MICROCONTROLLER BASED HIGH POWER 809-nm DIODE LASER DESIGN FOR BIOPHOTONICS APPLICATIONS

by

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ABSTRACT

MICROCONTROLLER BASED HIGH POWER 809-nm DIODE LASER DESIGN FOR BIOPHOTONICS APPLICATIONS

High power diode lasers irradiating near infrared light (800-980-nm) have a wide range of applications in many branches of medicine due to the developments in the laser technology for the last 20 years. The ability of having high penetration property in soft tissues and enhancing indocyanine green (ICG) dye induced approaches in biophotonics applications provides possible usage of 809-nm diode laser for diagnostic and therapeutic purposes. In this thesis, a high power 809-nm diode laser system was designed and manufactured. System was consisting of 809-nm high power diode laser module with 10 W output power, current source unit, current sensor, switch mode power supply unit, microcontroller based controller unit, and fiber coupling. Diode laser driver system provides current to 809-nm diode laser module from voltage controlled current source in order to generate continuous wave 809-nm laser light. A current sensor was used to sense the operating current of laser diode for current feedback process of controller unit. Microcontroller based controller unit provided the control of whole system and it facilitated the user to access all the functionalities of the system. The user interface program was developed in C programming language to set diode current in amperes and duration in seconds via a PC. During laser operation, values of the diode current and diode temperature were controlled simultaneously and monitored by the interface program. The output power of the laser light was measured by using a powermeter and it was seen that the microcontroller based diode laser system was working accurately and efficiently.

Keywords: 809-nm diode laser, Microcontroller, ICG, Continuous laser light.

ÖZET

BİYOFOTONİK UYGULAMALARA YÖNELİK MİKRODENETLEYİCİ TABANLI YÜKSEK GÜÇLÜ 809-nm DİYOT LASER TASARIMI

Laser teknolojisinde son yıllarda görülen ileri gelişmeler sonucu yüksek güçte 800-980-nm arası ışıma yapan kızılaltı diyot laser sistemleri tıpta birçok dalda kullanım alanı bulmaktadır. 809-nm dalga boyundaki diyot laserlerin, yumuşak dokularda derinlere nüfuz etme özelliği ile ve literatürde Indocyanine Green maddesi baz alınarak yapılan biyofotonik calışmalara yönelik geniş bir uygulama alanı potansiyeli olduğu gözlemlenmektedir. Bu çalışmada, azami 10W çıkış gücüne sahip 809-nm diyot laser sistemi tasarlanıp üretilmiştir. Sistem, 10 W çıkış gücüne sahip 809-nm diyot modülü, akım kaynağı ünitesi, akım sensörü, anahtarlamalı güç kaynağı, mikrodenetleyici tabanlı kontrol ünitesi ve fiber kuplaj aparatından oluşmaktadır. 809-nm laser ışığı, diyot laser sürücü kısmı olarak kullanılan voltaj kontrollü akım kaynağı tarafından sağlanan elektrik akımı ile üretilmektedir. Akım sensörü, diyot çalışma akımını dedekte ederek kontrol ünitesi tarafından yapılan akım geri besleme işlemi için kullanılmıştır. Kontrol ünitesi bütün sistemi yönlendirerek kullanıcıyı sistemin çalışma durumuna ait olan verilerle bilgilendirmektedir. C programlama dili ile geliştirilen arayüz programı ile kullanıcı diyot lasere uygulanacak akım değerini ve çalışma süresini bilgisayardan girerek diyot laser sistemini kolaylıkla kullanabilmektedir. Aynı zamanda diyot laser çalışıyorken diyot laserin o andaki akım değeri ve sıcaklık bilgisi arayüz programı ile kullancıya gösterilmektedir. Bu sistemde üretilen laser ışığı güç ölçer kullanılarak ölçülmüş ve sistemin sorunsuz bir şekilde bir bütün olarak çalıştığı gözlenmiştir.

Anahtar Sözcükler: 809-nm diyot laser, Mikrodenetleyici, ICG, Sürekli laser ışığı.

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LIST OF SYMBOLS

B	Material specific constant
GaAs	Gallium Arsenide
h_{FE}	DC current gain
I_B	Base current
I_C	Collector current
I_E	Emittor current
I_{PN}	Primary nominal current
I_S	Reverse saturation current
k	Boltzmann's constant
P_D	Power dissipation
q	Electron charge
T	Temperature
V_{AC}	AC voltage
V_{BE}	Base-emitter voltage
V_{CE}	Collector-emitter voltage
V_{DC}	DC voltage
V_{IN}	Input voltage
V_{OUT}	Output voltage
V_T	Thermal voltage

LIST OF ABBREVIATIONS

ADC	Analog to digital conversion
CMOS	Complementary metal oxide semiconductor
DAC	Digital to analog conversion
FDA	Food and drug administration
IC	Integrated circuit
ICG	Indocyanine green
IDE	Integrated development environment
NSCLC	Non-small cell lung cancer
NTC	Negative temperature coefficient
PC	Personal computer
PCB	Printed circuit board
PDT	Photodynamic therapy
PS	Photosensitizer
RMS	Root mean square
SMPS	Switch mode power supply

1. INTRODUCTION

High power diode lasers irradiating near infrared light (800-980-nm) have been commercially available due to the developments in the laser technology for the last 20 years. They are manufactured with the semiconductor technology that provides practical usage (portable, lightweight and more economic) besides being reliable and having a long life time. These lasers have a wide range of applications in many branches of medicine because of having such beneficial characteristics [1].

Cancer is a fatal disease causing many deaths all over the world. Widely used cancer treatment methods (surgery, radiotherapy, chemotherapy) which have side effects decrease the quality of life. Developments in laser technology provides possible noninvasive diagnostic and therapeutic approaches for cancer. Diode lasers offers the opportunity for noninvasive treatment methods for cancer. Photodynamic therapy (PDT) is a one of the new approaches in biophotonics applications for the treatment of localized tumors in the body by using different kinds of photosensitizers, light-activated drugs, destroying the tumors by using laser light having power approximately 1W. With respect to other widely used cancer treatment methods, PDT has limited side effects [2].

Indocyanine Green (ICG) solution having high absorption at around 800-810nm infrared light has been used in biophotonics applications [3]. Infrared light offers the advantage of deeper tissue penetration making ICG ideal for photothermal interactions [4]. The effect of the selective photothermal tumor tissue destruction by using ICG was also demonstrated in both in vitro and in vivo experiments using mammary tumors in rats [5]. Moreover, ICG is extensively used in laser tissue welding applications by using laser light having at least 5 W output power [6].

In this thesis, a microcontroller based high power (10 W) 809-nm diode laser driver system is designed and manufactured in order to find its potential novel approaches in biophotonics applications because of the ability of 809-nm laser light to enhance ICG induced reaction with target tissues and to provide high penetration property in soft tissues. In Chapter

2, some important types of biophotonics applications in that 809-nm diode laser can be used are described to give an understanding of the underlying mechanisms. In Chapter 3, the structure of the diode laser is briefly explained. In Chapter 4, the system design procedure is discussed in a detailed way by giving all significant design steps of the whole system. Finally, Chapter 5 includes concluding remarks and possible future work suggestions.

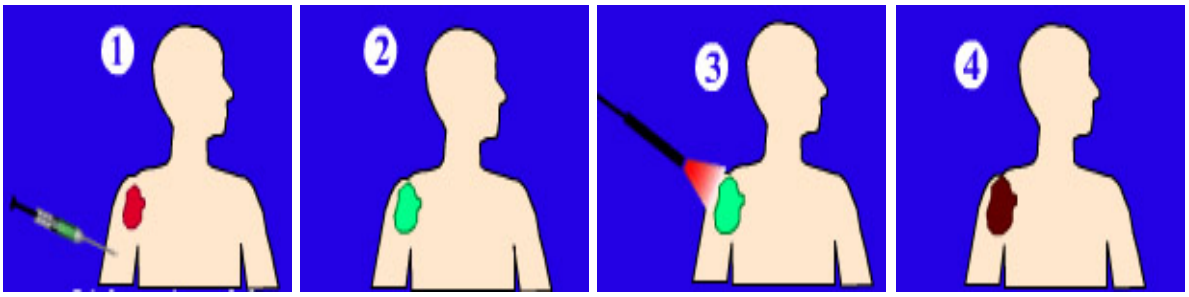
2. BIOPHOTONICS APPLICATIONS OF DIODE LASERS

PDT, also called photoradiation therapy, phototherapy, or photochemotherapy, is a relatively new prospective therapeutic modality in biophotonics applications for the treatment of definite types of malicious neoplastic formations. The method is based on the combination of a photocytotoxic action of a drug (toxic effect produced on the cells upon the drug's interaction with light of the specific wavelength) with its predominant accumulation in neoplastic tissues. It has been approved by the United States Food and Drug Administration (FDA) for certain cases of cancer of the esophagus and non-small cell lung cancer (NSCLC), and was most recently approved to treat actinic keratosis, a precancerous skin condition [3].

Phototoxic effect of a row of natural dyes chemically represented by a series of conjugated macrocycles (eosine, psoralene, cyclic tetrapyrroles, etc.) was discovered by Oscar Raab - a medical student from Munchen, Germany in 1898 when he did research under the guidance of Prof. Fon Tappeiner. Oscar Raab experimented with a dye named acrydine, which revealed its property to kill a protist - *paramecia* - upon irradiation with light. There was no such effect observed in the absence of light. The method was at once tested to treat some skin diseases with certain success followed by reports in the literature in 1903-1907.

In 1903 skin cancer was firstly successfully treated with dye **eosine** and light. Such natural dyes was named "**photosensitizers**" (**PS**) (*fon Tappeiner, 1903*), and the method itself - "photodynamic action" on a cell (*fon Tappeiner, 1904*). At first the terms denoted all the processes where PS, living tissue (cell) and irradiation procedure were involved, and later on (*Blum,1941*) they began to use the notions of "**photosensitizer**" (**PS**) and "**photodynamic therapy**" (**PDT**) only at describing the processes involving molecules aroused with light, generating singlet oxygen, and destroying cells.

PDT works since the photosensitizing agent collects more readily in cancer cells than in normal cells. When the agent is then exposed to light, it reacts with oxygen to create chemicals that kill the cell (Figure 2.1). Because the approved light sources can only penetrate a limited depth through tissue, PDT is mainly used to treat areas on or just under the skin, or in the lining of internal organs.



(1) Light-activated drug is applied topically or injected intravenously.

(2) Drug accumulates in the affected tissue.

(3) Low power light is delivered through the illuminating device and focused on the affected tissue.

(4) Light activates photo reactive drug, releasing agents that destroy only affected cells.

Figure 2.1 Steps of PDT [7].

How PDT selectively destroys tumors is a simple concept. The PDT agents, mainly porphrins and their derivatives, preferentially accumulate in neoplastic tissue. This occurs either from selective up-take or delayed elimination relative to normal tissue. When the photosensitizer is activated by a light source (laser or filament), the molecule absorbs the light energy. In this excited state it is extremely reactive and interacts with molecular oxygen to produce highly reactive oxygen “singlet” (Figure 2.2). This moiety is highly cytotoxic. Since the agent is concentrated in the tumor and the light is directed at the mass, the resulting direct tumorocidal activity and micro vascular damage destroys tumor cells. The result is inflammation and necrosis of the cancer. If the cancer is adjacent to a cavity or lumen (esophagus, bronchus, intestinal tract or bladder) the treated tissue sloughs away and there is normal healing and re-epithelialisation of the affected site [3, 8].

Since this PDT process is a “cold” photochemical process, there is essentially no thermal damage to the tissues; connective tissue (collagen and elastin) and vasculature are largely spared. Compared to surgery and conventional thermal YAG and Argon laser treatment, there is much less damage and disruption of the underlying and adjacent normal tissue structures [4, 9]. Both the patient and clinician have much to benefit from this approach. Superficial treatments do not require sterile theatre conditions and can be delivered in an outpatient setting. There is little post-treatment discomfort and the only significant side effect is residual photosensitivity (protection from direct sunlight is necessary for a period of time).

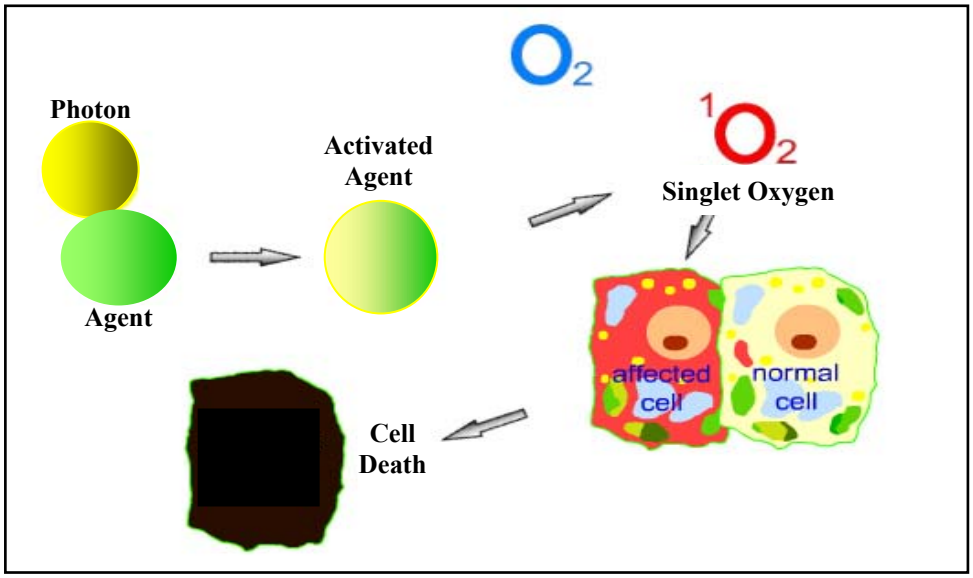


Figure 2.2 Cellular level of PDT [10].

PDT might be applied in many cases where surgery, chemotherapy and X-ray radiation are contra-indicated. PDT patients don't have to go through surgery, and usually don't even need to check into the hospital. Another advantage is that PDT can be repeated a number of times, unlike radiation and chemotherapy. Another plus is that PDT can work in places where surgery would not be feasible, and destroys selectively only affected cells [11].

The major side effect of PDT is photosensitivity, or sensitivity to light. Most people find this inconvenient, but not intolerable. The photosensitizing drug currently used for PDT stays in the skin for 24 hours up to 4-6 weeks (depends on the type of the photosensitizer) [2].

