conducting and behaving like an open switch the connection between input and output parts of the circuit will be lost. Stopping of the current flow from input to output passing through the inductor, will cause the magnetic field of the inductor to change. This will generate back emf voltage on the inductor which is in the reverse polarity according to the polarity on the inductor during the on-state. Back-emf voltage will generate current flow from inductor to the load at the same direction with on-mode of the switch. The diode will conduct current since it is forward biased [23]. The charged capacitor in the previous stage, will discharge its energy through the load during the off-stage of the transistor. The inductor also will be discharged releasing its stored energy in the off state, and again it will be charged during the on-state of the switching transistor.

Switching regulators has higher efficiency than other type of regulators, since any current is not drawn from the input during the off-state, and stored energy in the inductor is used to supply current to the load, in addition any extra energy is not wasted in the input part.

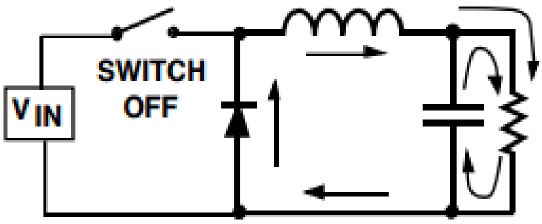

Figure 2.13 Current flow in a buck converter during Off-mode operation [22]

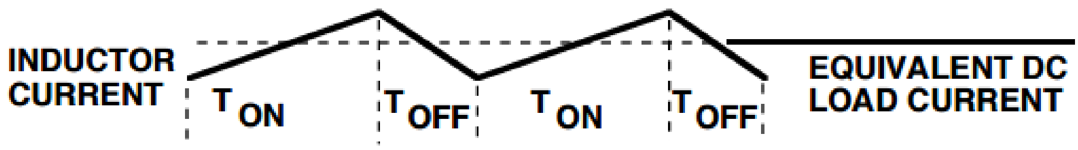

Figure 2.14 Inductor current in a buck converter [22]

Buck converters can operate in continuous conduction mode or discontinuous conduction mode. In continuous coduction mode the current of the inductor never reaches to zero, it’s always higher. On the ohter hand, in discontiuous conduction operation the current level becomes zero at the end of off states of the transitor. For higher output current, continuous conduction operation is preferred while DCM operation is preferred for lower output current since it doesn’t require big inductor values and saves space in the converter [24].

Buck Converter Equations

Before designing a buck converter, requirements of the load, which will be connected to the output of converter, must be known. These requirements are operating current and voltage of the load, suitable ripple ratio and switching frequency. Knowing these parameters, on-time of the switch to get required current at the output, so duty cycle of PWM signal, and required inductor value can be calculated according to the equations mentioned below.

As it is mentioned in previous section, when the switch is on in a buck converter, a dc voltage will be applied across the inductor terminals. This voltage will result in a current rising as a ramp through the inductor which can be seen in Figure 2.14. This result also could be verified from the voltage current equation of inductor. According to this equation, applying a constant voltage to an inductor generates a lineraly increasing current by the time [25].

$$V = L\frac{di}{dt} \tag{2.1}$$

The current flowing through the inductor will be stored as energy in the inductor’s magentic field.

When the switch is off, the inductors’ current will be interrupted. Change in the current will cause the magnetic field to change. To compansate this change, a back-emf voltage will be induced on the inductor. Then, the inductor will act as a battery by releasing its stored energy in form of supplying current to the load of the circuit. Supplied current from the inductor to the circuit will decrease linearly by the time as it is seen in Figure 2.15.

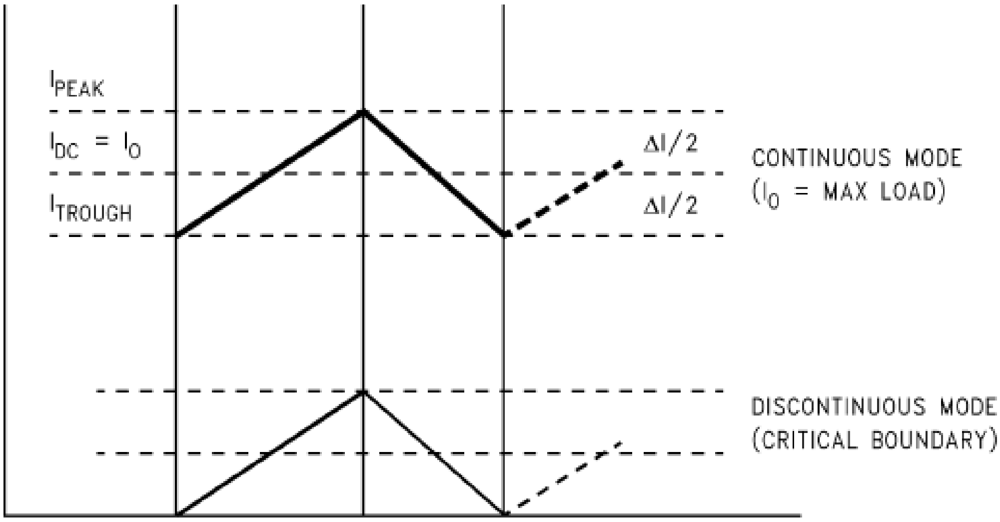

Figure 2.15 : CCM and DCM of buck converter [26]

I_{peak} : Highest level of current passing through the inductor

I_{trough} : Residual current in the inductor. Its level changes depending on the load

$I_{DC} = I_O$: Average value of the inductor current. It's also the load current since the same current is passing through the load.

