T.C.
FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

DEVELOPMENT OF THE WHITE LIGHT EMITTING DIODE ILLUMINATED ENDOSCOPIC LIGHT SOURCE

MUZAFFER ÖZTÜRK

MSc THESIS
BIOMEDICAL ENGINEERING PROGRAMME

ISTANBUL, MAY / 2015

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THESIS ADVISOR
PROF. DR. SADIK KARA

ISTANBUL, MAY / 2015

T.C.
FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

ENDOSKOPİ CİHAZLARI İÇİN BEYAZ LED IŞIK KAYNAĞI GELİŞTİRME

MUZAFFER ÖZTÜRK

YÜKSEK LİSANS
BİYOMEDİKAL MÜHENDİSLİĞİ PROGRAMI

DANIŞMAN
PROF. DR. SADIK KARA

İSTANBUL, MAYIS / 2015

T.C.

FATIH UNIVERSITY

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Muzaffer ÖZTÜRK, a **MSc** student of Fatih University **Institute of Biomedical Engineering** student ID **52011120**, successfully defended the **thesis** entitled "DEVELOPMENT OF THE WHITE LIGHT EMITTING DIODE ILLUMINATED ENDOSCOPIC LIGHT SOURCE", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Director

Committee Members

Date of Submission: 8 May 2015

Date of Defense : 25 May 2015

To My Parents, My Wife and My Son,

This study was supported by Endoser Tıbbi Cihazlar San. ve Tic. Ltd. Şti. / TÜBİTAK with the project number of **7120540.**

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May 2015 Muzaffer ÖZTÜRK

Electronics Engineer

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LIST OF SYMBOLS

τ_n	Electron minority-carrier lifetimes
τ_p	Hole minority-carrier lifetimes
λ	Wavelenght
α	Current fluctuation level
Ω	Ohm
Φ	Radiant & luminous flux (power)
ηi	Intrinsic carrier concentration of the semiconductor
ΔI_L	Inductor ripple current
°C	Celsius
cd	Candelas
D_n	Electron diffusion constants
D_p	Hole diffusion constants
D_{MIN}	Minimum duty rate
D_{MAX}	Maximum duty rate
E_g	Energy gap
E_v	Irradiance & illuminance
f_{SW}	Switching frequency
I	Current
I/O	Input/ output pin
I_F	Forward bias current
I_{IN}	Input current
I_{LED}	LED current
I_{MIN}	Minimum current
I_{MAX}	Maximum current
I_{OUT}	Output current
I_S	Reverse bias saturation current
I_v	Radiant & luminous intensity
L_i	Radiance & luminance
K	Kelvin
kW	Kilowatt(s)

kWh Kilowatt-hour(s)

lm Lumen

Lm/W Lumen(s) per watt

mAh Mili amper hour

N_A Acceptor concentrations

N_D Donor concentrations

sr Steradian

U Radiant & luminous energy density

Q Radiant & luminous energy

V_{BAT} Battery Voltage

V_{DIODE} Forward diode bias voltage

V_F Forward bias voltage

V_{FB} Feedback voltage

V_{F_MAX} Maximum forward voltage

V_{F_MIN} Minimum forward voltage

$V_{IN(MAX)}$ Maximum input voltage

$V_{IN(MIN)}$ Minimum input voltage

$V_{OUT(MAX)}$ Maximum output voltage

$V_{OUT(MIN)}$ Minimum output voltage

ABBREVIATIONS

2D : Two Dimensional
3D : Three Dimensional
A : Ampere(s)
AC : Alternating Current
ADC : Analog to Digital Convertor
AFE : Analog Front End
AMP : Amplifier
ATM : Atmosphere (Unit)
CCD : Charge Coupled Device
CCP : Compare Capture PWM
CCT :Correlated Color Temperature
CCU : Camera Control Unit
CD : Compact Disc
CFL : Compact Fluorescent Lamp
CMOS : Complementary Metal Oxide Semiconducto
CRI : Color Rendering Index
DAC : Digital to Analog Converter
DC : Direct Current
DCR : Direct Current Resistance
DIM : Dimming pin
DVD : Digital Versatile Disc
DVI : Digital Visual Interfac
EGD : Esophagogastroduodenoscopy
ESD : Electrostatic Discharge
ESR : Equivalent Series Resistance
FPC : Flexible Flat Cable
FSM : Finite State Machines
FWHM : Full Width Half Maximum
GND : Ground
HD : High Definition