Lasers, with precise energy-delivery mechanisms, can be effective tools in photothermal treatment of cancer. However, selectivity has been a major challenge in non-invasive treatment of deep tumors. Absorption of laser energy by tissue depends on the light wavelength and the tissue optical properties. Strong absorption can cause thermal injury mainly to the surface tissue being treated, which in turn limits the scope of the thermal effect in deeper tissue. Weak absorption by tissue does not sufficiently raise the tissue temperature. To solve this problem, dye enhanced laser–tissue interaction has been investigated. Using a near-infrared laser, which results in low tissue absorption, and an in situ dye with a corresponding absorption peak, selective tissue destruction can be achieved. Such a laser beam can penetrate tissue with little heat absorption. However, when a laser-absorbing dye is present in the target tissue, the laser energy is strongly absorbed by the dye molecules. Upon returning to ground states, those molecules release the absorbed energy in the form of heat, hence causing cell destruction in the surrounding tissue [4].

Specifically, by injecting **indocyanine green (ICG)** solution into target tissue, an diode laser at around 800-nm can non-invasively raise target tissue temperature significantly, while keeping the surface temperature below the 40^{o}C damage threshold. The effect of the selective photothermal tumour tissue destruction was also demonstrated in both in vitro and in vivo experiments using mammary tumours in rats [5]. ICG (**$C_{43}H_{47}N_2O_6S_2Na$)** (Figure 2.3), has a molecular weight of 775. A tricarbocyanine type of dye with infrared absorbing properties; peak absorption at about 800-nm., has little or no absorption in the visible range [6]. It is used in infrared photography and in the preparation of Wratten filters. It is also used as a diagnostic aid for blood volume determination, cardiac output, or hepatic function [12].

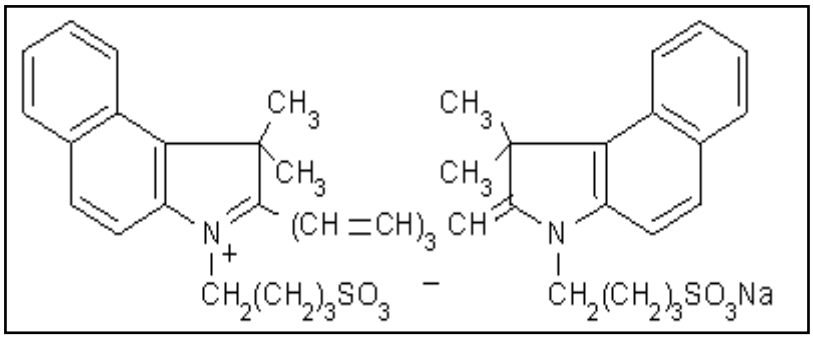


Figure 2.3 Indocyanine green ($C_{43}H_{47}N_2O_6S_2Na$) [13].

After its introduction by Fox et al. (1957) ICG soon came into general use for recording dye dilution curves, in particular for the determination of cardiac output. The principal advantages causing the rapid acceptance of the dye were the presence of an absorption maximum near the isobestic point of hemoglobin and oxyhemoglobin around 800nm, the confinement to the vascular compartment by binding to plasma proteins, the very low toxicity, and the rapid excretion, almost exclusively into the bile.

ICG has been used extensively in laser welding because of its absorption properties at the laser diode wavelength of 800-nm (Figure 2.4). ICG has somewhat bizarre light absorption behavior as a function of concentration because it tends to aggregate in water at high concentrations. This means that the effective absorption does not increase linearly with increasing concentration. Furthermore, ICG tends to degrade with exposure to light [6]. The photodegradation is mitigated when ICG is bound to albumin, but it still proceeds slowly (days). The photodegradation is also concentration dependent. When ICG is added to blood plasma, it is rapidly bound to proteins in the serum. This also changes its absorption spectrum. To summarize, ICG absorption depends on its concentration and its solute [14].

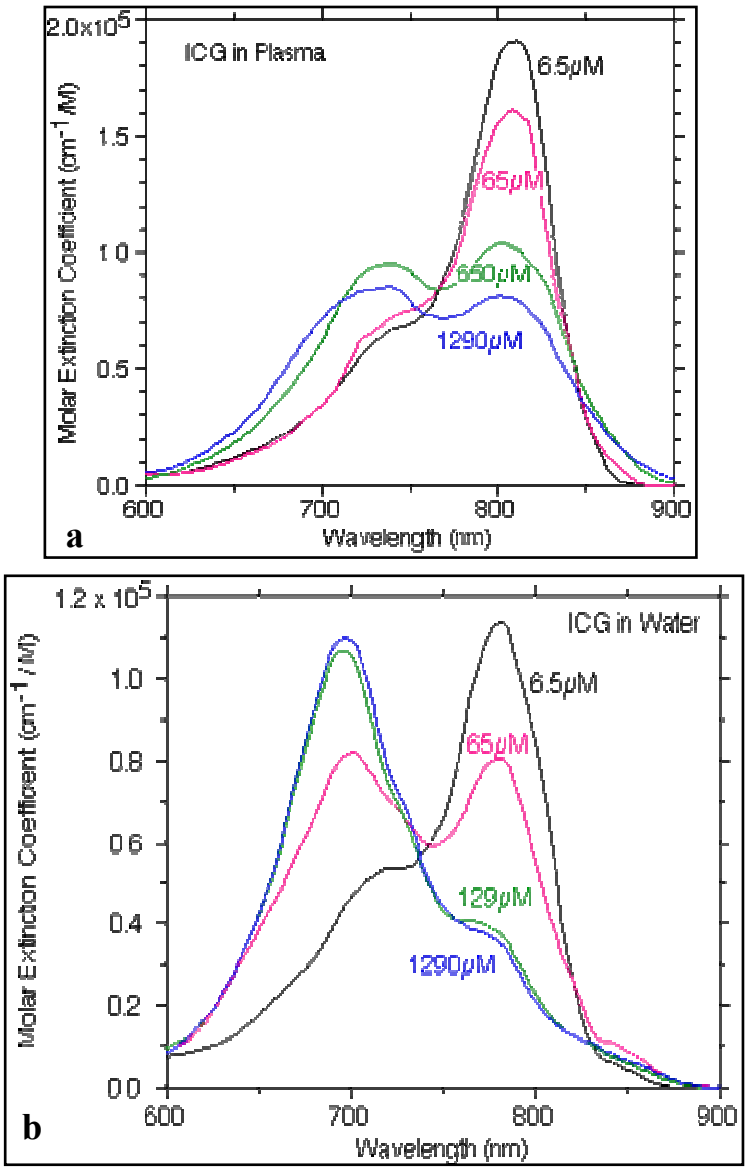


Figure 2.4 Absorption spectrum of ICG (a) in plasma, and (b) in water [15].

3. DIODE LASERS

Laser, whose name is based on "Light Amplification by Stimulated Emission of Radiation", allows the generation of light with properties (being coherent, monochromatic and collimated) not available from natural light sources. Lasers incorporate laser oscillators consisting three basic parts, namely pump energy, active material, resonator as shown in Figure 3.1.

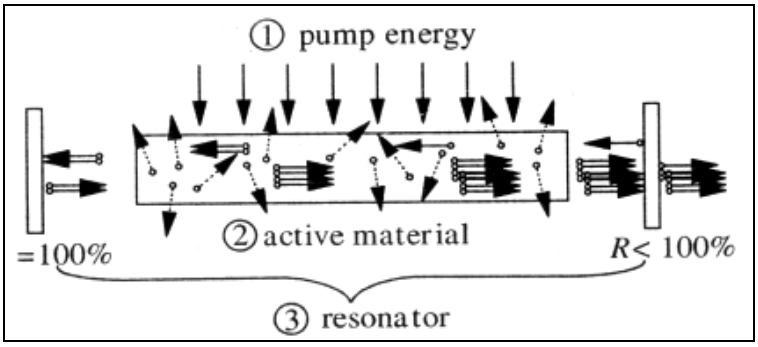


Figure 3.1 Three basic parts of laser oscillator [16].

Basically, lasers are operating in the following manner:

- The pumping mechanism (either electrical or optical energy) supplies energy in the active material and produces population inversion of electrons resulting in the higher electron population of the upper energy level compared to the lower energy level in active material.
- Spontaneous emission in the operation of lasers produces photons in all directions, and the resonator mirrors reflect some of these photons according to their propagation direction, polarization and wavelength.
- These reflected photons are duplicated by the stimulated emission in active material and so that a large number of equal and coherent photons are produced forming the laser beam.
- This laser beam is partially coupled out of the resonator by moderately transparent mirror at one side of the resonator [16].

Diode lasers are distinguished from other types of lasers by their ability to be pumped directly by an electrical current that results much more efficient operation. Diode lasers are usually fabricated by growing a p-doped layer on top of a n-doped semiconductor substrate and active material is built in p-n junction (e.g. GaAs - Gallium Arsenide) as depicted in Figure 3.2.

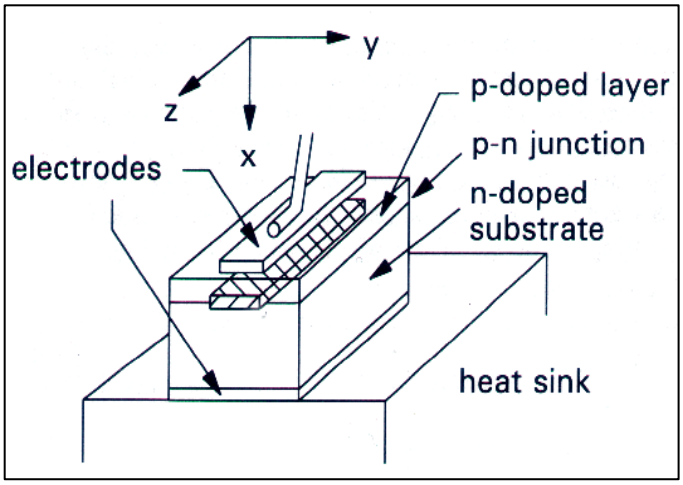


Figure 3.2 Schematic structure of a diode laser [17].

When electrical current is applied by using the electrodes, the lasing occurs in the active region because the movement of the electrons from n-doped layer to p-doped layer causes stimulated emission of photons [17].

Diode lasers fabricated with heterostructures, that means multiple semiconductor layers, provide low threshold necessary for continuous wave operation and room temperature operation. The power of the diode laser is dependent on the fabrication process. For example, if the laser produced with broad active region, it gives higher output power. Moreover, the lifetime of the diode lasers reaches values of many thousands of hours with specified for more than 80 percentage of the maximum output power. These attributes enable the diode laser to have different application areas by drawing more attention than other types of lasers [17].

4. SYSTEM DESIGN

Diode laser driver system shown in Figure 4.1 basically provides current (maximum 40 A) to 809-nm diode laser module from voltage controlled current source in order to generate 809-nm laser light. The switch mode power supply unit delivers the required voltage and the current to this current source that consists of transistor array. Diode laser module gives maximum output power of 10W with respect to current value of 35 A.

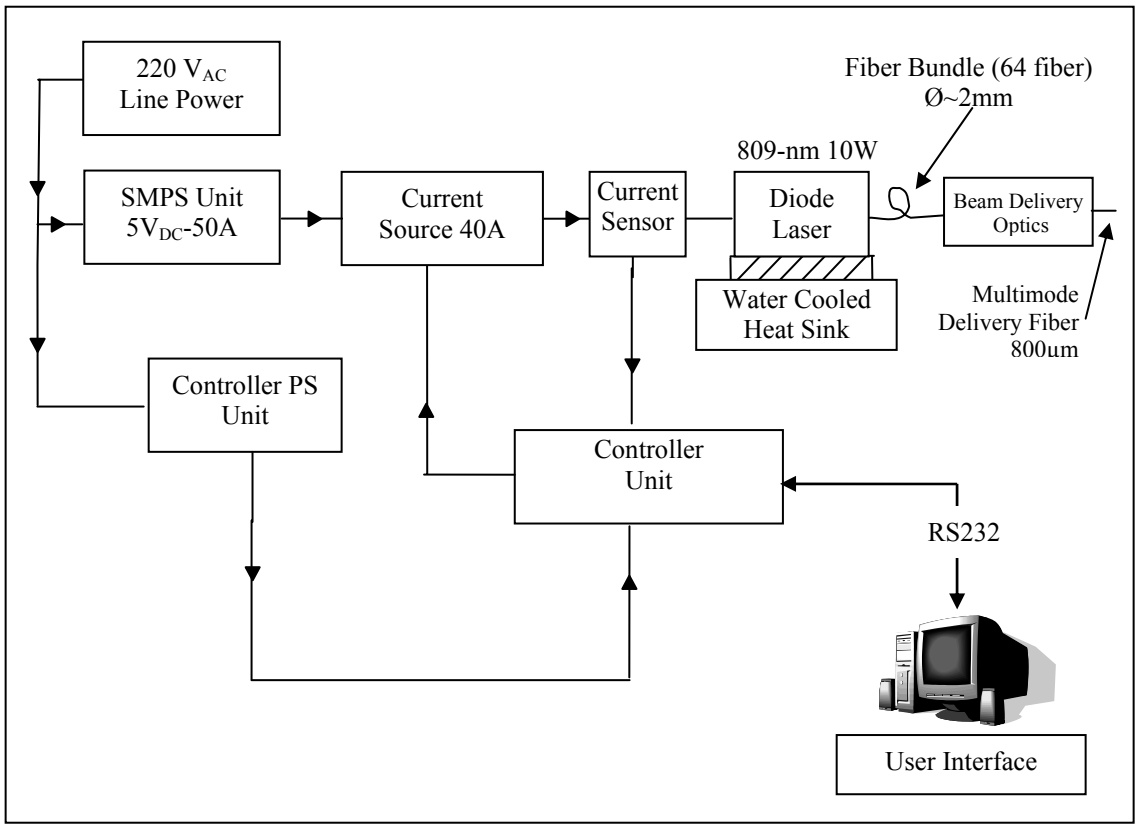


Figure 4.1 Block diagram of the diode laser system.

Current sensor is used to sense the operating current of laser diode for current feedback process of controller unit. Stimulated laser light at the output of the diode module is focused into 800-μm optical fiber by means of the optical assembly. Water cooled heat sink unit is used to protect the diode laser module from the excessive heat produced by lasing process.

Therefore, the temperature of the diode module will be kept stable and damages caused by excessive heat will prevented.