$\Delta I = I_{AC}$: Ripple current of the inductor

$$\Delta I = I_{AC} = I_{peak} - I_{trough} \quad (2.2)$$

r : Current ripple ratio which is ratio of ac component of current to dc component

$$r = \frac{\Delta I}{I_o} \quad (2.3)$$

The duty cycle and required inductance values are calculated according to the equations below

$$D = \frac{V_D + V_{OUT}}{V_{IN} - V_{SW} + V_D} \quad (2.4)$$

D: Duty cycle

V_{OUT} : Output voltage

V_D : Catch diode drop voltage

V_{SW} : Switching voltage of mosfet

The required inductance value for a buck converter can be calculated in different ways. In this section voltseconds method will be explained. Voltseconds is the multiplication of the voltage across the winding of the inductor and the duration of the voltage applied in microseconds.

$$Et = V\Delta t = L\Delta I \ V\mu secs \tag{2.5}$$

In the equation above V is voltage across the inductor which is:

$$V = V_{IN} – V_{SW} – V_{O} \tag{2.6}$$

Δt is the duration that the voltage applied, it is also “on time” of the converter :

$$t_{ON} = \frac{D}{f} \tag{2.7}$$

Knowing the equations above inductance value can be derived as ;

$$L = \frac{Et}{\Delta I} = \frac{V_{IN} - V_{SW} - V_{OUT}}{\Delta I} \times t_{ON} \tag{2.8}$$

2.2.3 Controlling Diode Laser Drivers

A proportional-integral-derivative controller is a feedback control loop mechanism in which the ouput of the system is sensed, then the difference between desired output value and the real output value is calculated as error. Later on, the error is computed by calculating and summing proportional, integral, and derivative responses of the control system. Then processing this control signal, the output signal of the system is generated [27]. In sum, a PID controller attempts to correct the error between the set point and the measured process value, computing the error signal with a control algorithm. Main goals of the control system are regulating the system according to the desired value and to ensure stability at the output of the system [28].

2.2.3.1 Proportional Term

The proportional term is proportional to the difference between the setpoint and the process variable which is error of the system. The proportional term is directly multiplication of the error and a constant Kp called as proportional gain.

$$e: SP – PV \tag{2.9}$$

SP : setpoint

PV : process variable

P : Proportional term

$$P = Kp * e(t) \tag{2.10}$$

High proportional gain increases speed of the control system response. On the other hand higher proportional gain causes the process variable, which is output of the system, to oscillate and the system to become unstable [27]. Smaller gain decreases speed of the system response. Also too small gain is not capable of eliminating steady state error.

2.2.3.2 Integral Term

The integral term is multiplication of the integral gain with accumulation of the errors over time, so it continually increases. Its effect is eliminating the steady state error. Steady state error is the difference between setpoint and the process value when the system become stable. Since the integral term is accumulation of the errors in the past, it may cause overshoot at the output [29].

2.2.3.3 Derivative Term

The derivative term is multiplication of the derivative gain and slope of the error over time. Its effect decreases when the process value gets closer to the setpoint. Derivative control improves stability of the system, prevents overshooting. It is too sensitive to noise in the feedback signal. If the feedback signal is noisy the derivative term may cause the system to become unstable [27].

2.3 Applications of 808nm Diode Laser in Medicine

Lasers are intensively used in biomedical field in recent years. They are used in treatment, diagnosis and therapy. Developing technology and invention of new laser types expanded lasers usage areas. Especially diode lasers gained importance because of its being reliable, compact and having long-life time [30].

Diode lasers are popular in tissue welding, wound healing, dermatologic applications [31], endodontics [32], photodynamic therapy.

Ott B. et Al. used 1-W, 808nm diode laser for in-vitro tissue welding. 2-3 mm tissue damage was created on porcine arteries and veins. Then, they have been welded using ICG albumin solder. Consequently the vessels soldered with 808nm showed high tensile strength. The study demonstrated that 808nm diode laser proimses a stable, fast, and tight microvascular anastomosis [33].

Diode lasers with lower outputs are used in biostimulation, low level laser therapy. In one of the study, wound healing effect of 808nm diode laser on diabetic rats was observed. Following, incision performing on diabetic rats, laser treatment were started and repeated on the second, fourth, sixth, and eighth days. On the rats received laser stimulation, beneficial wound healing effect was observed [34].

Photodynamic therapy is another field that diode lasers are mostly used. Mechanism of photodynamic therapy is based on the photochemical interaction between laser light and tissue. There are three vital elements for PDT applications that are pohotosensitizing agent, light source and oxygen in the tissue [35, 36, 37]. As a first step of PDT photosensitizer is injected into the body. After a time the sensitizer gathers in unhealthy region and stays inactive until it is exposed to light. In the next stage the laser light is exposed to the region that photosensitizer is gathered on. The interaction between laser light and the chemical agent starts some chemical reactions in the tissue. At the end of these reactions singlet oxygen is formed which causes cell-tissue apoptosis.

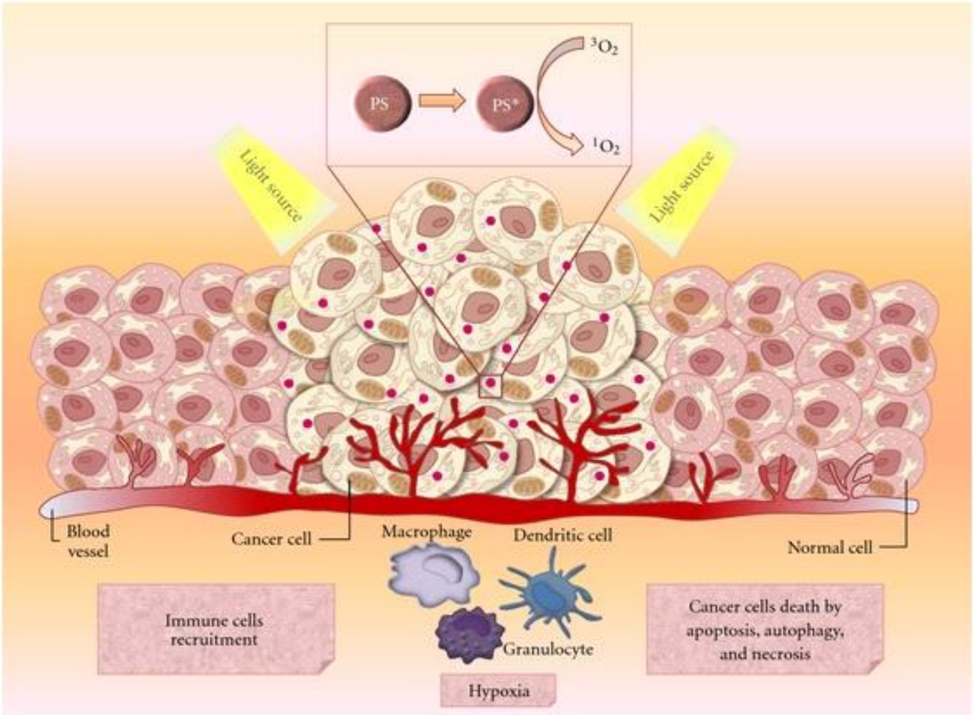

Figure 2.10 Forming of singlet oxygen with effect of light [38]