HDMI : High Definition Multimedia Interface
HDTV : High Definition Television
HID : High Intensity Discharge Lamps
HPS : High Pressure Sodium
HPLED : High Power Light Emitting Diode
Hz : Hertz
IC : Integrated Circuit
LED : Light Emitting Diode
Li-on : Lithium-ion
LVDS : Low Voltage Differential Signaling
mA :Milliampere(s)
MCU Microcontroller Unit
MH :Metal Halide
MIS : Minimally Invasive Surgery
MOSFET: Metal Oxide Semiconductor Field Effect Transistor
MWh :Megawatt-hour(s)
NMOS : N-Channel MOSFET
NTSC : National Television Systems Committee
OP-AMP: Operational Amplifiers
PWM : Pulse Width Modulation
PCB : Printed Circuit Boards
PAL : Phase Alternating Line
RGB : Red Green Blue
SD :Standard definition
SEPIC : Single Ended Primary Inductance Converter
SOT : Small Outline Transistor Package
S-VHS :Super Video Home System
S-Video :Super Video
SOIC-8 : Small Outline Integrated Circuit 8 Pin Package
V :Volt(s)
W :Watt(s)
WSON : Very Very Thin Small Outline No Lead Package

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SUMMARY

DEVELOPMENT OF THE WHITE LIGHT EMMITING DIODE ILLUMINATED ENDOSCOPIC LIGHT SOURCE

Muzaffer ÖZTÜRK

Biomedical Engineering Programme

MSc Thesis

Advisor: Prof. Dr. Sadık KARA

Endoscopy systems consist of biomedical devices used for the purpose of diagnosis, identification and treatment in hospitals. Cold light sources comprising xenon, halogene or LED light are a major part of this system. The greatest disadvange of cold light sources like xenon and hallogene is that they are rather costly and short-lived. Today these costly and bulky structures are replaced by inexpensive, portable and long-lasting LED light sources. Large-scale studies conducted over the subject in developed countries and fewer studies performed in our country as to the cold light sources with LED have urged us to conduct studies in this direction. In this context, a portable and applicable endoscopic LED cold light source was created in our thesis study.

We can sum up our study under three main titles as research, hardware configuration and software.

Research: An extensive literature research regarding endoscopic devices and light sources was performed. The qualities of the light sources used in the endoscopic system were determined.

Hardware: This was dealt with under two separate headings as Mechanical hardware and Electronic hardware. At the stage of the electronic hardware, the LED examinations were performed, the equipments to be used were determined, and the electronic card design was made. In the mechanical design, on the other hand, an applicable trunk compatible with the endoscopic telescope and the drawings of the components were made, and they were produced as samples.

Software: An interface design was created for the control of the electronic design.

Keywords: Endoscopy cold light source, LED light source, Xenon light source, Halogen light source

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ÖZET

ENDOSKOPİ CİHAZLARI İÇİN BEYAZ LED IŞIK KAYNAĞI GELİŞTİRME

Muzaffer ÖZTÜRK

Biyomedikal Mühendisliği Programı
Yüksek Lisans Tezi

Danışman: Prof. Dr. Sadık KARA

Endoskopi sistemleri, hastanelerde teşhis, tanı ve tedavi amacıyla kullanılan biyomedikal cihazlardan oluşan bir sistemdir. Xenon, Halojen veya LED lamba içeren soğuk ışık kaynakları bu sistemin önemli bir parçasıdır. Xenon ve Halojen soğuk ışık kaynaklarının maliyetlerinin çok yüksek olması ve ömürlerinin kısa olması en büyük dezavantajlarıdır. Günümüzde bu pahalı ve hantal yapıların yerini, ucuz, taşınabilir, uzun ömürlü LED ışık kaynakları almaktadır. Konunun gelişmiş ülkelerde geniş ölçekte çalışılıyor olması ve ülkemizde LED'li soğuk ışık kaynakları üzerine yeterince çalışma yapılmamış olması bizi bu yönde çalışmalar yapmaya teşvik etmiştir. Bu bağlamda tez çalışmamızda portatif kullanılabilir endoskopik LED'li soğuk ışık kaynağı yapılmıştır.