Microcontroller based controller unit provides the control of whole system and it helps the user to access all the functionalities of the system. The user can easily control the system with user friendly interface by a PC that communicates with the controller unit. In the following sections, detailed descriptions of subunits will be given.

4.1. SMPS Unit

SMPS unit is LPS252-C manufactured by Astec Corporation and it provides 5 V_{DC} output voltage and 50 A output current at maximum load. It has input voltage range 85 -264 V_{AC} and it has overvoltage and overload protection. This unit is used to provide the operating current for the diode laser module by driving the transistors array because of high output current, its reliability and self electrical protective properties.

4.2. Current Source Unit

Current source unit is designed as transistor array that is composed of six high power transistors paralleled to each other as it shown in the following structure (see Figure 4.2).

High power npn transistor 2N3055 with TO-3 package manufactured by ST Microelectronics Company is chosen for this parallel structure due to maximum continuous collector current (I_c) of 15 A. All transistors are identical with the same production serial number. This feature cancels out possible production impurities that cause the differences in biasing conditions affecting whole structure.

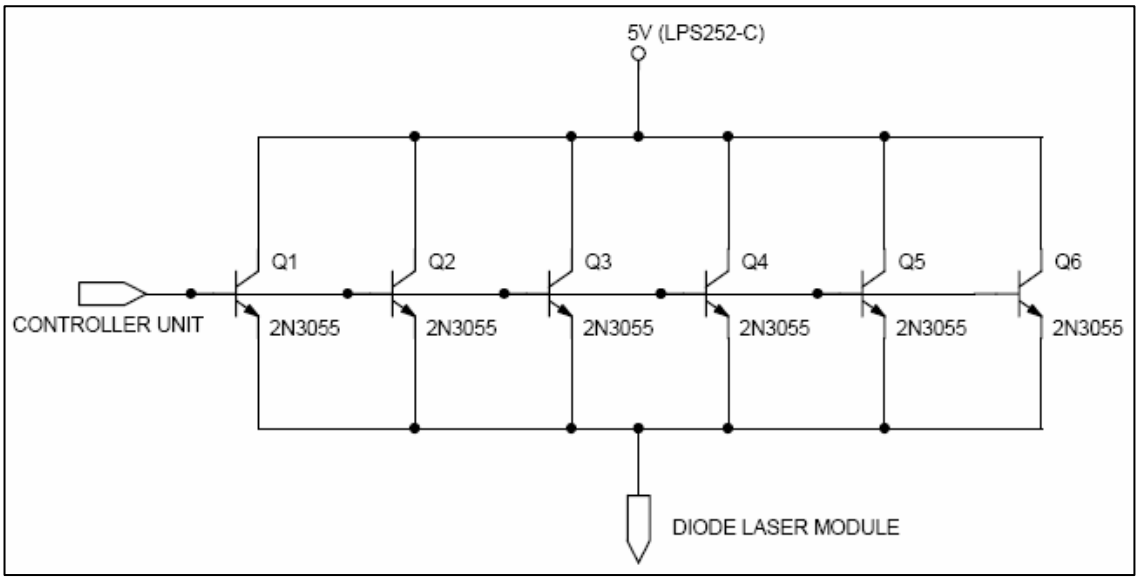


Figure 4.2 Schematic of the current source unit.

Transistors are paralleled by connecting corresponding terminals to each other. Common collectors of the structure are supplied by 5 V from SMPS unit. Common bases are biased from the controller unit by leading the transistors to operate in the forward active region. Common emitters are connected to the diode laser module to supply the diode current up to 40 A. 2N3055 npn transistor has the device data shown in Figures 4.3 and 4.4.

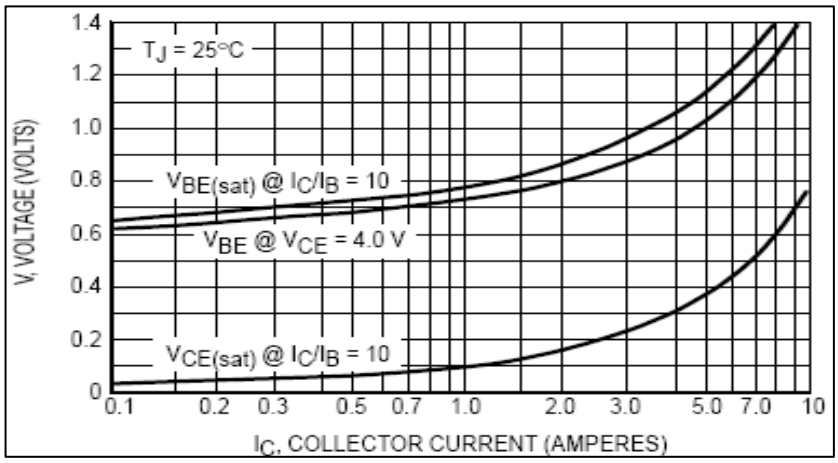


Figure 4.3 Voltages when transistor is active (On) state [18].

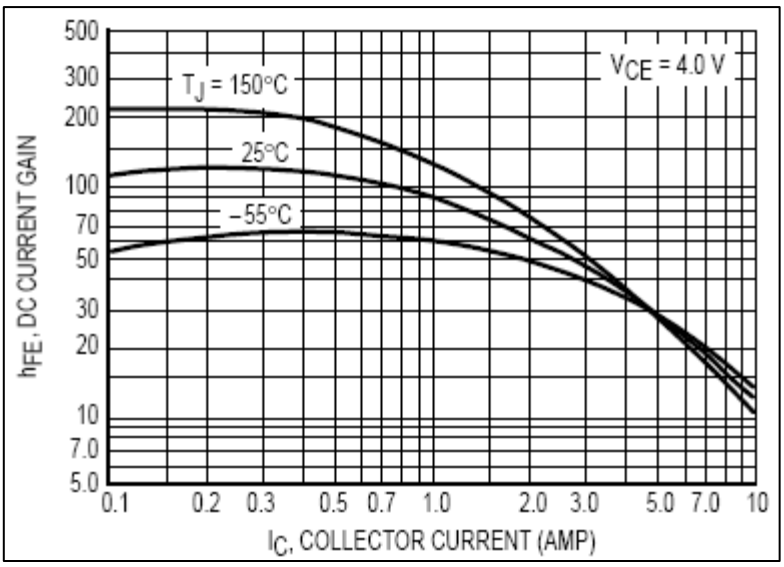


Figure 4.4 DC current gain (h_{FE}) versus I_c graph [18].

Common bases of the parallel transistor structure are biased with the controller unit. This is a dynamic system because the base emitter junction of transistor has voltage and current relation according to formula:

$$I_B = I_s\left(e^{V_{BE}/V_T} - 1\right) \tag{4.1}$$

$$V_T = \frac{kT}{q} \tag{4.2}$$

where V_{BE} is the base-emitter voltage, I_B is base current, I_s is reverse saturation current, V_T is thermal voltage, k is Boltzmann's constant, T denotes absolute temperature and q is the electron charge [19]. The relation between the base current and the emitter current (I_E) of a transistor can be derived as follows:

$$I_c = h_{fe} I_B \tag{4.3}$$

$$I_E = I_c + I_B = (h_{fe} + 1)I_B \tag{4.4}$$

Substituting equation (4.1) into (4.4) yields:

$$I_E = (h_{fe} + 1)I_s\left(e^{V_{BE}/V_T} - 1\right) \tag{4.5}$$

From this equation, it can be seen that the voltage applied to common bases of parallel transistor creates I_E. This provides us voltage controlled current source structure.

The voltage on the diode laser is changing with respect to value of applied diode current because of having the p-n type semiconductor composition and diode characteristics. Therefore change on the diode voltage is directly affecting the biasing conditions of parallel transistor structure and this causes the change in the diode current as a reverse effect. Therefore the voltage applied to common bases of transistor should be changed to adjust the diode current. While the diode laser is operating, the negative current feedback on diode current is done by the controller unit to adjust the voltage applied to common bases of the transistors in order to have stable diode laser current.

Current source unit provides maximum 40 A to the diode laser unit. If one transistor is used with high I_c to provide 40 A, there would be a huge power dissipation (P_D) on this transistor according to formula:

$$P_D = I_C V_{CE} + I_B V_{BE} \tag{4.6}$$

Total power dissipation of this parallel structure is divided by the number of transistor used, therefore the temperature effect on the input and output characteristics of transistors are minimized by decreasing power dissipation on each transistor and the life time of the current source is increased.

4.3. Current Sensor

Current sensor (Figure 4.5) used in the system design is the current transducer, HAL 100-S, with the primary nominal current (I_{PN}) measurement range between 0 and ± 100 A. It gives analog output voltage ± 4 V with respect to ± I_{PN} value. It has a response time lower than 3 μs at 90% of measured I_{PN} value. This current sensor is open loop transducer and it is connected to directly to the current line of diode laser module to measure diode current while it is operating.

Current sensor produces output voltage from 0 and 1.6 V_{DC} with respect to value of operating current of diode laser from 0 to 40 A and this signal is processed by the controller unit.

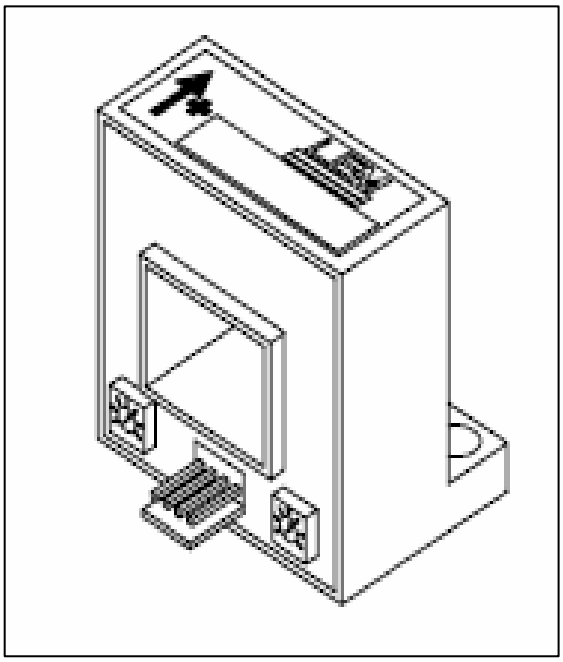


Figure 4.5 Current sensor with the current measurement range of ±100 A [20].

4.4. Controller Power Supply (PS) Unit

Controller PS unit (Figure 4.6) is designed to generate the dc supply voltages required by the integrated circuits (IC) used in the controller unit. The DC supply voltages are 24, ± 15, 12 and 5 V specified according to datasheets of the components selected for the design.

220 V_{AC} line power is reduced to 34 $V_{AC\text{-}RMS}$ and 20 $V_{AC\text{-}RMS}$ with a step down transformator. Full wave rectification is done by bridge rectifiers and linear voltage regulators (7915, 7815, 7812, and 7805 ICs) are used to get regulated dc supply voltages.

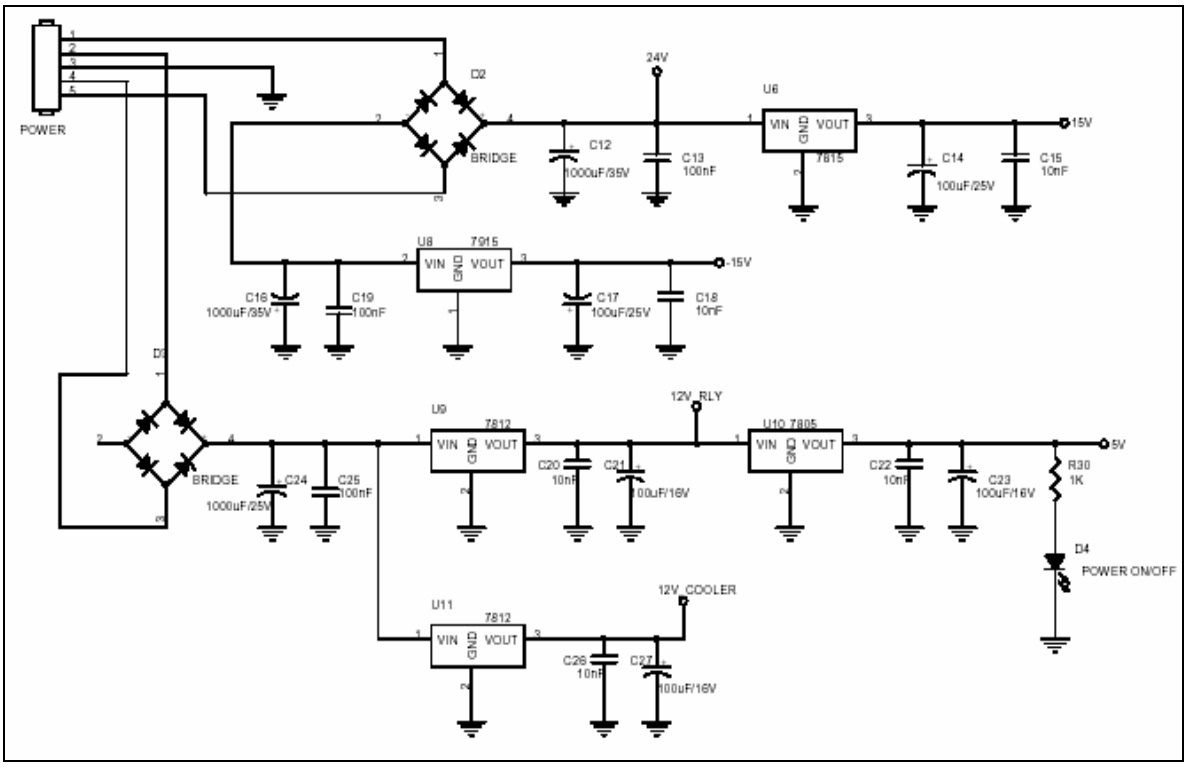


Figure 4.6 Schematic of the controller power supply unit.

4.5. Controller Unit

Controller unit is designed to provide reliable and accurate operation of diode laser driver system for the user. In this unit, PIC16F873 microcontroller manufactured by Microchip Company is chosen as a central control-processing unit to control functions of other units as depicted in Figure 4.7. These units and the properties of the circuit will explained in a detailed way in the next sections.