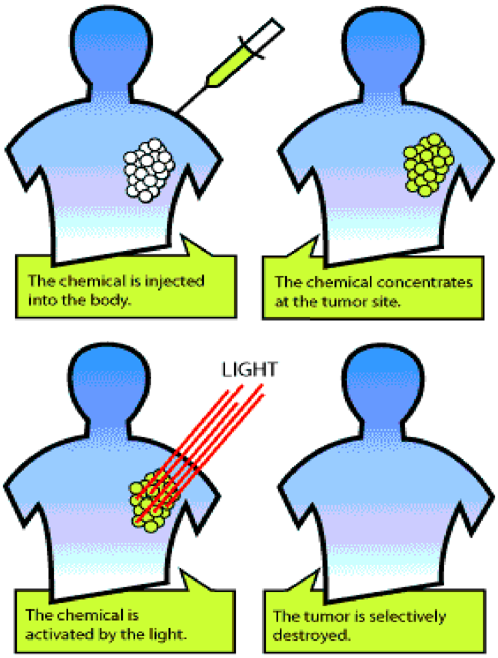

Figure 2.21 Steps of PDT [39]

PDT is mostly used in cancer treatment, killing bacterias, viruses. There have been many researches on the effect of PDT on brain, stomach, pancreas, uterus and bladder cancers. In a research conducted by William W. et Al. The effect of PDT on cancerous pancreatic cell was observed. A diode laser with 0.45 W output was used as light source and the ICG was used as photosensitizing agent. Pancreas cells were incubated with ICG and exposed to the laser light. A significant decrease was observed in growth of tumorous cells after the procedure and it was concluded that PDT is an effective and consistent treatment to prevent pancreas cancer growth [40].

CHAPTER 3

SYTEM DESIGN

The aim of this study was to design a diode laser driver system which inolves a buck converter employed as regulated power source to provide current to 808nm-3W laser diode, additionally composing an MSP430 microcontroller based controller unit which controls the whole system. Main parts of the driver system is shown in Figure 3.1.

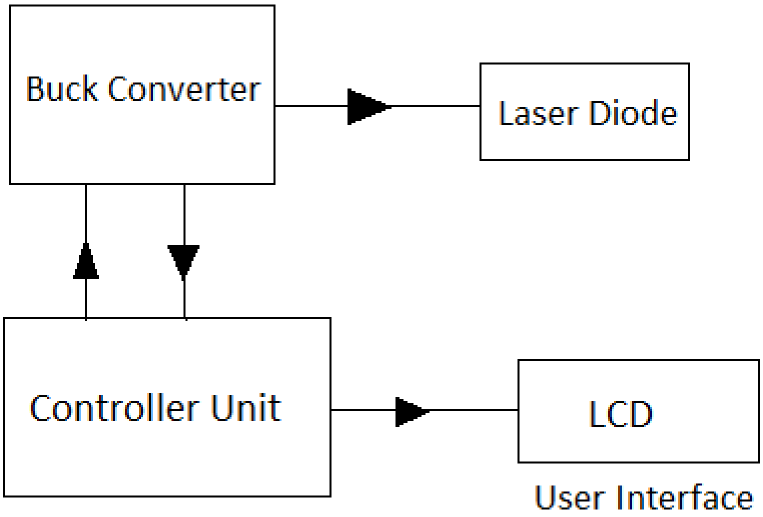

Figure 3.1 Block Diagram of the diode laser driver system

3.1 Laser Diode Unit

The laser diode that will be driven by our driver system has specifications below. Emission wavelength of the laser diode is 808-nm with 4-nm spectral width. Maximum operating current of the diode is 5.1-A and its maximum optical output power is 3W. The driver system was designed according to those specifications.

Specifications

Item	Symbol	Min.	Typ.	Max.	Unit
Optical Specifications					
CW Output Power	P_O	-	3	-	W
Center Wavelength	λ_C	805	808	811	nm
Spectral Width (FWHM)	$\Delta\lambda$	-	4	-	nm
Electrical Specifications					
Threshold Current	I_{th}	-	0.55	-	A
Operating Current	I_{op}	-	5.1	-	A
Slope Efficiency	H	-	0.65	-	W/A
Operating Voltage	U_{op}	-	2.2	-	V

Figure 3.2 Specifications of the 808-nm laser diode

3.2 Buck Converter Unit

The built-up buck converter, within this study, shown in Figure 3.3 is powered by a DC voltage source which is supplying 12V to the converter. The converter steps-down the input voltage to a lower level by switching the transistor and provides current to the laser diode. Switching of the transistor is controlled with PWM signal which is generated by microcontroller unit. Output current of the converter changes with change in duty cycle of PWM signal.