Araştırma, donanım yapılandırması ve yazılım olarak çalışmamızı üç ana başlık altında toplayabiliriz.

Araştırma: Endoskopi cihazları ve ışık kaynakları ile ilgili kapsamlı bir litaratür araştırması yapılmıştır. Endoskopi sisteminde kullanılan ışık kaynaklarının nitelikleri belirlenmiştir.

Donanım: Mekanik ve elektronik donanım olarak iki ayrı başlıkta ele alınmıştır. Elektronik donanım aşamasında, LED incelemeleri yaparak ve kullanılacak ekipmanlar belirlenerek elektronik kart tasarımı yapıldı. Mekanik tasarımda ise endoskopi teleskopu ile uyumlu olacak şekilde kullanışlı bir gövde ve bileşen çizimleri yapılarak numune olarak üretildi.

Yazılım: Elektronik tasarımın kontrolü için arayüz tasarımı yapıldı.

Anahtar kelimeler: Endoskopi, Xenon, Halojen, LED, Endoskopi soğuk ışık kaynağı

CHAPTER 1

INTRODUCTION

Endoscopes are used to see internal organs to catch the diseases. A physician using endoscope have a capable of exploring gastrointestinal, urinary tracts and respiratory, as well as internal organs via a small incision.

There are two type endoscopes rigid and flexible. An endoscopes includes a long tube to capture the internal images and extra instruments for grasping and cutting the organs to provide patient care and decrease recovery time. If a physician want to inspect confined spaces, it is an obligation to use borescopes.