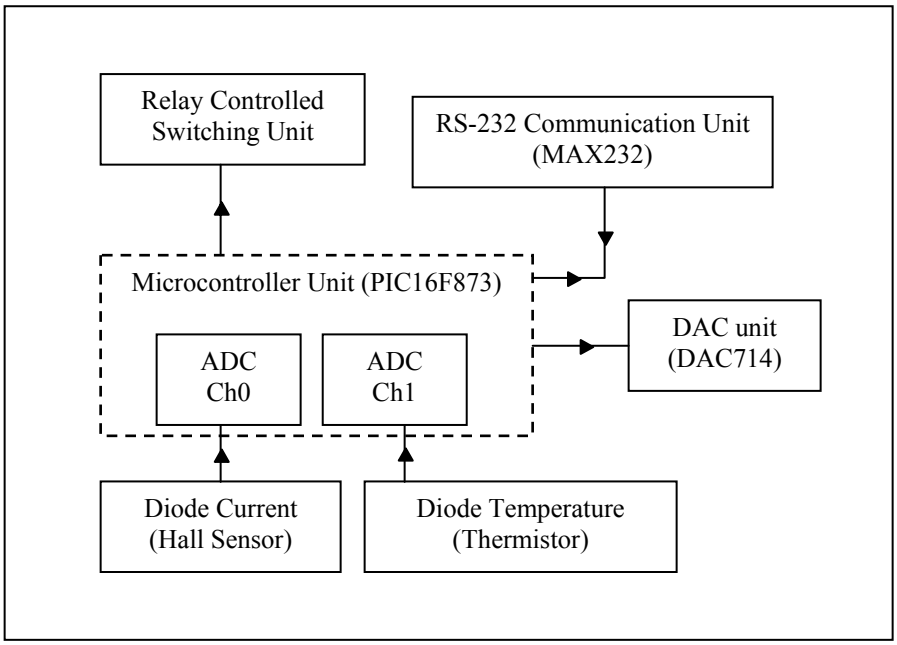


Figure 4.7 Block diagram of the controller unit.

At the design procedure, all units of the circuit are tried on the breadboard. After that, the schematic of the circuits is drawn in ORCAD 9.2 capture program. Layout of the circuit is designed and drawn in ORCAD 9.2 layout program and then printed circuit board is produced (see appendix A for the schematic and appendix B for PCB layout drawings).

4.5.1. Relay Controlled Switching Unit

In this unit, there are four relays that are activated by ULN2003 integrated circuit (IC) controlled by microcontroller unit. ULN2003 IC has high current seven open collector darlington pairs with common emitters. When 5 V_{DC} is applied to the input pin of ULN2003 IC, the output pin is pull down to ground and the corresponding relay is activated (Figure 4.8).

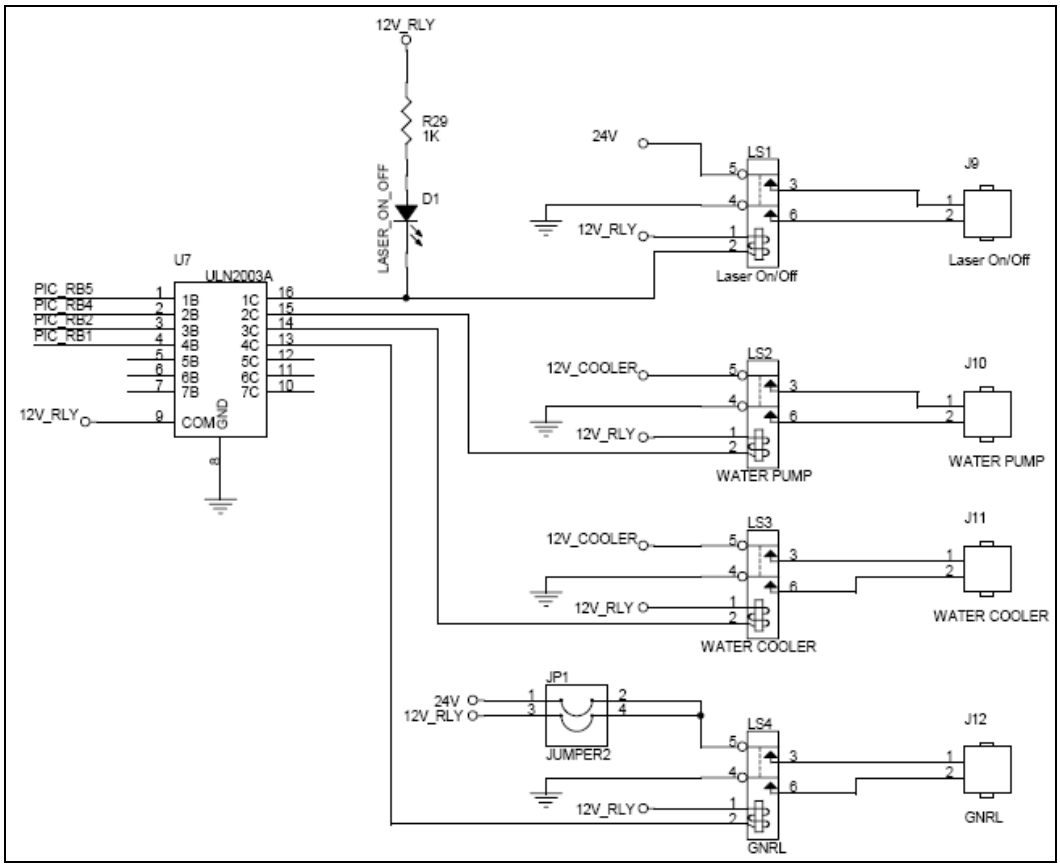


Figure 4.8 Schematic of the relay controlled switching unit.

One of the relays is used to turn on and off the diode laser module by applying 24 V_{DC} to relay on the module. Normally, relay on the diode laser module is configured to set short circuit path on the laser diode as shown in Figure 4.9. When 24 V_{DC} is applied, relay is activated so that short circuit is removed and diode laser module starts to operate.

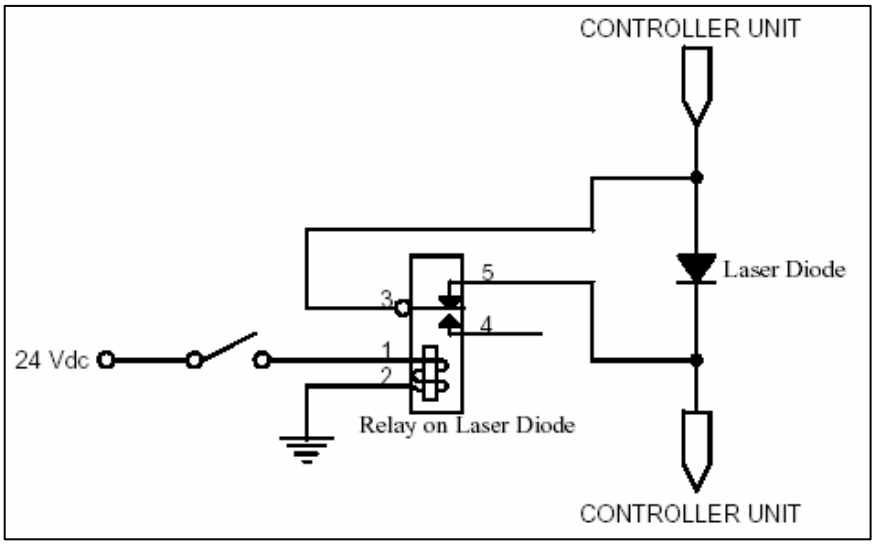


Figure 4.9 Relay pinout connections on the diode laser module.

Other three relays are optionally added to controller unit to power up the fan coolers, if it is needed, by using the power supply unit of the controller unit.

4.5.2. RS-232 Serial Communication Unit

Controller unit provides to diode laser driver system serial communication with a PC from its serial port by using RS-232 serial communication with baud rate of 57600 bps. For this purpose, MAX232 IC (Figure 4.10) multi channel RS-232 driver/receiver is used and data transfer between PIC16F873 and PC is realized to allow the user to set the laser operation parameters and to check the system status while the system is working.

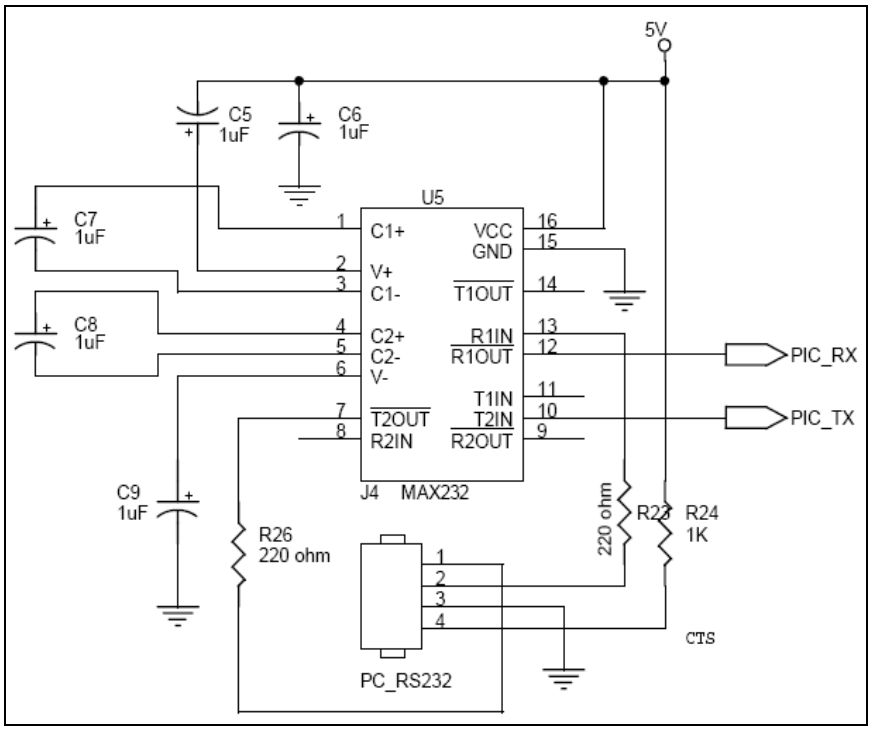


Figure 4.10 RS-232 serial communication circuit.

4.5.3. Digital to Analog Conversion (DAC) Unit

DAC unit has DAC714 IC to convert digital data taken from microcontroller unit to analog signal in order to set the diode laser current in the range of 0-40 A by giving 0-5 V control voltage as an input to common base of the transistor array of current source unit. DAC714 is 16-bit digital to analog converter and it is used in its bipolar configuration as shown in Figure 4.11 to give output from 0 to 5 V.

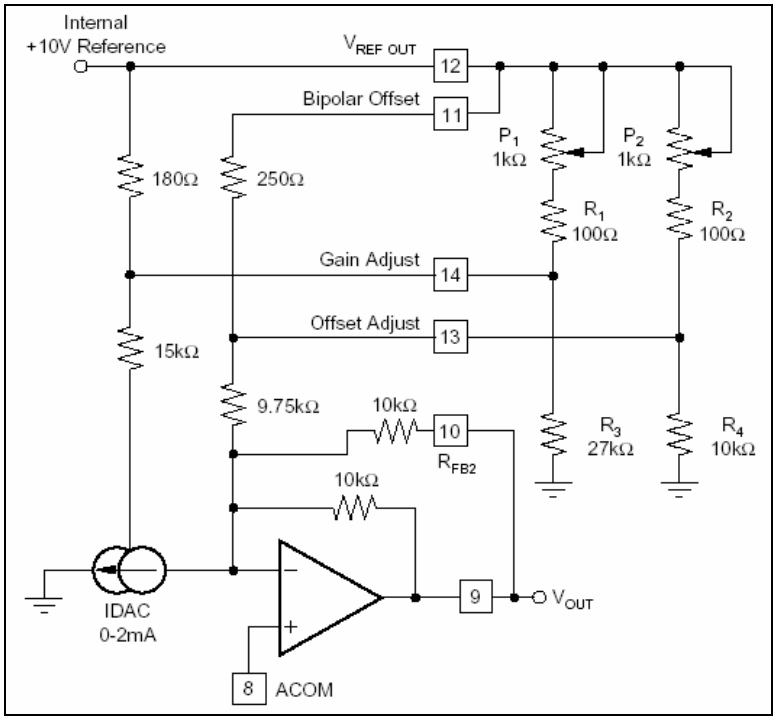


Figure 4.11 Bipolar configuration of DAC714 (-5V to +5V output) [21].

DAC714 is controlled by PIC16F873 and in order to start conversion, it takes digital input code as two bytes in 2's complement binary format from PIC16F873, then it produces the corresponding voltage level as an output. This relation is shown in table 4.1 below.

Table 4.1

Digital input and analog output voltage levels of DAC714 [21].

DIGITAL INPUT CODE BINARY TWO'S COMPLEMENT, BTC	ANALOG OUTPUT (V) BIPOLAR 20V RANGE	ANALOG OUTPUT (V) UNIPOLAR 10V RANGE
$7FFF_H$	+9.999695	+9.999847
4000_H	+5.000000	+7.500000
0001_H	+0.000305	+5.000153
0000_H	0.000000	+5.000000
$FFFF_H$	–0.000305	+4.999847
$C000_H$	–5.000000	+2.500000
8000_H	–10.00000	0.000000

4.5.4. Microcontroller Unit

In this unit, PIC16F873 microcontroller is chosen due to its high quality core and peripheral features listed below:

- 8 bit CMOS flash microcontroller with 4 Kbit program memory.
- 200 ns instruction cycle with 20 MHz operating frequency.
- 10-bit analog to digital converter module with 5 input channel
- Serial peripheral interface.
- In circuit serial programming.
- 3 timer/counter modules [22].

PIC16F873 is the most important component of the controller unit because it processes the data coming from the sensors around the diode laser module and also it controls all other units by implementing its software.

The software written in C programming language is compiled in MPLAB Integrated Development Environment (IDE) program supplied by Microchip Company with integrated CCS-C compiler (Detailed description of the microcontroller software is given in appendix C). According to algorithm (Figure 4.12) followed in the software developed for PIC16F873, microcontroller unit works in slave mode by waiting commands from the user and it simultaneously checks the diode laser unit status while it is working. After the controller unit is powered up, PIC16F873 configures its initial settings and it sets the current of diode laser unit by adjusting DAC unit to give 0 V output to current source unit. The user should first send the diode current value and then the operation duration from a PC by using the interface program. After that, the laser is activated and it operates until duration is over.