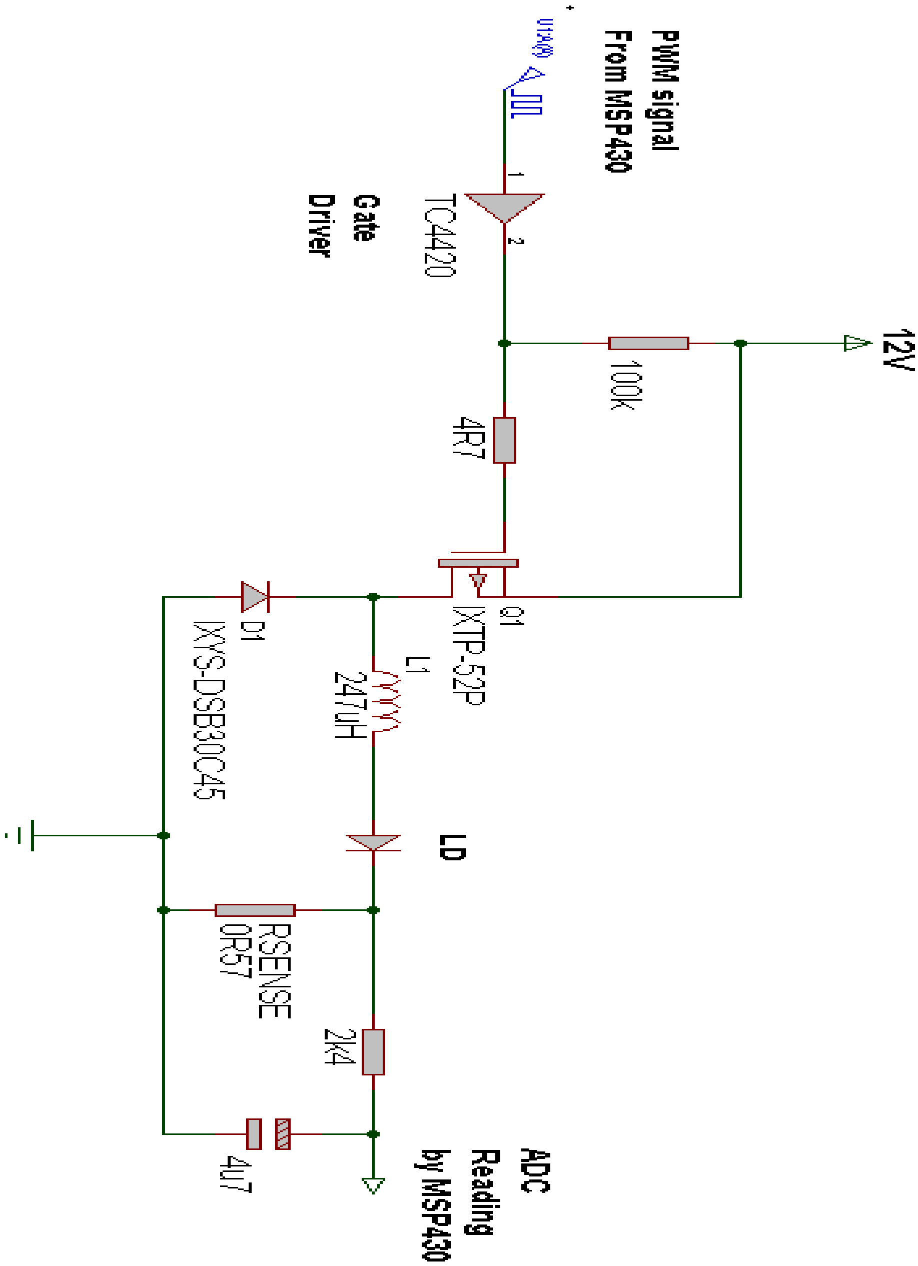

Figure 3.3 Designed Buck Converter Circuit

3.2.1 MOSFET

IXTP-52P10P, p-type Mosfet was used as switching transistor. Its electrical characteristics are:

V_{DSS} = -100V

I_{DS} = -52A

R_{DS} < 52 mohm

3.2.2 Gate Driver

Power MOSFETs have considerable gate capacitance. Thus, they need to be driven with high current to charge the capacitance within required time. In this system, MSP430 produces PWM signal to drive the MOSFET. But its pins' output current is max 6mA which is not enough to turn-on and off the MOSFET. Therefore, TC4420 gate driver was used after microcontroller which provides 6A current.

3.2.3 Diode

As freewheeling diode IXYS-DSB30C45HB was used which has characteristics :

I_F = 30A

V_F = 0.8V

3.2.4 Selection of The Inductor

For the selection of inductor the equations written in Chapter 2 were used. The required parameters to calculate suitable L value are:

V_{IN} = 12V

f = 40 kHz (Switching frequency of the control signal)

T = 25 μsec

V_O = 2.2V(Operating voltage of the laser diode)

I_O = 5.0 A (Max. operating current of the laser diode)

V_D = 0.8V (Forward voltage drop of flywheel diode)

$r = 5\ \%$ (Ripple ratio needs to be small for laser diode application)

Firstly we need to calculate duty cycle, according to the Equation 2.4,:

$D = 23\ \%$, then t_{ON} will be :

$t_{ON} = D / f = D \times T = 0.23 \times 25us = 5.86\ us$

According to the equations 2.5, 2.6, 2.7 :

$Et = V\Delta t = L\Delta I$

$Et = V\Delta t$

$V = V_{IN} – V_{SW} – V_O = 12 – 2.2 = 9.8V$

$Et = 9.8V \times 5.8us = 57.43$ Vuseconds

Here we can derive L from the equation:

$L = Et / (r \times Io) = 57.43Vus / (0.05 \times 5A) = 230\ \mu Henry$

After building-up buck converter circuit, small resistor called Rsense is added to the circuit, to monitor current passing through the laser diode. By reading voltage across Rsense with microcontroller, the current of the circuit will be calculated.

Additionally, a low pass filter was added which eliminates high frequencies from the output signal, also reduces the ripple.

Cutoff frequency of the low pass filter is:

$f c = 1 / 2\pi RC = 1 / (2 \times 3.14 \times 2.7k\Omega \times 4.7\mu F) = 12.5\ Hz$

3.3 Microcontroller Unit

In the controller unit MSP430 launchpad was used which is product of the Texas Instruments. Processor on the launchpad was MSP430G2553. It is a 16-bit microprocessor, having two input/output ports with 8-pins, also has internal clock modules up to 16-MHz and external digital clock source. It has two 16-bit timer with capture compare registers, 10-bit and 12-bit ADC peripherals and USCI peripheral interface. Pin configuration of the controller is shown in Figure 3.2. C language was used for programming and IAR-Integrated Development Environment was used to develop applications with MSP430.

As it is shown in Figure 3.4, At the beginning of the written software, duration of lasing operation is set by the user. Then the port pins are configured according to their tasks in the system, output current of laser diode is set to 0Ampere. After that, the microcontroller waits for he button to be pressed by the user. When the button is pressed, a flowing current through the laser diode is generated at the adjusted level by the user, and the laser light at the output is formed as well. This lasing operation lasts until the duration is finished. Finally, the controller stops lasing operation by setting output current to 0A, and again waits for the button to be pressed.