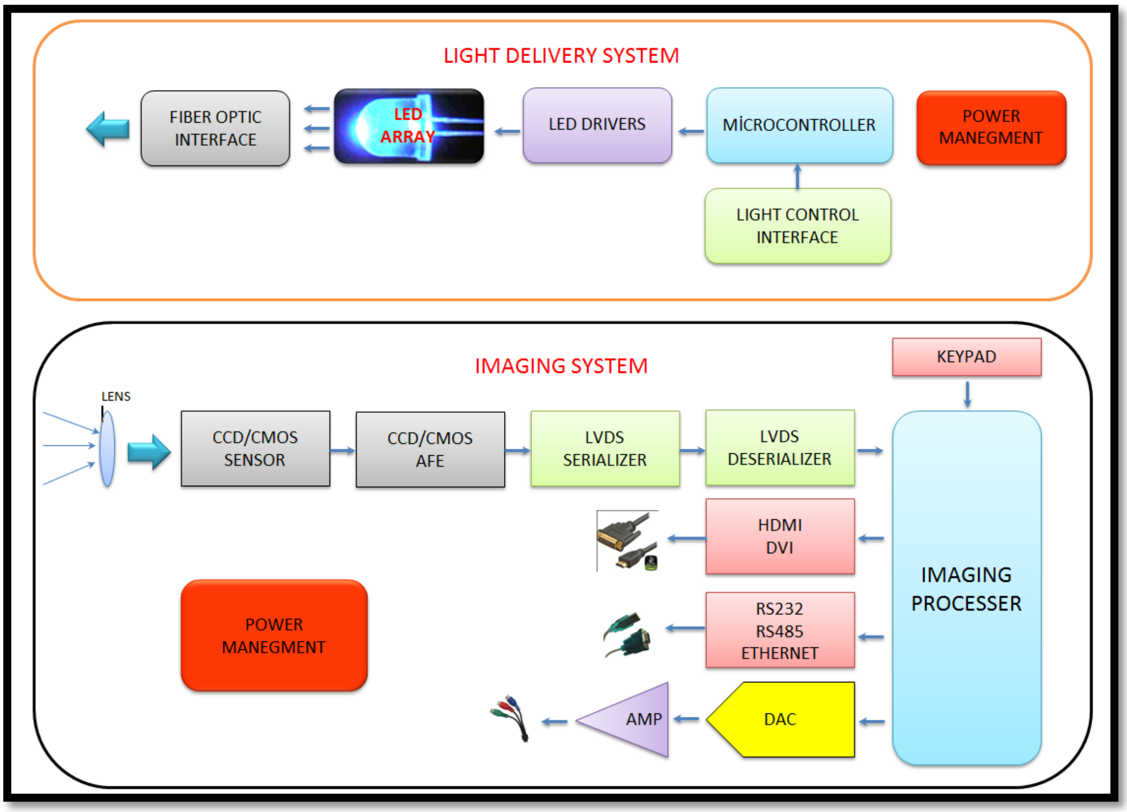

Figure 1.1 Endoscope system block diagram

An endoscopes and borescopes includes four basic requirements; light source, tube, lens, image-capture system. The current standard light source for minimally invasive surgery procedures: 1. Halogen cold light source 2. Xenon / metal halide cold light source 3. Light emitting diode (LED) cold light source.

Sources of halogen light has got a lower temperature than sources of xenon light and inexpensive. Xenon temperature are similar to that of sunlight and hence more accuprecisely brighten the natural colors of tissues. Yet the brightness of halogen light sources will send out much less beam than powerfull xenon since it gives more lumens of gleam per watt.

The common regular light source for largest minimal invasive surgery protocols is the xenon arc lamp which send out over a wide prism across the observable range, rendering a colour nearby to light of day. These lamps are forceful but highly wasteful of energy, demanding nearly 180- 300W of electrical power to convey just over 1W of dioptric power. They are costly, needing an first payment of about $7000- $5000 and $700- $1000 for substitution bulbs, which have a comparatively little lifelong.

Recently, forceful light emitting diode (LED) sources are turning into attainable for medical use and have the benefits of trivial size, energy conservations, noiseless operation, and never requiring to take the place of the bulb. Light emitting diode source with an regular lamp life of 35000 - 60000 hours. LED founded on endoscopic lighting aparatus have few advantage over arc-lamp combinations. LEDs are uses electrical energy economically, softly, sturdy, and loe-priced.

Recently LED lighting perform will be astrided direct on whole stiff borescopes. The LED production will be situated straight on the glass fiber junction of the borescope the shiny light will be to illuminate unless any loss toward the inside the borescope. This illumination unit will be very small and lightweight. In this study, we aimed to design a portable and physically minimized led light source for endoscopy system. This device can be used instead of other light sources. The portability of the device with its lifetime feature is the first advantage over other classical cold light sources. The amount of used LED chips and other components makes us to have a cheaper than xenon and halogen cold light sources.

1.1 Overview of the Thesis

Within the scope of the thesis, the design of LED cold light sources having compatible qualities with endoscopic devices along with their sample production were made.

From past to present, xenon arc lamps and halogene lamps are used as cold light sources in endoscopic systems. The fact that colour temperatures are quite approximate to sunlight and that the rates of the color rendering index (CRI) are rather high as well as the height of the luminous (light) fluxes are the main reasons for their use in endoscopic systems.

In recent years, thanks to the advancements in LED manufacturing technologies, LED lights with high a luminous flux, a color temperature approximate to sunlight and with high color rendering indexes are being manufactured. As the result of the developments in LED manufacturing technology, they have become applicable in endoscopy systems.

The general scheme of the light source designed within the scope of this thesis and produced as a prototype can be seen in Figure 1.2. With the proper top structure, rigid or flexible telescopic connection in various brands and models can be made for our device with an outer casing of aluminium. A 3.7V 3100mAh Li-on battery was used as a power source. As the control interface, a membrane switch with three buttons (increase, decrease, on/off) was used. The high power LED light intensity is performed through the led driver circuit in current control. The LED driver circuit can be controlled by PWM (Pulse-Width Modulation) signal modulation and the microcontroller, and thus, the light intensity can be changed.