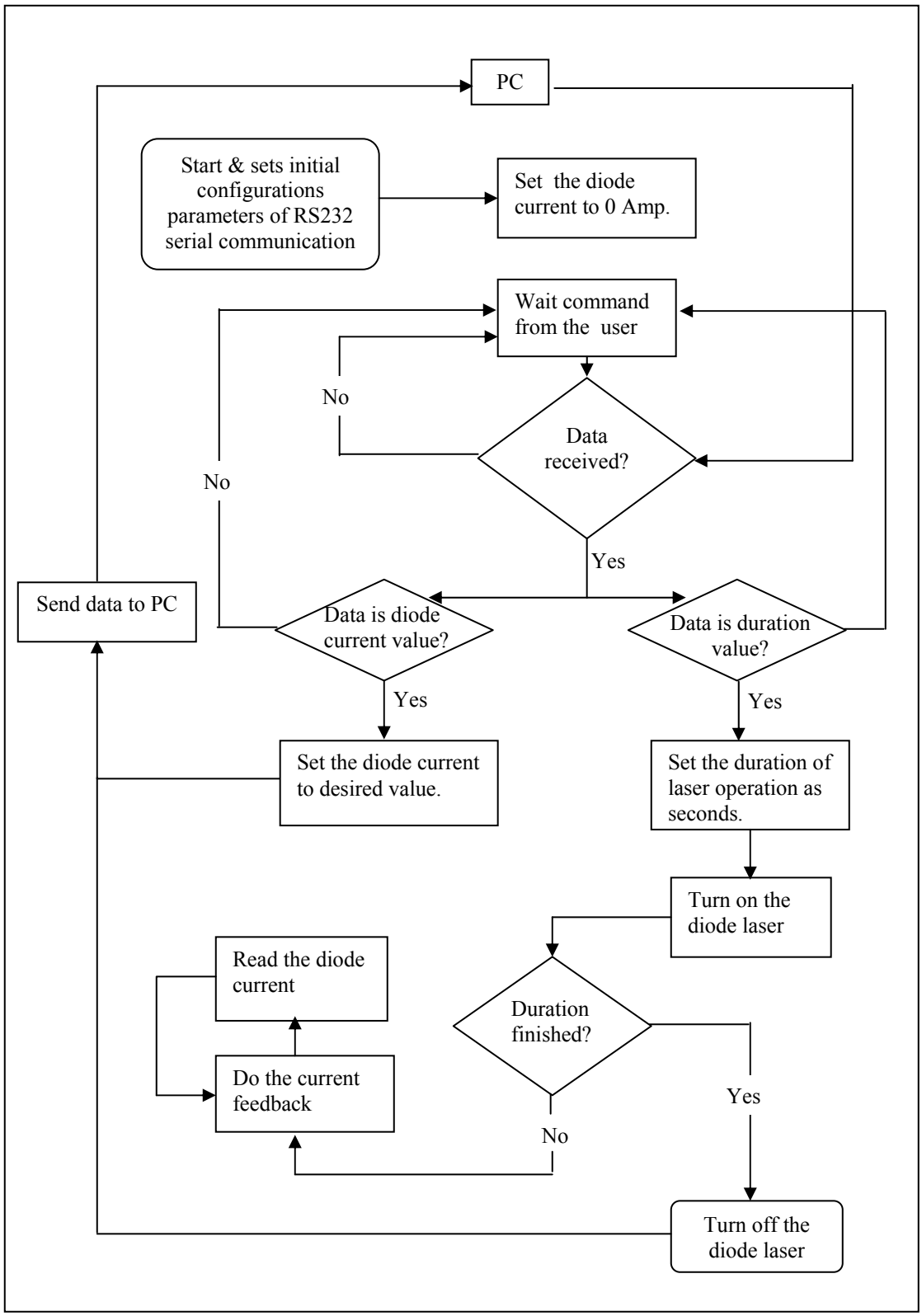


Figure 4.12 Flowchart of microcontroller software.

Two channels of analog to digital conversion (ADC) module of PIC16F873 are used to read the diode current and diode temperature values while laser is operating. 10 bit ADC channels are configured to input voltage range from 0 to 5 V. Therefore each channel has a voltage resolution of 4.87 mV.

However the current sensor used for diode current sensing gives maximum 1.6 V output at 40 A operating current. Thus, the output of the current sensor should be amplified to the range from 0 to 5 V in order to have accurate sampling from the ADC channel.

The amplification of the current sensor output is done in the controller unit by using non-inverting amplifier structure as shown in Figure 4.13.

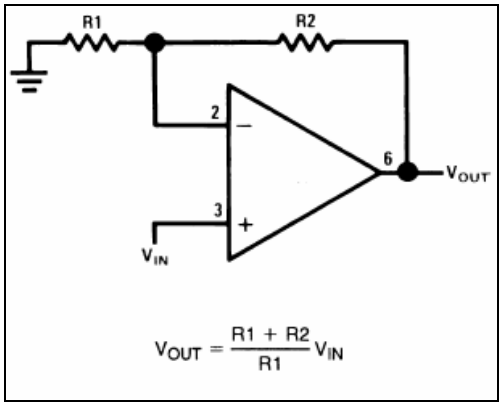


Figure 4.13 Non-inverting amplifier structure [23].

The proper resistor selection is done by the following calculations to amplify 1.6 V input voltage (V_{IN}) to 5 V output voltage (V_{OUT}) by using an operational amplifier (op-amp). The gain of the op-amp equals to:

$$Gain = \frac{V_{OUT}}{V_{IN}} \tag{4.7}$$

and the gain is calculated as 3.125 by using this equation. The gain of non-inverting amplifier also equals to:

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} \tag{4.8}$$

by substituting (4.7) to (4.8) R_1 and R_2 are calculated as 10 kΩ and 21.25 kΩ respectively.

Diode temperature measurement is done by using negative temperature coefficient type (NTC) thermistor with rated resistance value of 5 kΩ at room temperature and material specific constant ($B_{25/100}$) with value of 3988 [24]. It is intended to measure the diode temperature from 25 °C to 50 °C. Resistance change of an NTC type thermistor with respect to temperature is calculated by the following formula [25]:

$$R = R_r e^{B\left(\frac{1}{T} - \frac{1}{T_r}\right)} \tag{4.9}$$

where R is NTC resistance at a temperature T in Kelvin, R_r is NTC resistance at rated (room) temperature T_r in Kelvin and B is material specific constant. However, linearization of NTC thermistor output is needed to get linear change in resistance (R) of thermistor with respect to temperature change. Thus, thermistor is paralleled with a resistance (R_P) 2.7 kΩ that is selected by considering the minimum and maximum value of parallel combination. This parallel combination yields resistance of 1.75 kΩ at 25 °C and 1.07 kΩ at 50 °C. The comparison of values of the resistance (R) calculated by using equation (3.3) of NTC type thermistor and linearized resistance (R_linearized) of parallel combination is shown in Figure 4.14.

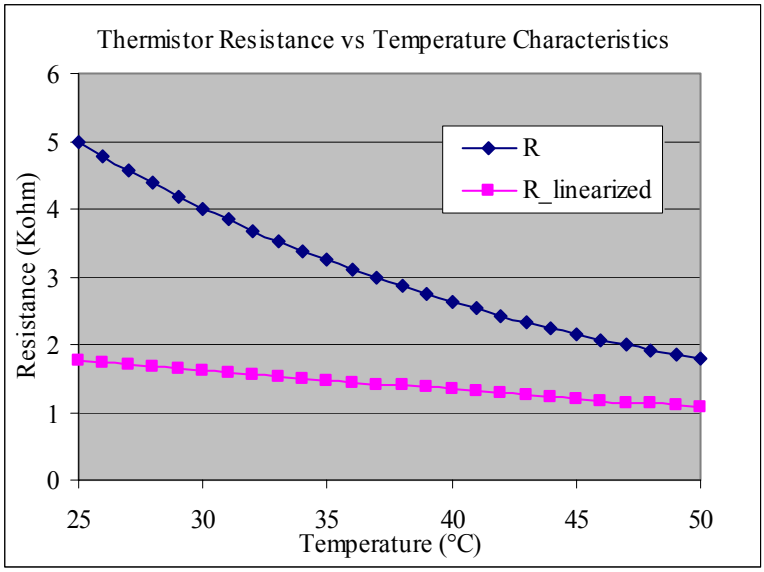


Figure 4.14 Thermistor resistance change versus temperature.

Thermistor output, change in resistance is converted to voltage by using voltage divider circuit coupled with a difference amplifier in order to be processed in microcontroller. The voltage change is adjusted to be 5 V at 25 °C and 0 V at 50 °C by designing the circuit depicted in Figure 4.15.

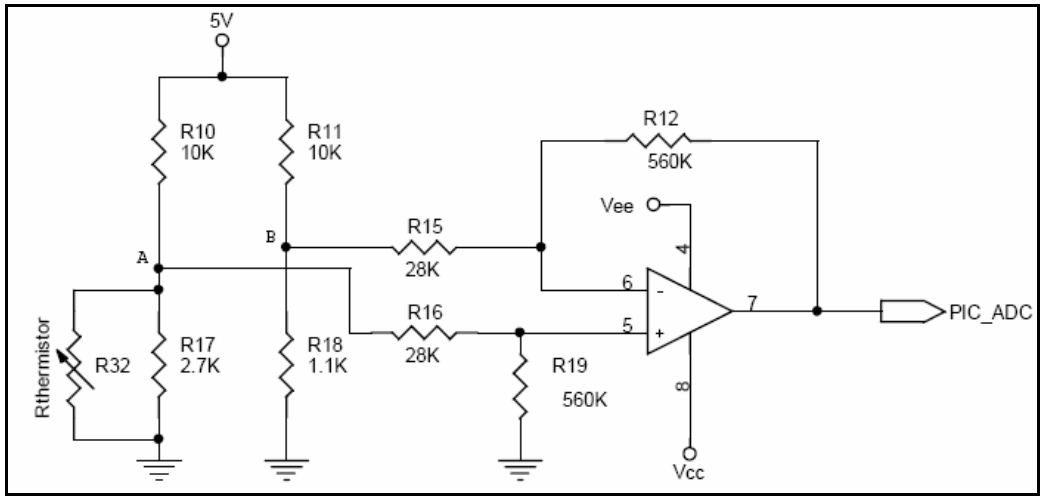


Figure 4.15 Temperature measurement circuit.

When the temperature is at 50 °C, the linearized resistance of the thermistor is 1.07 kΩ calculated above. The voltages on node A and B (Figure 4.15) are equal to each other due to voltage divider circuit. Therefore the difference voltage in the inputs of opamp equal to 0V that yields output voltage of 0V. When the temperature is at 25 °C, the linearized resistance of the thermistor is 1.75 kΩ. The voltages on node A and B are calculated as 0.745 V and 0.495 V respectively corresponding to thermistor resistance. The voltage output of the temperature measurement circuit is adjusted to 5 V at 25 °C and 0 V at 50 °C with respect to these node voltages. This voltage level is processed by PIC16F873 to make conversion of the diode laser operating temperature. The resistor values should be more accurate with less tolerance percentages to proper amplification. Therefore, metal film resistors having least tolerances are used in the circuit production.

Output power of the laser light is directly related with the diode current supplied by the current source. There should be no oscillation on the output current so as to have accurate power. Therefore, diode current measurement is crucial for current feedback process done by the microcontroller unit. While the laser is operating, diode operating current is always read by the current sensor, processed by the microcontroller unit, and compared by the desired current value. Negative feedback is done to minimize the error term as calculated in the microcontroller and this leads to stable output current by adjusting the current source unit.

4.6. Water Cooling System

Thermal management of the diode laser module is crucial to protect it from excessive heating. The wavelength of the laser light is temperature dependent and temperature of the diode module should be kept stable to get laser light with constant wavelength. Therefore, the best cooling method, water cooling is chosen to eliminate over heating problem.

Thermaltake CL-W0005 CPU water cooling system is used by modifying the apparatus to stick it to the heat sink of the diode laser module.

4.7. User Interface

The user interface program developed in C programming language communicates with the controller unit of the diode laser driver system to set the operating parameters of the diode laser module. When the program is implemented, it asks the user to select communication port that is used for RS-232 serial communication (Figure 4.16).

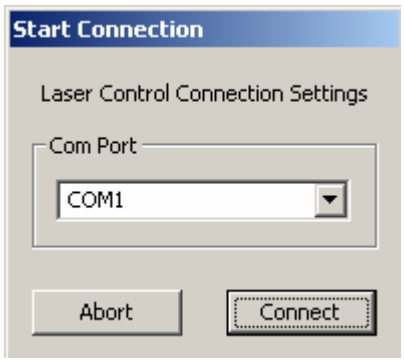


Figure 4.16 Snapshot of communication port setting screen.

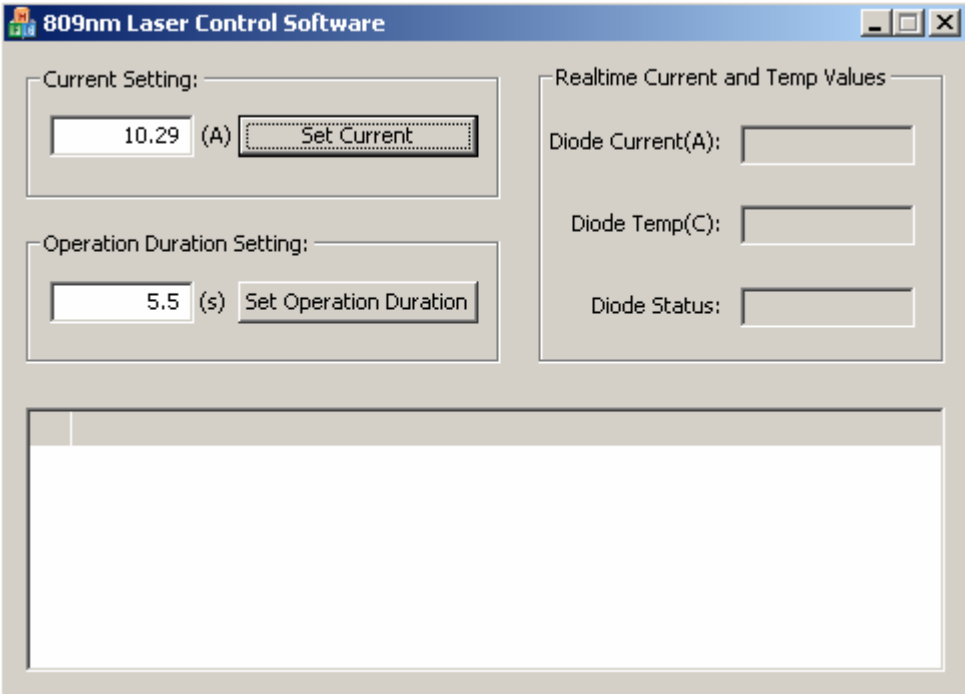


Figure 4.17 Snapshot of the interface program.