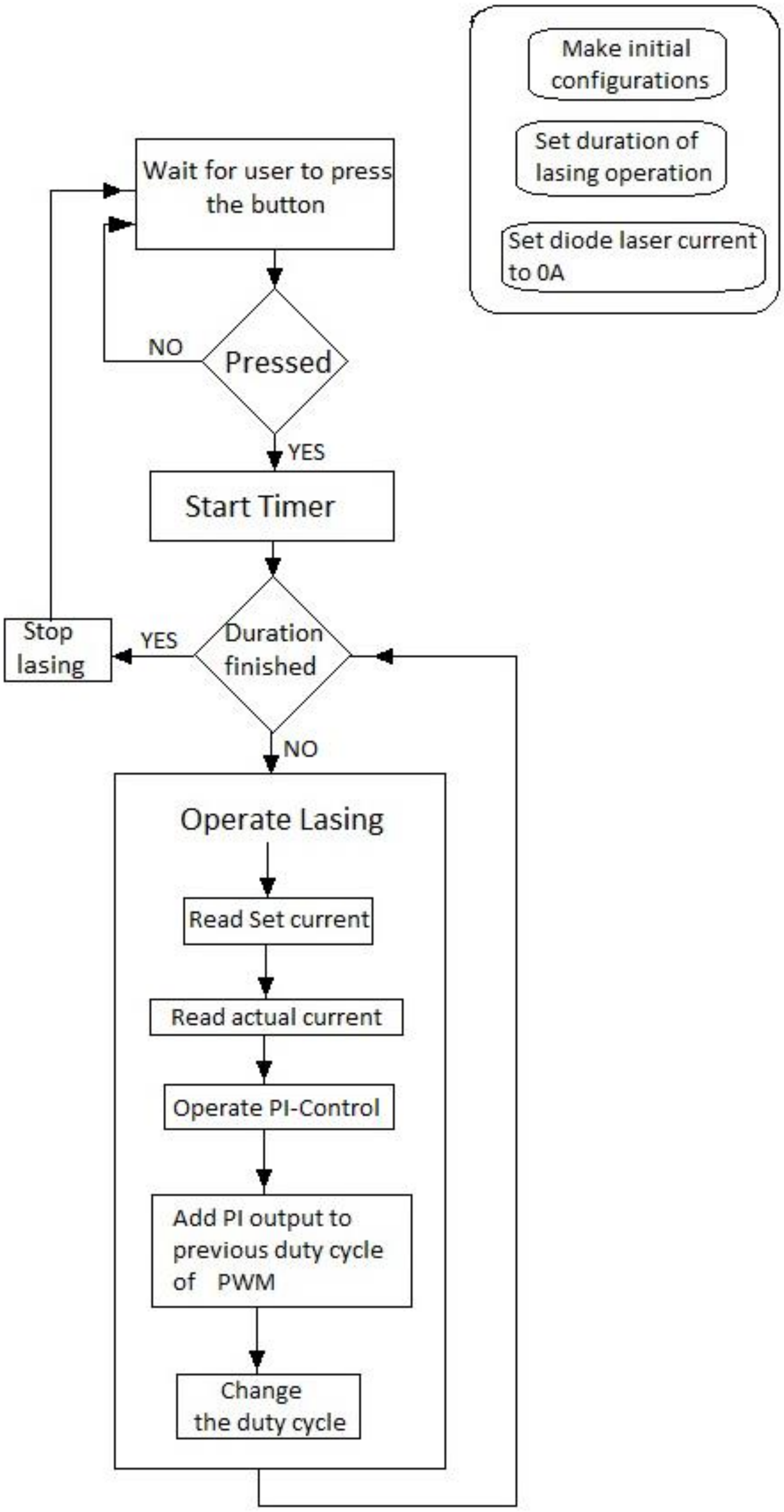

Figure 3.4 Flowchart of the software

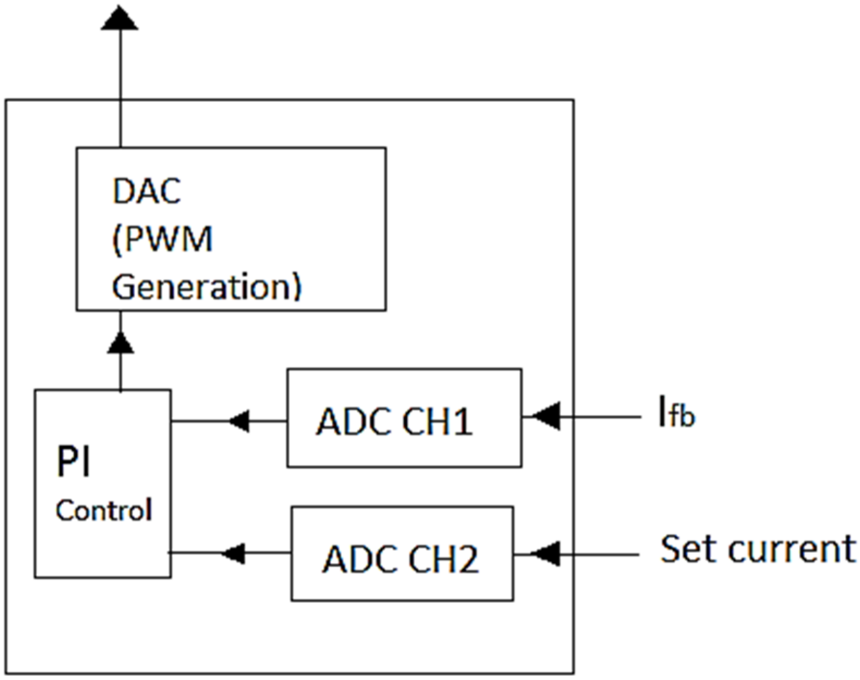

Figure 3.5 Block diagram of tasks of the controller

Peripherals of the microcontroller enables it to achieve many tasks in the driver system. Main roles of the microcontroller shown in Figure 3.5 are explained below.

3.3.1 PWM Signal Generation

MCU generates PWM signal to drive the buck converter. In the designed system, MSP430 produces PWM signal at 40 kHz with variable duty cycle using 8MHz clock source. Duty cycle of PWM signal was assigned depending on output of proportional-integral controller.

3.3.2 Analog to Digital Conversion

For analog to digital conversions ADC10 module of MSP430 was used which is 10-bit and has 3.57 reference voltage and 3.48mV resolution. Two ADC channels were used, channel-1 senses output current of the converter, channel-2 reads the set current level which is adjusted with a potentiometer by the user. Channel-1 and channel-2 were read sequentially in repeating mode. In each 3 msec, 25 samples were taken from each channel. Later on, this samples were sum, averaged and converted to analog values and sent to PI-executing function in the software.

As triggering source for ADC conversions, timer clock was used. Conversions were started at the rising edge of timer output which matches to the average point of the output current level as seen in Figure 3.6.