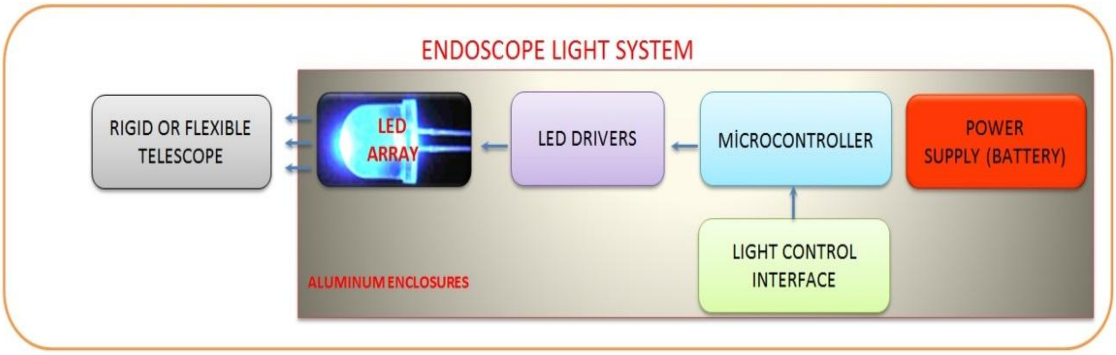

Figure 1.2 Endoscopic light system

1.2 Purpose of the Thesis

Due to their disadvantages, xenon and halogene light sources used in endoscopic devices are rapidly replaced by LED light sources throughout the world. In our country, however, none of the led light sources, xenon or halogene are manufactured for endoscopic devices.

In our thesis project, parallel to these developments abroad, a design on cold light sources for endoscopic devices, which eliminate the disadvantages of other light sources and bring with them a number of innovations through the use of highly-radiant (exclusive) HPLED, has been made.

1.3 The Methods Applied / Practices

Literature reviews were made prior to our thesis project. The endoscopic device users were interviewed, right after which a road map was determined for the project in question. Different types of endoscopic light sources still being used in our hospitals were examined. The LED to be used was determined according to the data obtained as the result of the analyses. The appropriate one was determined by performing analyses on power sources in accordance with the structure to be used. A design on an electronic driver circuit to be adapted to the LED and the power source was made. An outer casing to be compatible with the system consisting of the combination of an electronic driver circuit, a led and a power source was designed and manufactured in a prototype fashion.

CHAPTER 2

LITERATURE SURVEY AND DEFINITIONS

The first endoscope was formed by Philipp Bozzini in 1806. This device guided the light through within the body and later conducted to the eye of the observer [1].

German surgeon Georg Killing invented the first experimental laparoscopy in 1901. This device consist a cystoscope to watch into the abdomen of a dog after insufflating it with air. Surgeon Killing also used filtered atmospheric air to create a pneumoperitoneum [2].

The use of electric light was a big step for the development of endoscopy. They were first used in the external light sources. Subsequently, smaller bulbs named hysteroscope turn into available making internal light possible by Charles David in1908 [1,3].

In 1910, Hans Christian Jacobaeus reported the first laparoscopic operation also called minimally invasive surgery (MIS), in humans. [4]. Jacobaeus was the first to use the "laparothorakoskopie" term [5].

Bertram M. Bernheim presented first laparoscopic surgery to the United States in 1911. He named the method of minimal access surgery as "organoscopy" [2].

Developments in endoscopy has focused on the wide angle lens and a trocars for port introduction of instruments, and insufflation devices in during the 1920s and '30s [6].

Endoscopy is used in the diagnosis and treatment of gallbladder and liver disease by Heinz Kalk who a German gastroenterologist in the 1930s. He has developed a dual approach trocar and 135 degrees lens system. [1,5]

Janos Veress improved a specially conceived springloaded needle in 1938. Interestingly, Veress did not support the use of his Veress needle for endoscopy function. Today, Veress needle is the most important tool to create pneumo-peritoneum. [2].