4.8. Installation of The System into PC Case

Components of the diode laser system mentioned above are installed to a PC case to make it portable and robust for easy handling and long time usage. PC case has many holes to screw the components fitting them properly. However, drilling of new holes is necessary process to mount the components having different mounting holes. After careful planning of installation practice, the whole system is mounted into PC case consisting carrier holder as shown in Figure 4.18 and 4.19.

Figure 4.18 Side view of PC case after installation.

Figure 4.19 Front and back view of PC case after installation.

4.9. Power versus Current Curve

The output power of 809-nm diode laser unit (providing maximum 10 W output power) is measured by using a powermeter (Coherent 100-BM63) for each increment of the value of the diode current from 0 to 35 A and power versus current curve is plotted (Figure 4.20). This graph is used to set the diode current to get desired output power during the laser applications. The output power of diode laser light shows almost linear trend with respect to the applied diode current according to this graph.

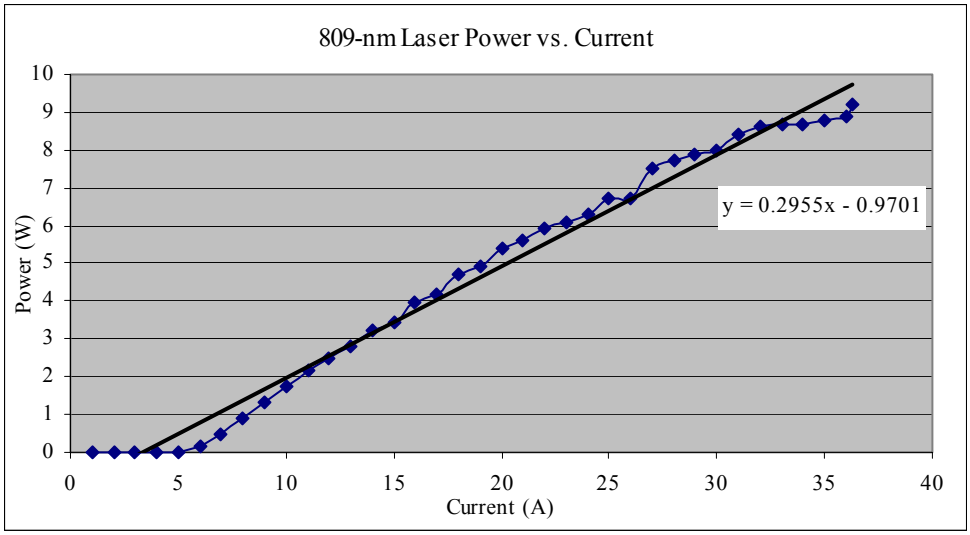


Figure 4.20 Diode laser output power with respect to current change.

5. CONCLUSIONS AND FUTURE WORK

In this study, the systematic design and manufacturing steps of a microcontroller based 809-nm high power diode laser system are presented. The system produced as a portable and robust device works successfully and communicates with a PC via a user interface program.

Diode laser module generates continuous 809-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 10 W with respect to the value of applied diode current from 0 to 35 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 does negative current feedback to provide steady operating current. The operating current measurement is done by using a current transducer having high output precision. Thermal management of the diode laser module is done by using a water cooling system to protect the diode module from overheating. The system protections to prevent the breakdown of the system are watchdog timer set in the controller unit and automatically shutdown property at high temperature. Watchdog timer resets the system if any breakdown is seen in system operation causing failures in execution of the software of microcontroller unit. Temperature of the diode module is continuously measured by the system and if the temperature value goes higher than preset maximum tolerable value, the system automatically shutdowns.

The user interface program allows to set the operating current of the diode laser module and the duration of operation. The diode current is simultaneously shown to the user while the laser is working.

The system designed in this study is for general purpose usage in biophotonics applications with required power range of 0 to 10 W. For future work, the effect of continuous 809-nm diode laser light on tissues for different types of biophotonics applications should be investigated by doing in vitro tissue studies. The user protective issues in the current system should be clearly studied and if constructive modifications are required, they would be added

to the current system. Pulsed wave mode of operation to diode laser system can be included by changing circuit configuration of the developed current source and controller unit.

APPENDIX A. SCHEMATICS

This section includes the schematics of the current source unit (Figure A.1.) and subunits of the controller unit (Figure A.2, A.3, A.4, A.5 and A.6) drawn in Orcad 9.2 Capture program.

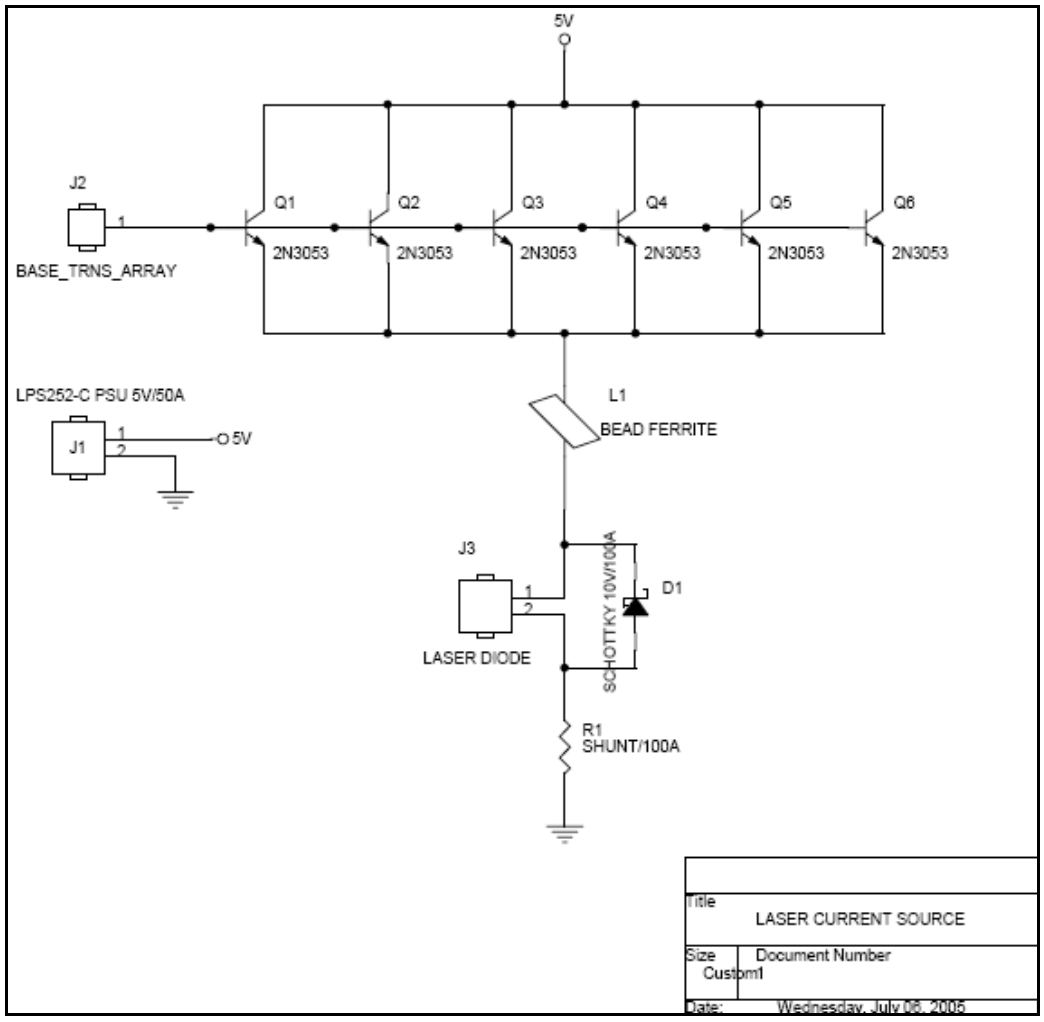


Figure A.1 Schematic of the current source unit.

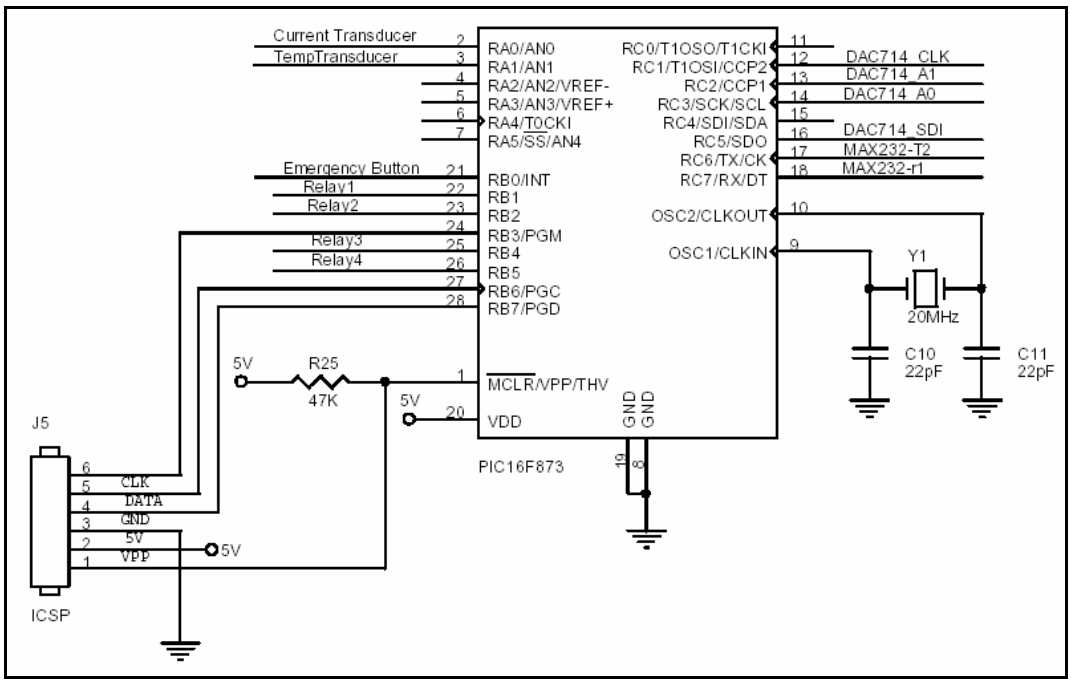


Figure A.2 Schematic of microcontroller unit.

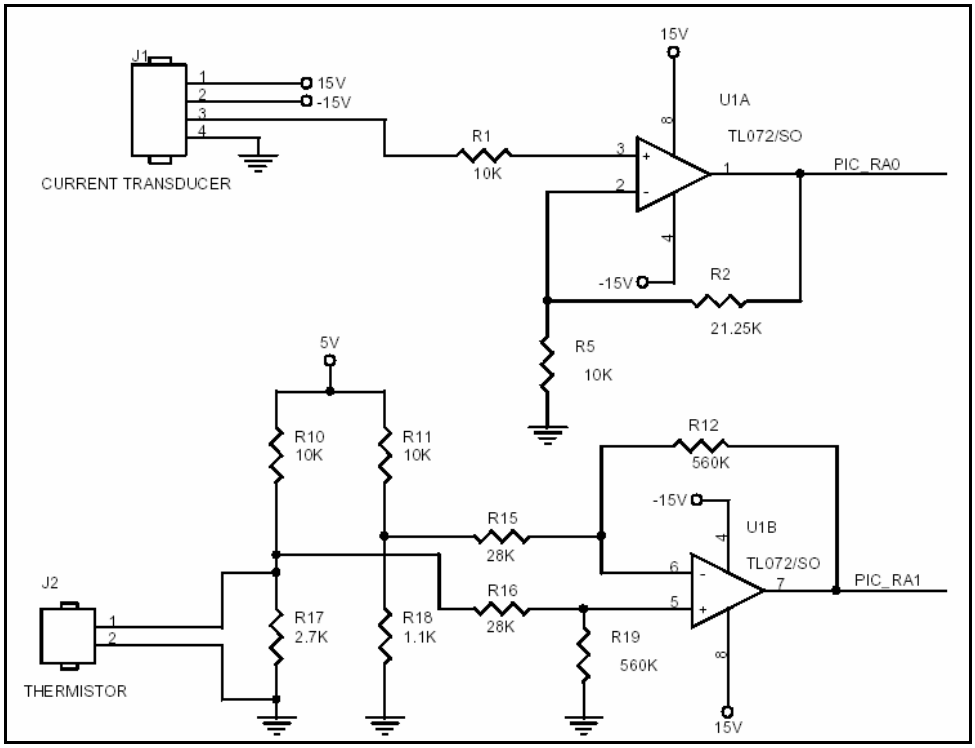


Figure A.3 Schematic of the current and temperature measurement.