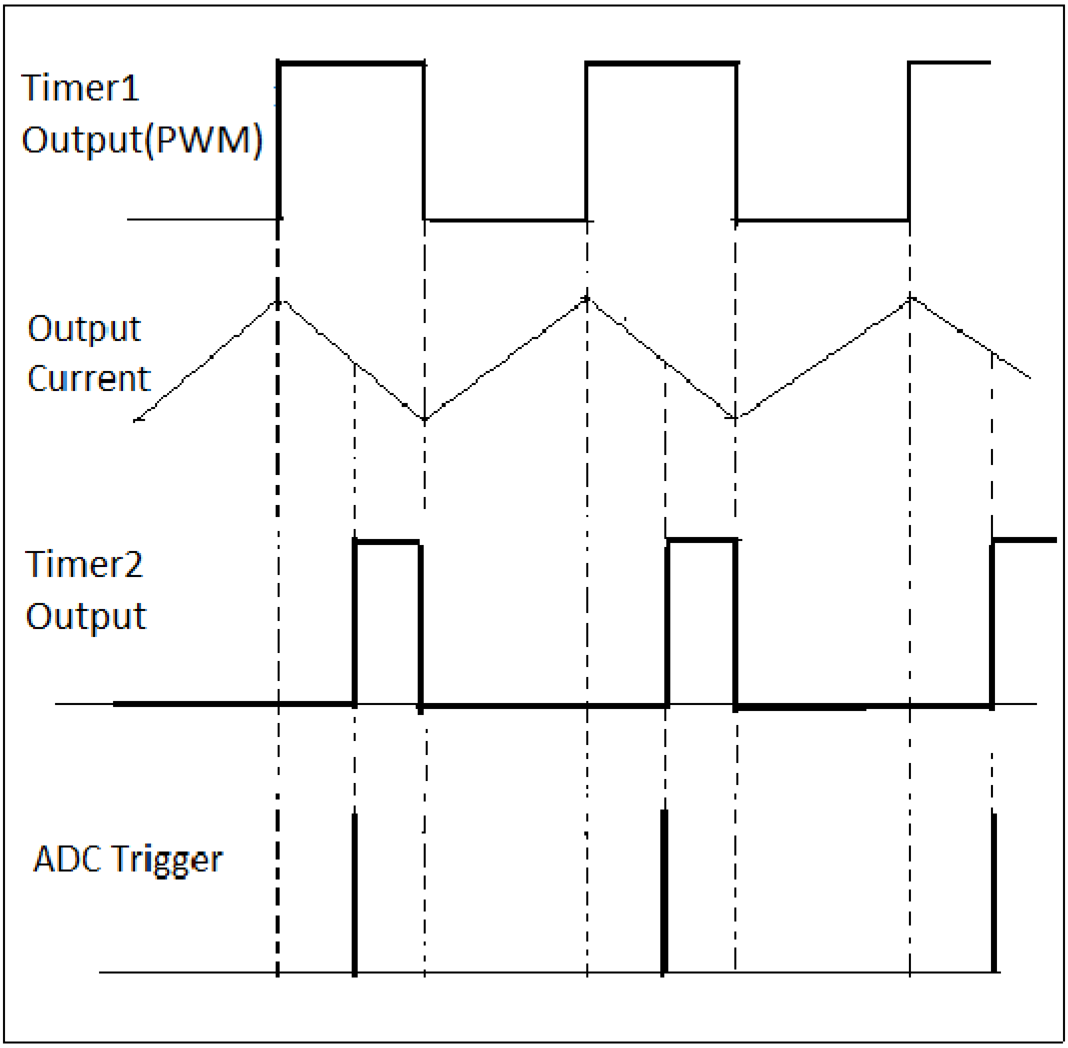

Figure 3.6 Output of timers

3.3.3 PI-Control

Controlling output current of the laser diode was another important role of controller unit. MSP430 achieves control of the output current with proportional-integral control function in the software. After obtaining set current and actual current of the laser diode with analog-to-digital conversion, error of the system was calculated within control function. Then, calculating proportional and integral terms, output of pi-control function was obtained and it was assigned as duty cycle of PWM signal. Each time pi-control codes were executed and the duty cycle was changed, the error of the system was decreased and finally brought to zero.

CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this thesis was to design a driver circuit to provide constant current to the laser diode up to 5A.

According to theoretical calculations made in Chapter 3 buck configured driver circuit was built-up as in Figure 3.3. The output voltage signal through the sense resistor and the driving PWM signal were monitored by the oscilloscope. In Figure 4.1 signals on the monitor are seen while 5 Ampere is passing through the laser diode. The red colored signal is actually current through the inductor, so current through the laser diode, while the yellow colored signal is PWM drive sginal of the buck converter.

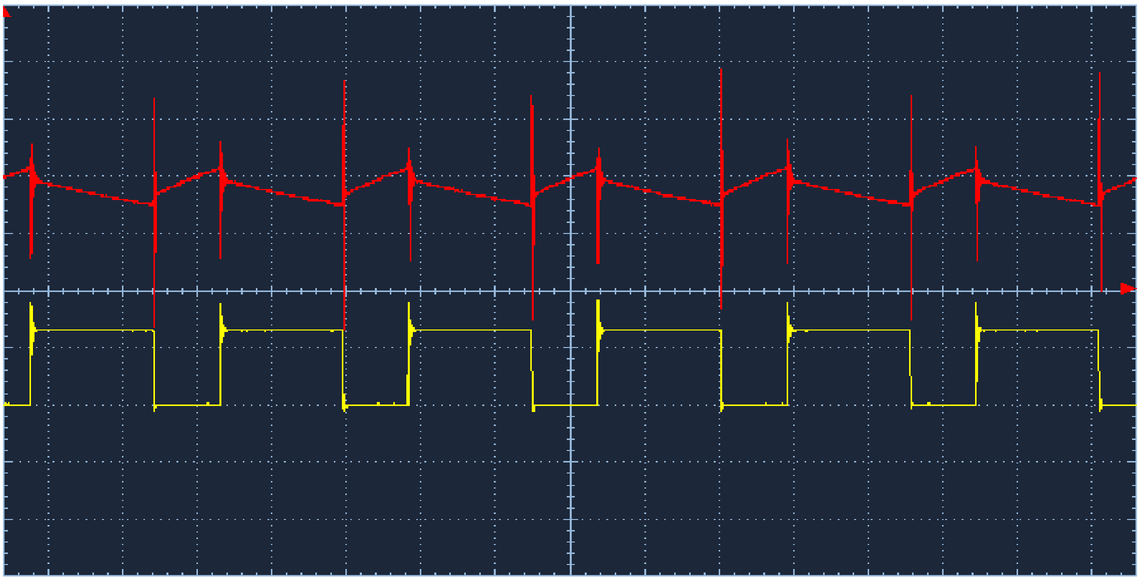

Figure 4.1 Output current and PWM signal

Depending on theoretical calculations, the buck converter requires 6 μs on-time to provide 5A current. The designed system can provide 5A current properly, although it requires 9μs.