Gynecological laparoscopy was performed by Raoul Palmer in 1944 in Paris. During a laparoscopic procedure, he emphasized the importance of continuous intra abdominal pressure monitoring. [5].

In during the 1950s and ‘60s, rod-lens system and fiberoptics has been developed by Hopkins. Rodlens systems and fiberoptics are very important for endoscopy systems. [5].

Harold Hopkins had invented a “fibroscope” in 1950s. Consisting of a flexible glass fiber bundles fibroscope, the image was used to transmit. This invention was very helpful in the medical and industrial fields. First fiber optic endoscope has been developed by Basil Hirschowitz and Larry Curtiss in 1957. [1].

In 1906, rigid endoscopes were manufactered by Georg Wolf. In 1945, an instrument was manifactured which capable of looking inside of the human body by Karl Storz who performed very importanat role in the progres of endoscopy [1].

In 1960, Dr. Karl Storz invented the cold light source. Since that time, light has been generated outside of the endoscope and transmitted to the tip through high quality fiber-optic light guides to minimize the heat generated at the endoscope [1,5].

The first video endoscopy system was developed by Dr. Philippe Mouret in Lyons in 1987 [6].

2.1 Endoscopy

Video endoscopy systems contain following components: camera system, telescop, image manegment unit, monitor, light sources, insufflator and irrigation / aspiration. In the following figure 2.1 (a) video (tower) endoscopy system is seen.

The rigid or flexble telescope generally captures images through objective lens. As seen figure 2.1 (b) and (c), flexible and rigid telescope are seen.

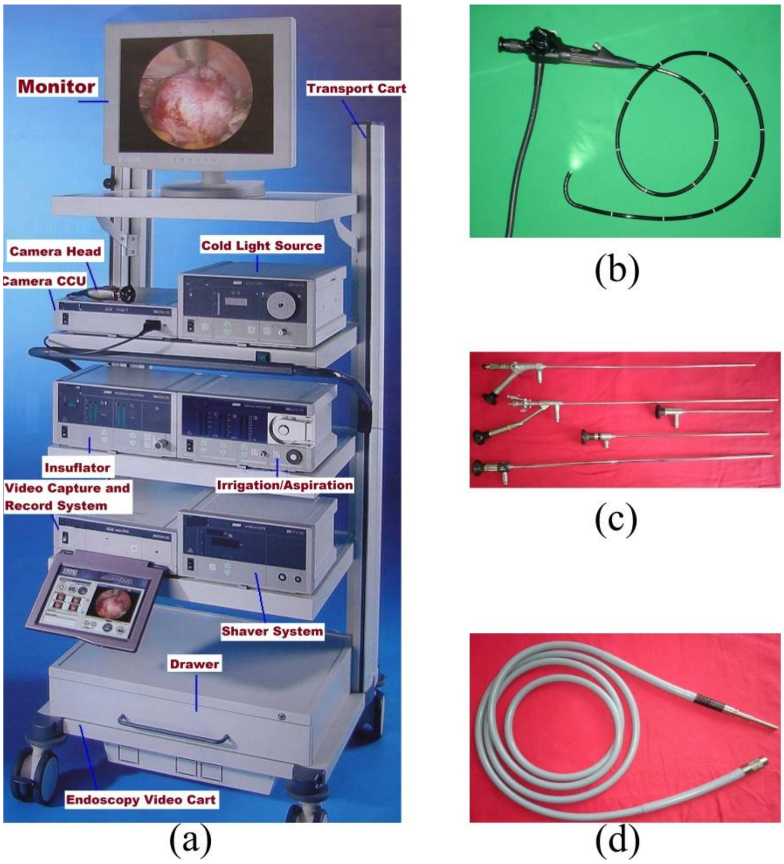

Figure 2.1 (a) Endoscope video tower systems [7] (b) Flexible telescope [1] (c) Rigid telescope (d) Fiber light cable