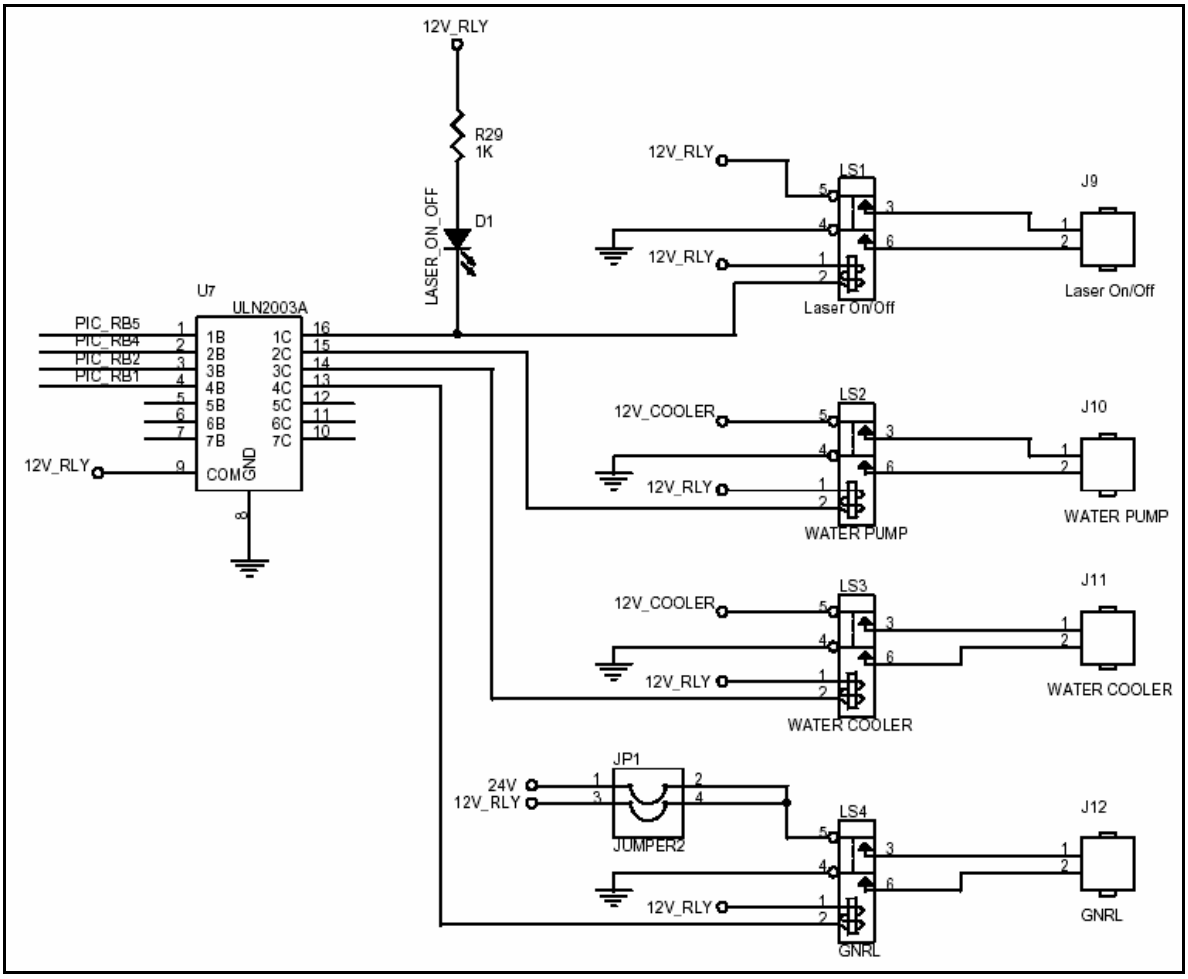


Figure A.4 Schematic of relay controlled switching unit.

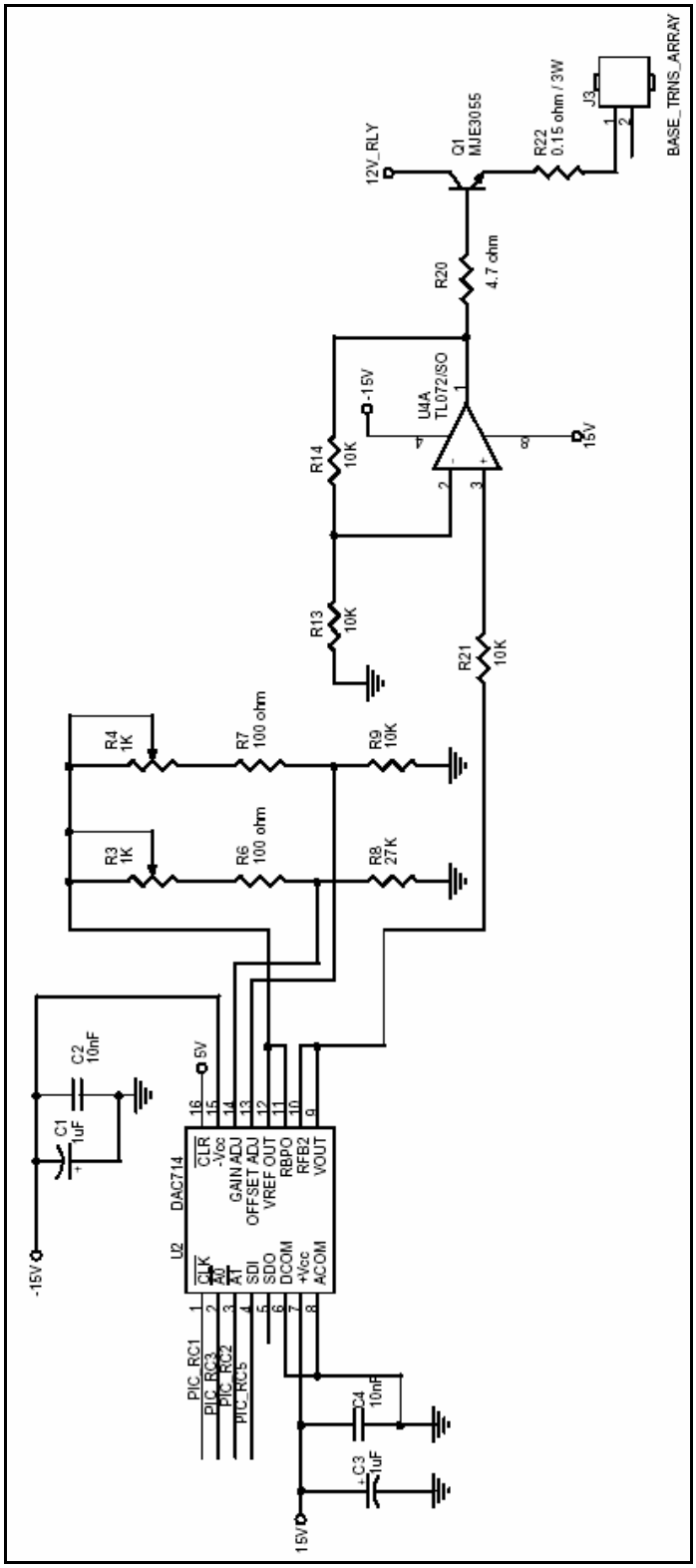


Figure A.5 Schematic of DAC unit.

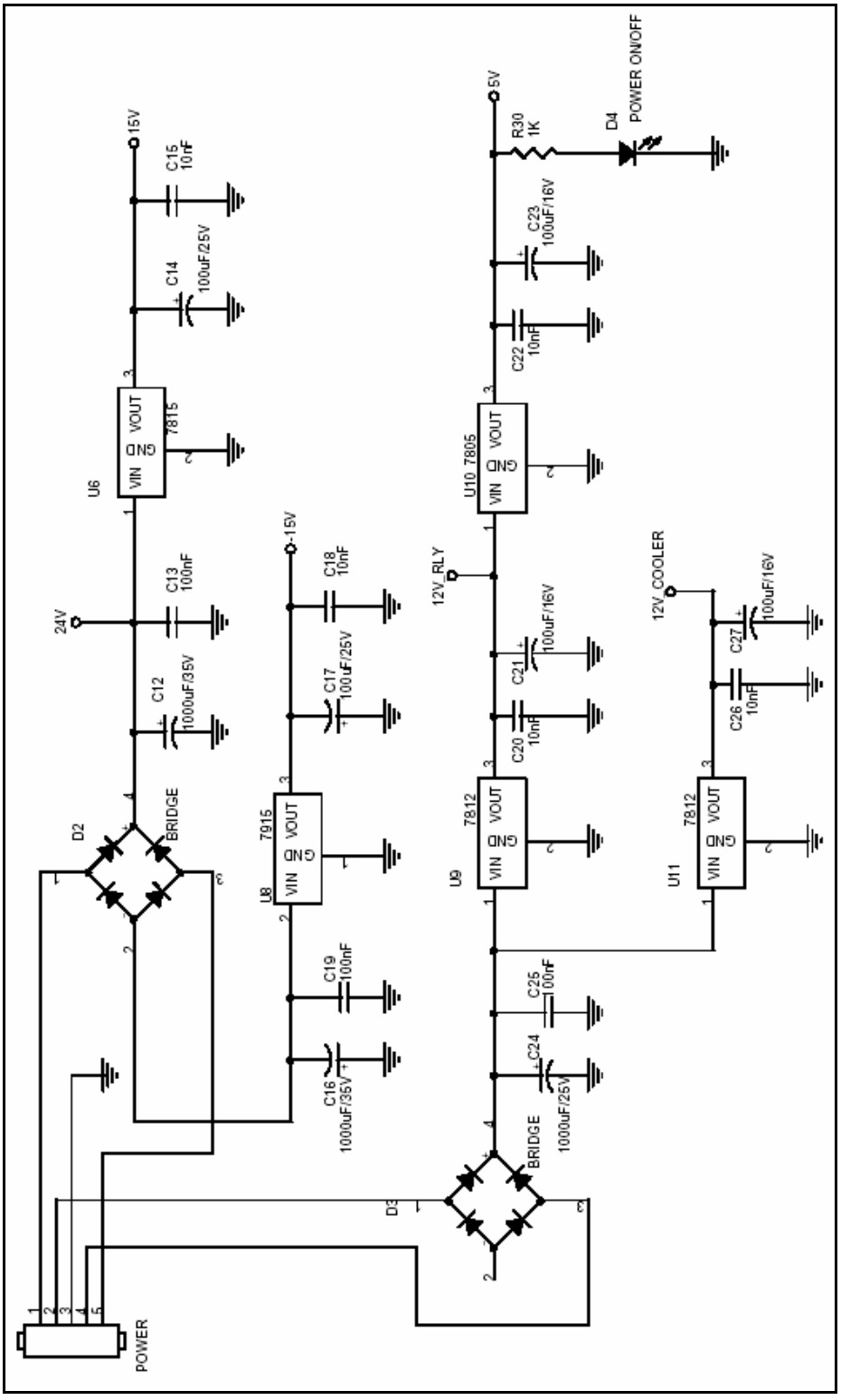


Figure A.6 Schematic of PS unit.

APPENDIX B. LAYOUT

Layout of the controller unit (Figure B.1) is drawn in Orcad 9.2 Layout Program. PCB is produced as through hole and double sided.

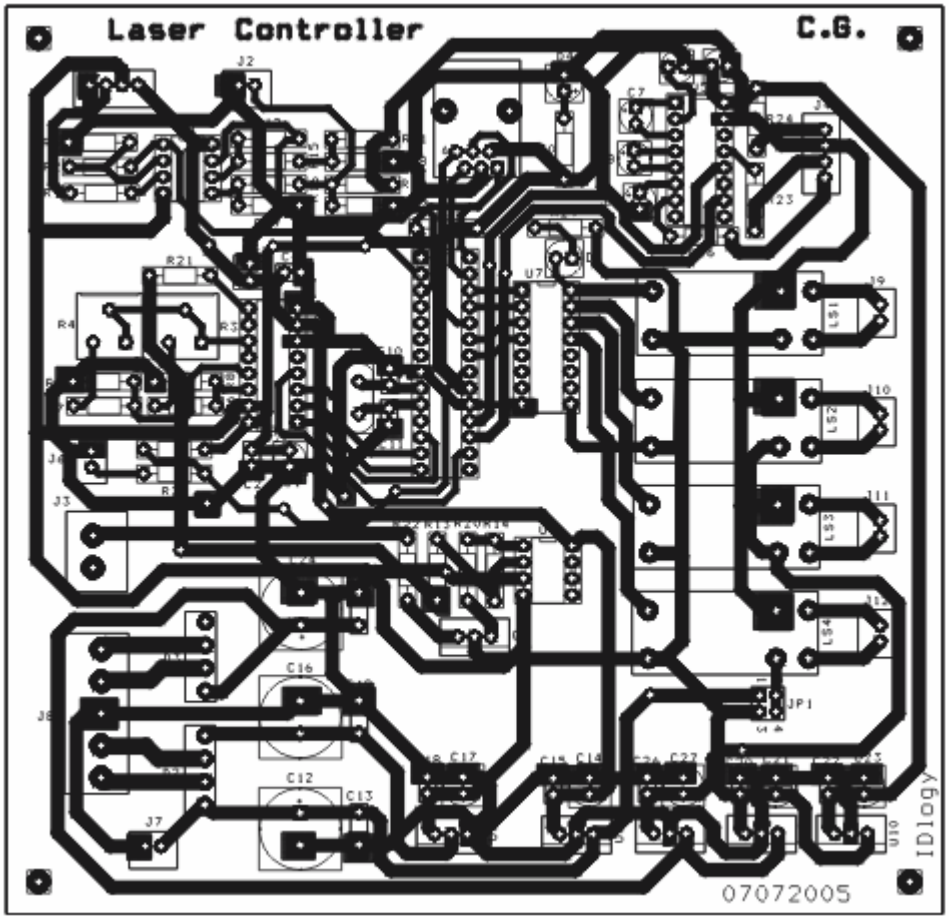


Figure B.1 Layout drawing of the controller unit.