Antoher requirement for the diode laser driver circuit was low current ripple ratio. According to oscilloscope measurements peak voltage of Rsense was 3.1V while Vrough was 2.85V. From these datas ripple current was found as ΔI= (3.1 – 2.85)/0.57 = 438 mA. Then the current ripple ratio was calculated as r = 0.438/5 = 8% which is low as it was required.

Control of the laser diode current was another important need for the driver system. PI-control was used here which is capable of keeping the output current at the desired level. Figure 4.2 demonstrates response of the controller against to change of set current from 0 to 5A. For the system, it takes 100ms to bring the output to steady state.

Figure 4.2 Response of PI-controller

The whole system was mounted on a board as seen in Figure 4.3. The system parameters; set current and actual current are shown on LCD screen. Output current is set with potentiometer as it is seen in the figure.

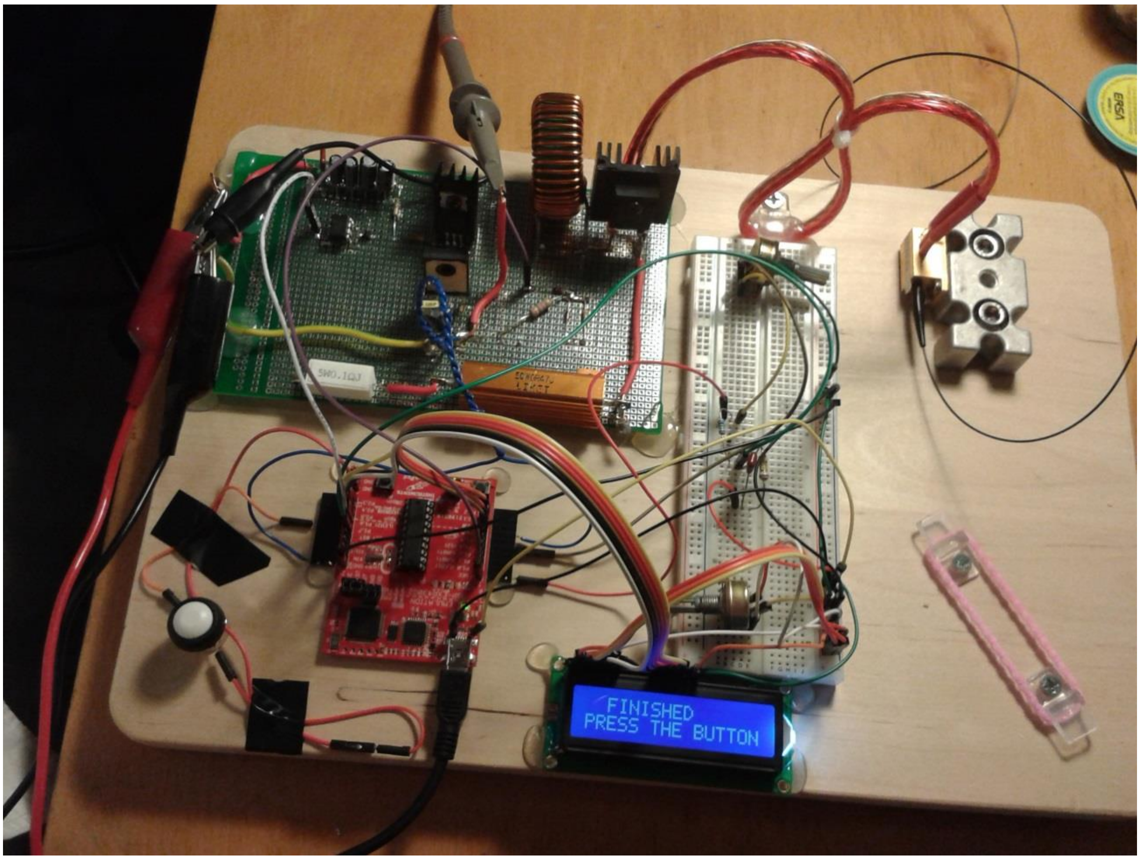

Figure 4.3 The designed diode laser driver system

The completed system can successfully and safely drive and control the laser diode. However it will be improved by designing pcb of the driver circuit which will ensure more portable and reliable system. PCB design of the driver circuit will enhance performance of the system preventing parasitics at the output signal, will provide more stable platform for the components and will result in more consistent performance.