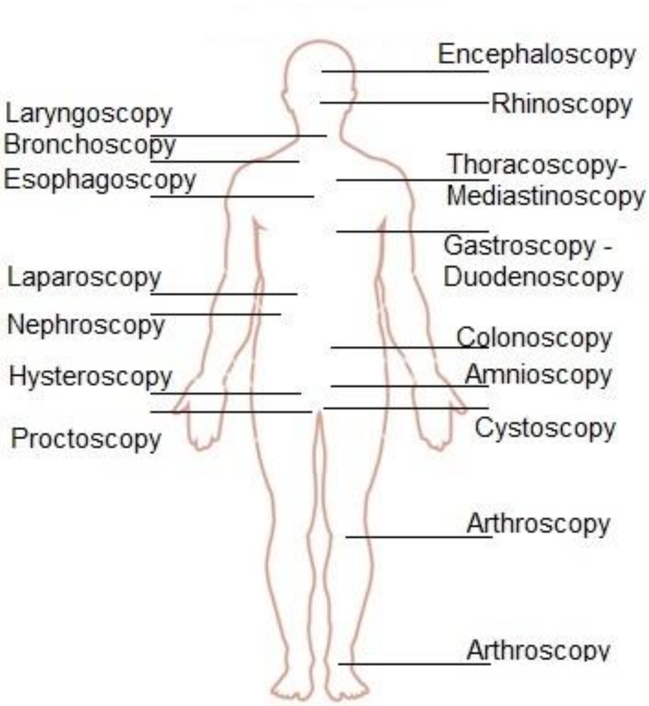

Figure 2.2 Based on the location in body of internally used types of endoscopy

Table 2.1 Some types of endoscopes and the areas of the body they view [8]

TYPE OF ENDOSCOPE	NAME(S) OF PROCEDURE	PUT IN THROUGH	BODY PART OR AREA(S) LOOKED AT
Arthroscope	Arthroscopy	Cuts in the skin	Joints
Bronchoscope	Flexible Bronchoscopy, Bronchoscopy	Mouth or nose	Bronchi (tubes going to the lungs) and trachea (windpipe)
Cystoscope	Cystourethroscopy, Cystoscopy,	Urethra	Bladder
Colonoscope	Lower Endoscopy, Colonoscopy	Anus	Colon and large intestine
Hysteroscope	Hysteroscopy	Vagina	Inside of uterus
Laparoscope	Peritoneal Endoscopy, Laparoscopy	Cut(s) in the abdomen (belly)	Pelvis and space inside abdomen
Esophagogastroduodeno-scope	Gastroscopy, Upper Endoscopy, Esophagogastroduodenoscopy (EGD), Panendoscopy	Mouth	Stomach, esophagus (swallowing tube), and duodenum (first part of small intestine)
Enteroscope	Enteroscopy	Mouth or anus	Small intestine
Mediastinoscope	Mediastinoscopy	Cut(s) above the sternum	Mediastinum (space between the lungs)
Thoracoscope	Pleuroscopy,Thoracoscopy	Cut(s) in the chest	Space between lungs and chest wall
Laryngoscope	Laryngoscopy	Mouth or nose	Larynx (voice box)
Sigmoidoscope, Flexible Sigmoidoscope	Proctosigmoidoscopy, Sigmoidoscopy, Flexible Sigmoidoscopy	Anus	Sigmoid colon (lower part of large intestine) and rectum

2.1.1 Medical Camera and Monitor Systems

Basic endoscopic camera system; consist camera head, camera control unit (CCU) and monitor [7].