APPENDIX C. MICROCONTROLLER SOFTWARE

This section includes the source code of PIC16F873 microcontroller used in the controller unit. Code written CCS-C integrated MPLAB IDE program is given below.

```
#include <16F873.h>

#DEVICE ADC=10    // The # of ADconverter bits should be written as a device pre-processor
command

#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=20000000)
#use rs232(baud=57600, xmit=PIN_C6, rcv=PIN_C7)  // Jumpers: 8 to 11, 7 to 12



#include <stdlib.h>
#include <input.c>


//=========================Definitions=====================//

#bit INTF_BIT = 0x0B.1
#bit TIMER1_INTF_BIT = 0x0C.0


#define CLK PIN_C1
#define A1 PIN_C2
#define INT_SCND 250                    // 250 msec intr for diode  temp read


 //----------------FUNCTION PROTOTYPES--------------------//

#int_ext                                                    // External int is used for button
void int_ext_isr(void);
#INT_TIMER1                         // Timer1 is used to set the period to read temperature
void timer1_isr(void);
#int_rtcc                                                   // RTCC(Timer0) is used to set the
duration for laser operation
void clock_isr(void);

void duration(void);                            // sets time duration for laser operation
void sendtodac714(int16 dacdata);       // sends data to DAC714
void  ADC_chn_0(void);                                  // read diode current from hall sensor output
void  ADC_chn_1(void);                                  // read diode operating temperature
void currentset(void);                          // sets diode current between 0 & 40 Amp
```

```
void currentfeedback(void);                    // Feedback is done while laser operating to set the
diode current to desired
void reset(void);                                    // turn off the diode laser and system is set to
default values(0 Amp current)


//=====================Variables============================//


char arraycur[6];                                    // stores diode current value as string
char arrayscnd[6];                                   // stores duration of laser operation
value as string
int16 dacdata;                                       // sets DAC714 output
int16 value_cur,value_temp;                    // stores data of ADC channel 0&1
int16 temperature;                                   // stores diode operating temperature
int16 int_count;                                     // sets Timer1 counter for ISR period
int16 miliseconds;                                          // seconds for working
duration
int16 intcount;                                      // integer type data for duration
int16 currenthall;                                   // stores hall sensors output (diode
current)
int16 currentdesired;                          // stores intended current values.

int buttonPressed;                                   // button status
int fb_done;                                         // current feedback status
int loop;                                                   // loop check to stop the
operation for given time duration
float hallreading;                                   // to prevent division error, float
number used
float temperature_read;                        // to prevent division error, float number used
signed int32 currentfb;                        // current feedback value that will set
DAC714


//=====================MAIN=================================//

#pragma zero_ram

main() {

        delay_ms(3000);
        printf("Program Started\n\r");

        sendtodac714(0);                                   //Initially Diode current set to 0 Amp


        setup_port_a( ALL_ANALOG );                        // Vref+ = Vdd  and Vref- = Vss
  setup_adc( ADC_CLOCK_INTERNAL );

        output_float(PIN_B0);                  // Make pin B0 into an input.
```

```
        ext_int_edge(H_TO_L);
        INTF_BIT = 0;

        setup_timer_1(T1_INTERNAL|T1_DIV_BY_1);                 //Timer1 enters interrupt rtn
with 1ms periods
   TIMER1_INTF_BIT=0;
        int_count=INT_SCND;

        setup_counters( RTCC_INTERNAL, RTCC_DIV_256); // RTCC(Timer 0) is used to set the
time duration
                                                                                        // for laser
operation.
        enable_interrupts(INT_EXT);
        enable_interrupts(GLOBAL);

        output_high(PIN_B1);                    // After duration is set, the dac714 is set and the relay
on diode is
                                                                        // opened so that laser emits
809nm light until the time ends up by RTCC timer
        buttonPressed=0;
        loop=0;
        currentfb=0;

        while(TRUE)                                             // while routine is always performed

        {                                                               // at normal conditions, first user
sets diode current
                if(loop==0)                                     // then enter the duration of operation.
                {
                        if(buttonPressed==0)    // check the emergency shutdown button is pressed or
not
                        {
                                currentset();
                                duration();
                        }
                        else
                                reset();
                }
                else
                        loop=0;
        }
}

//================================Functions============================== //

void sendtodac714(int16 dacdata)                // Communucation with DAC714 is done by using
{                                                                               // SPI feature of PIC.
        int temp8;                                                      // First MSB data and then
LSB data is sent.
```

```
        if(dacdata>=0 && dacdata<=32768)
        {
                setup_spi(SPI_MASTER|SPI_H_TO_L|SPI_CLK_DIV_4|SPI_SS_DISABLED);
                output_bit(CLK, 0);
                temp8 = dacdata >> 8;
//              printf("n\rmsb=%X\n\r",temp8);
                SPI_WRITE(temp8);
                temp8 = dacdata & 0xff;
//              printf("lsb=%X\n\r",temp8);
                SPI_WRITE(temp8);
                output_bit(A1, 0);
                output_bit(A1, 1);
                output_bit(CLK, 1);

        }
        else
        {
                printf("\n\r Invalid Current Value!! Try Again:\n\r");
        }
}


void currentset(void)
{
        if(loop==0 && buttonPressed==0)
        {
                printf("\n\r Enter Diode Current between 0 & 32767=");
                get_string(arraycur,6);
        printf("\n\r%s\n\r", arraycur);
                currentdesired=atol(arraycur);          //Arraycur array converted to 16bit int value.
        }
}

void duration(void)
{
        if(loop==0 && buttonPressed==0)
        {
                printf("\n\rEnter duration for laser operation:");
        get_string(arrayscnd,6);
         // printf("\n\r%s\n\r",arrayscnd);
        intcount=atol(arrayscnd);                                       // INTS_PER_SECOND=76
---->(20000000/(4*256*256))
           miliseconds=intcount;                                                // intcount sets
duration of operation by using RTCC timer

           enable_interrupts(INT_RTCC);
//              enable_interrupts(INT_TIMER1);
                currentfeedback();                                                      // While laser
is working, current feedback is done to hold the diode current
```

```
        }
        // closer to the value of desired operating current.
}

void  ADC_chn_0(void)
{
        if(loop==0 && buttonPressed==0)
        {
        set_adc_channel( 0 );                                   // 10 msec delay used to
ensure the DAC is set its value and ADC can read
                delay_ms(10);                                                   // correct
current value.
        value_cur = Read_ADC();
           hallreading=value_cur*(32767.0/1024.0);
                currenthall=hallreading;
                printf("\n\r Diode Current: %ld Amp\n\r",currenthall);
        }
}

void  ADC_chn_1(void)
{
        if(loop==0 && buttonPressed==0)
        {
        set_adc_channel( 1 );
                delay_ms(10);
        value_temp = Read_ADC();
                temperature_read=value_temp*(32767.0/1024.0);
                temperature=temperature_read;
           printf("\n\r Diode Temperature: %ld ºC\n\r",temperature);
        //      if(temperature<400)
        //      {
        //              printf("\n\r High Diode Temperature!!!\n\r");
        //              reset();
        //      }
        }
}

void currentfeedback(void)
{
        fb_done=0;
        currentfb=9000;
        sendtodac714(currentfb);
        delay_ms(10);

        while(loop==0 && buttonPressed==0)
        {
                ADC_chn_0();
                if(currenthall>currentdesired)
                {
                        if((currenthall-currentdesired)>20)
```

```
                {
                        fb_done=0;
                }
        }
        else
        {
                if((currentdesired-currenthall)>20)
                {
                        fb_done=0;
                }
        }

        if(currenthall>currentdesired && fb_done==0 && loop==0 && buttonPressed==0)
        {
                while(currenthall>currentdesired && loop==0 && buttonPressed==0
&& fb_done==0)
                {
                        if((currenthall-currentdesired)>10000)
                                currentfb-=(currenthall-currentdesired)/10;
                        else if((currenthall-currentdesired)>1000)
                                currentfb-=(currenthall-currentdesired)/10;
                        else if((currenthall-currentdesired)>100)
                                currentfb-=(currenthall-currentdesired)/10;
                        else if((currenthall-currentdesired)>10)
                                currentfb-=(currenthall-currentdesired)/10;

                        if(currentfb>=0 && currentfb<=32767)
                        {
                                printf("\n\r Feedback current:%ld\n\r",currentfb);
                                sendtodac714(currentfb);
                                delay_ms(10);
                        }
                        else
                        {
                                currentfb=0;
                        }

                        ADC_chn_0();

                        if((currentdesired-currenthall)<10)
                        {
                                fb_done=1;
                                printf("\n\r fbdone=1\n\r");
                        }
                        else
                        {
                                if((currenthall-currentdesired)<10)
                                {
                                        fb_done=1;
                                        printf("\n\r fbdone=1\n\r");
```

```
                                        }
                                }
                        }
        }

                if(currenthall<currentdesired && fb_done==0 && loop==0 && buttonPressed==0)
                {
                        while(currentdesired>currenthall && loop==0 && buttonPressed==0
&& fb_done==0)
                        {
                                if((currentdesired-currenthall)>10000 )
                                        currentfb+=(currentdesired-currenthall)/10;
                                else if((currentdesired-currenthall)>1000)
                                        currentfb+=(currentdesired-currenthall)/10;
                                else if((currentdesired-currenthall)>100)
                                        currentfb+=(currentdesired-currenthall)/10;
                                else if((currentdesired-currenthall)>10)
                                        currentfb+=(currentdesired-currenthall)/10;

                                if(currentfb>=0 && currentfb<=32767)
                                {
                                        printf("\n\r Feedback current:%ld\n\r",    currentfb);
                                        sendtodac714(currentfb);
                                        delay_ms(10);
                                }
                                else
                                {
                                        currentfb=32767;
                                }

                                ADC_chn_0();

                                if((currentdesired-currenthall)<10)
                                {
                                        fb_done=1;
                                        printf("\n\r fbdone=1\n\r");
                                }
                                else
                                {
                                        if((currenthall-currentdesired)<10)
                                        {
                                                fb_done=1;
                                                printf("\n\r fbdone=1\n\r");
                                        }
                                }
                        }

                }

        }
```

```
}

#int_ext                                                                    // Button is
used to shutdown the laser in emergency status
void int_ext_isr(void)
{
          disable_interrupts(INT_EXT);
          disable_interrupts(INT_RTCC);
   disable_interrupts(INT_TIMER1);
          delay_ms(30);
          buttonPressed=1;
          enable_interrupts(INT_EXT);
}


//#INT_TIMER1
//void timer1_isr(void)
//{
//          disable_interrupts(INT_TIMER1);
//          set_timer1(60536);                                  // Set_timer value should be written
to timer1 register at the beginning of every isr()
//          --int_count;
//    if(int_count==0) {                                  // Every INT_SNCD (defined above) value,
temperature value is read by ADC_Ch1.
//      ADC_chn_1();
//            int_count=INT_SCND;
//    }
//          TIMER1_INTF_BIT=0;
//          enable_interrupts(INT_TIMER1);
//}

#int_rtcc
void clock_isr(void)                                                        // This function is
called every 10msec
{
          set_rtcc(60);                                         // the RTCC (timer0) overflows
(255->60).
   disable_interrupts(INT_RTCC);
   if(--miliseconds==0)
          {
     disable_interrupts(INT_TIMER1);
            sendtodac714(0);
            printf("\n\rLaser operation finished.\n\r");
            loop=1;
          }
          enable_interrupts(INT_RTCC);
}

void reset(void)
```

```
{
        sendtodac714(0);                                                    // sets the
diode current to 0 Amp.
        printf("\n\rLaser operation terminated!!.\n\r");
        buttonPressed=0;
        loop=1;
}
```

REFERENCES

1. Gülsoy, M., T. Çelikel, Ö. Kurtkaya, A. Sav, A. Kurt, R. Canbeyli, and İ. Çilesiz, "Application of the 980-nm Diode Laser in Stereotaxic Surgery," *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 5, No. 2, pp. 1090-1094, 1999.

2. Niemz, M.H., *Laser-Tissue Interactions: Fundamentals and Applications*, Springer-Verlag, New York, 1996.

3. Costa, R. A., M. E. Farah, J. A. Cardillo, and R. Belfort, "Photodynamic therapy with indocyanine green for occult subfoveal choroidal neovascularization caused by age-related macular degeneration," *Current Eye Research*, Vol. 23, No. 4, pp. 271-275, 2001.

4. Liu, V. G., T. M. Cowan, S. W. Jeong, S.L. Jacquesi, E. C. Lemley, and W. R. Chen, "Selective Photothermal Interaction Using an 805-nm Diode Laser and Indocyanine Green in Gel Phantom and Chicken Breast Tissue," *Lasers Med Sci*., Vol. 17, pp. 272-279, 2002.

5. Chen, W. R., J. W. Ritchey, K. E. Bartles, M. D. Lucroy, H. Liu, and R. E. Nordquist, "Laser immunotheraphy in treatment of metastatic prostate tumors in rats," http://optics.sgu.ru/SMF /2001/reports/w_chen.

6. Saxena, V., M. Saoqi, and J. Shao, "Degradation Kinetics of Indocyanine Green in Aqueous Solution," *J. Pharmaceutical Sciences,* Vol. 92, No. 10, 2003.

7. Photodynamic therapy, http://www.radapharma.ru/eng/pdt/ basics/ schema.php.

8. Varriale, L., E. Crescenzi, V. Paba, B. M. Celso, and G. Palumbo, "Selective light-induced modulation of Bcl-XL and Bax expressions in indocyanine green-loaded U937

cells: effects of continuous or intermittent photo-sensitization with low IP-light using a 805-nm diode laser," *J. Photochemistry and Photobiology B: Biology*, Vol. 57, pp. 66-75, 2000.

9. Greenwell, T. J., A. Wyman, and K. Rogers, "Chromophore-enhanced 805 nm laser therapy for gastrointestinal neoplasia," *EJSO*, Vol. 27, pp. 368-372, 2001.

10. Photodynamic therapy, http://www.radapharma.ru/eng/pdt/basics.php.

11. Chen, W. R., R. L. Adams, R. Carubelli, and R. E. Nordquist, "Laser-photosensitizer assisted immunotherapy: a novel modality for cancer treatment," *Cancer Letters*, Vol. 115, pp. 25-30, 1997.

12. Fickweiler, S., R. M. Szeimies, W. Baumler, P. Steinbach, S. Karrer, A. E. Goetz, C. Abels, F. Hofstadter, and M. Landthaler, "Indocyanine green: Intracellular uptake and phototherapeutic effects in vitro," *J. Photochemistry and Photobiology B: Biology*, Vol. 38, pp. 178-183, 1997.

13. Indocyanine green, https://www.sigmaaldrich.com.

14. Landsman, M. L. J., G. Kwant, G. A. Mook, W. G. Zijlstra, "Light- absorbing properties, stability, and spectral stabilization of indocyanine green (Abstract)," *J. Appl. Physiol.,* Vol. 40, pp. 575-583, 1976.

15. Indocyanine green, http://omlc.ogi.edu/spectra/icg.

16. Menzel, R., *Photonics: Linear and Nonlinear Interactions of Laser Light and Matter*, Springer-Verlag , Heidelberg, 2001.

17. Chow, W. W., S. W. Koch, and M. Sargent, *Semiconductor-Laser Physics*, Springer-Verlag, Newyork, 1997.

18. 2N3055, Complementary Silicon Power Transistors, Device Datasheet, ST Company, 1999, http://www.st.com/stonline/books/pdf/docs/4079.pdf.

19. Malik, N. R., *Electronic Circuits: Analysis, Simulation, and Design*, Prentice Hall, New Jersey, 1995.

20. Current Transducer HAL 100-S, Device Datasheet, http://www.lem.com.

21. DAC714, Device Datasheet, 16-bit Analog to Digital Converter, Burr-Brown Corporation, USA, 1997, http://www.physics.brocku.ca/courses/ 2p32/References /datasheets/DAC714.pdf.

22. PIC16F87X, Device Datasheet, 28/40-Pin 8-Bit CMOS FLASH Microcontrollers, MicrochipTechnology Inc., 2001, http://ww1.microchip.com/downloads /en/ DeviceDoc/30292c.pdf.

23. Op Amp Circuit Collection, National Semiconductor, Application Note 31, http://www.eetkorea.com/articles/ 2003sep/a/2003sep19_amd_an07.pdf.

24. B57703-M-703, NTC Thermistor Device Datasheet, Temperature Measurement Probe Assemblies, Siemens Matsushita Components.

25. NTC Thermistor, General Tecnical Information, Siemens Matsushita Components, pp 22-31.