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APPENDICES

APPENDIX A-Software

The appendix involves source code of the controller unit. It is written in IAR-IDE program.

```
//******************************************************************
*********

 //              ** MSP430 Controlled DIODE LASER DRIVER **

//           ** Proportional-integral Control of a buck converter  **

//                                          -------MSP430G2553------

//  Pot to read set_current  -->  |P1.3 ADC1       PWM P1.6|--> driving signal

//    Read voltage on Rsense-->|P1.5 ADC2        P2.0-P2.5|--> Drive LCD

//                          button-->|P1.7                              |

//

//******************************************************************
*********


#include "msp430g2553.h"

#include "lcd1.h"


void P2_Config();

void Set_Timer0();

void Set_Timer1();

void Initial_Settings();

void SetBIT6_Output();

void Start_Lasing();
```

```
void Stop_Lasing();

void adc_a5a4();

void adc_start();

void PI_Loop();

void Set_Duty();

unsigned int count1,count2,count3,sequence,countA1, operation_time = 0;

int sec1,sec2,sec3,i,k,l = 0;

float current,adc_sum,adc_sumpot,adc_sumpot1,currentforlcd = 0;

float volt_pot,volt = 0;

float error, pi_value,set_current,set_currentforlcd,pi_valueforlcd,duty_cycle = 0;

unsigned int adc[120] = 0;

unsigned int duration = 10 ;unsigned int adc[120] = 0;

unsigned int duration = 10 ;


void main(void)

{

WDTCTL = WDTPW + WDTHOLD;     // Stop WDT

BCSCTL1 = CALBC1_8MHZ;        // Clcok frequency is 8MHz

DCOCTL = CALDCO_8MHZ;

P2_Config();                  // Set port2 bits to drive 2x16 LCD

Set_Timer0();

Set_Timer1();

Initial_Settings();           // Setup LCD, ADC peripherals


while(1){
```

```
if(!(P1IN & BIT7))        // Control the button if it is pressed
{
while(!(P1IN & BIT7));          // Wait for the button to be released
lcd_command(0x01);              // Clear LCD
 __delay_cycles(10000);
P1SEL |= BIT6  ;                  // Set BIT6 as Pwm output
TA0CTL |= MC_1;                  // Start  timers
TA1CTL |= MC_1 ;
while (countA1 < operation_time)
Start_Lasing();
}
if (countA1 >= operation_time)
{
Stop_Lasing();
}
}
}
// Timer A0 interrupt service routine
#pragma vector=TIMER0_A0_VECTOR
__interrupt void Timer_A (void)
{
count1++ ;
if (count1 == 130)
{
sec1 = 1;
```

```
count2++ ;
if (count2 == 180){
sec2 = 1 ;
count2 = 0;
count3++ ;
if(count3 == 2)
{
sec3 = 1 ;
count3 = 0 ;
}
}
count1 = 0;
}
}
// ADC10 interrupt service routine
#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR(void)
{
  ADC10CTL0 &= ~ENC ;
}
// Timer A0 interrupt service routine
#pragma vector=TIMER1_A0_VECTOR
__interrupt void Timer_A1 (void)
{
countA1++ ;
```

```
}
void adc_a5a4(){
ADC10CTL0 &= ~ENC;
ADC10CTL0 = ADC10SHT_0 + ADC10ON + ADC10IE ;
ADC10CTL1 = CONSEQ_3 + INCH_5 + ADC10SSEL_3 + SHS_3 + ADC10DIV_6 ;
// Read channels between A0-A5, Triggering source TimerA2
ADC10DTC1 = 0x78 ;                    // Take 120 samples totally

ADC10AE0 |= BIT5 + BIT3 ;
}
void adc_start()
{
ADC10CTL0 &= ~ENC;
while (ADC10CTL1 & BUSY);
ADC10SA = (int)adc;
ADC10CTL0 |= ENC ;
}
void PI_Loop()
{
float Kp = 0.8 ;
float Ki = 0.001;
float integral_min = -50;
float integral_max = 50;
float proportional, proportional_term,integral,integral_term = 0;
proportional = Kp * error ;
```

```
integral = integral + error ;
if(integral> integral_max)     // Limit integral value to prevent wind-up
integral = integral_max;
if(integral < integral_min)
integral = integral_min ;
integral_term = Ki * integral ;
pi_value = proportional + integral_term ;
}
void  Set_Duty()
{
duty_cycle += pi_value ;     // add last calculated pi_value to previous duty cycle value
if (duty_cycle > 140) {     // Limit duty_cycle to prevent higher current driving
duty_cycle = 140 ;}
if(duty_cycle < 0){
duty_cycle = 0 ;}
CCR1 = 200 - (int)(duty_cycle) ;
}
void P2_Config()
{
P2DIR = 0xFF ;               // P2 is defined to drive 2x16 LCD
P2OUT = 0x00 ;
P2SEL = 0x00 ;
P2SEL2 = 0x00 ;
}
void Set_Timer0()
```

```
{
TA0CCTL0 = CCIE;
TA0CTL = TASSEL_2 + MC_0 + ID_0 ;
TA0CCTL1 = OUTMOD_7 ;
TA0CCR0 =  200;                    // CCR0 defines period of pulse
TA0CCR1 = 200 ;                   // CCR1 defines duty cycle of pulse
TA0CCR2 = 200 ;                   // CCR2 is triggering source for ADC10
TA0CCTL2 = OUTMOD_3;
}
void Set_Timer1()
{
TA1CCTL0 = CCIE;                     // Timer1 is used to adjust duration of the lasing
operation
TA1CCR0 = 10000 ;
TA1CTL = TASSEL_2 + MC_0 + ID_3 ;
}
void SetBIT6_Output()
{
P1DIR |= BIT6;                      // BIT6 is set as output and its voltage level is 3.57
P1SEL &= ~BIT6;
P1SEL2 &= ~BIT6;
P1OUT |= BIT6 ;
}
void Initial_Settings()
{
```

```
 _BIS_SR(GIE);                       // Enable all interrupts
lcd_init();                         // initialize lcd
__delay_cycles(5600);
adc_a5a4();                         // ADC10 module adjustments are made to read p1.3 and p1.5
__delay_cycles(100);
SetBIT6_Output();
operation_time = duration * 100 ;
gotoXy(0,1);
prints("PRESS THE BUTTON");
gotoXy(0,2);
prints("   TO   START  ");
}
void Start_Lasing()
{
if(sec1)
{
adc_start();
__delay_cycles(50);
for (k=0 ; k<=19 ; k++ )          // Sum 20 samples taken from channel5---> Rsense
{
adc_sum += adc[6*k];
}
volt = (((float)adc_sum / 20) / 1024) * 3.57 ;           // Find voltage on Rsense resistor
current = volt / 0.57 ;                        // Calculate current through the Rsense , thus load
adc_sum = 0 ;
```

```
error = set_current - current ;                // Find the error of the control system
PI_Loop();                                      // Calculate p,i terms an find pi_value
Set_Duty();                                     // Assign pi_value to duty_cycle
CCR2 = 100 + (int)(duty_cycle/2);
if(sec2)
{
for (l = 0; l<=19 ; l++)             // sum samples taken from ---> A3 --> set_current
{
adc_sumpot += adc[6*l + 2];
}
adc_sumpot1 = adc_sumpot;
set_current = (((float)adc_sumpot1/20)/1024) * 5.0 ;
adc_sumpot = 0;
if(sec3){
sec3 = 0 ;
currentforlcd = current * 100 ;
set_currentforlcd = set_current * 100 ;
gotoXy(0,1) ;
prints("Iset  = ");
numberToLcd(set_currentforlcd);
gotoXy(0,2);
prints("Iout  = ");
numberToLcd(currentforlcd);
sec3 = 0;
}
```

```
sec2 = 0;
}
sec1 = 0;
}
}
void Stop_Lasing()
{
TA1CTL |= MC_0;
countA1 = 0;
P1SEL &= ~BIT6;
P1SEL2 &= ~BIT6;
P1OUT |= BIT6 ;
lcd_command(0x01);
__delay_cycles(2000);
gotoXy(0,1);
prints("  FINISHED    ");
__delay_cycles(50000);
gotoXy(0,2);
prints("PRESS THE BUTTON");
}
```

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