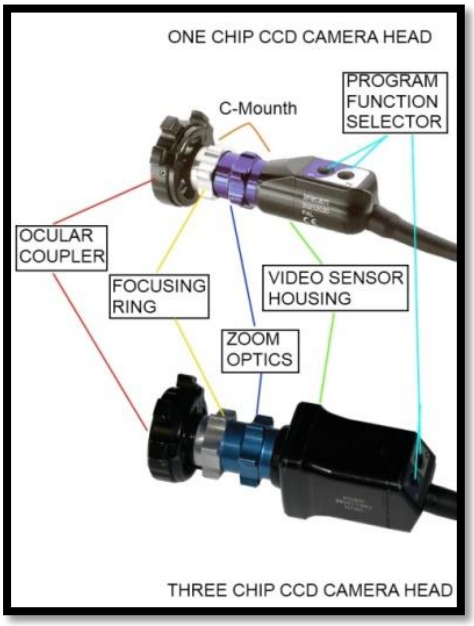

Figure 2.3 One CCD and three CCD camera head

The first video signal is supply from the head of camera to the unit of control by way of a cable termination in a precise instrumentation that lets attachment to the unit of control in alone the accurate orientation. The entering signal of video from the lead is then adapted and dispatched to the output connectors; then cables linked to the monitor and storage devices [9].

Figure 2.4 Camera control unit (CCU) (a) Front view (b) Back view

The input signal of video from the head is then adapted and dispatched to the output connectors; cables then link the display monitor. Monitors technical specifications must compatible with the camera head and the camera unit specifications [9].

Digital video recording and archiving units, endoscopic images taken during the operation to capture the image and records card and the hard drive, CD or DVD media [9].

2.1.2 Telescope

The telescope mostly catches images direct a distal-mounted impartial lens. The image is afterwards passed on through a rod-lens combination to a closest-mounted visual lens that enlarges it for the operator [10].

2.1.2.1 Rigid Telescope

There are the shaft of the sphere and body, the eyeball part, the light connector and the distal end In a inflexible range. The main body of the scope put up the process what consolidates the figure. The optical lenses, spacers and leap mechanism are put in an adjacent beam but are not attach with glue together [11].

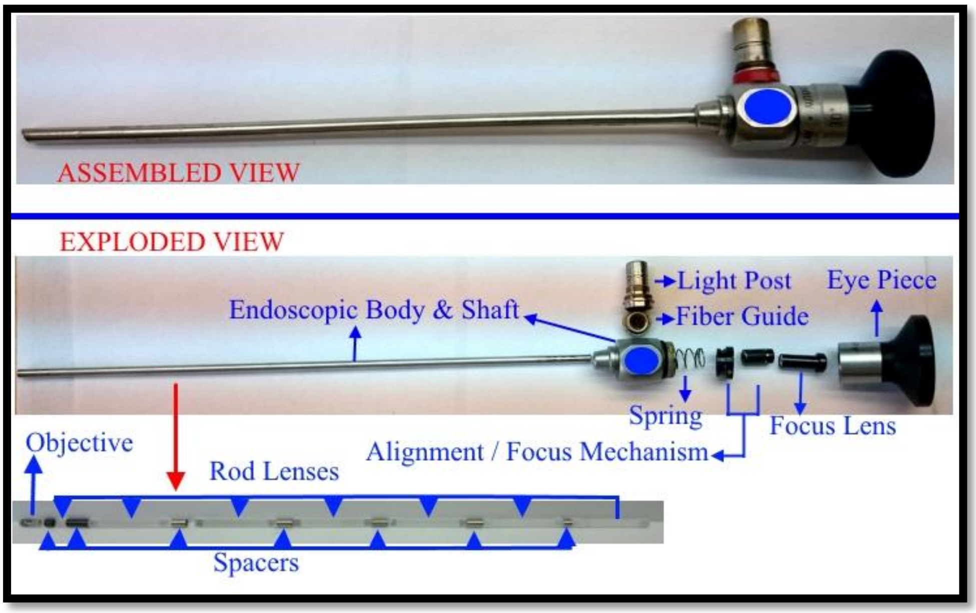

Figure 2.5 Rigid telescope assembled and exploded view

2.1.2.2 Flexible Telescope

Endoscopic devices are very compound biomedical devices. The intricacy happens as an effect of the need for optical fiber space and multiple throughout tight channels to be included within a cylindrical building in other words compel in the resticted sizes of the main cavity opening (e.g., intestine, throat , trachea) [12].

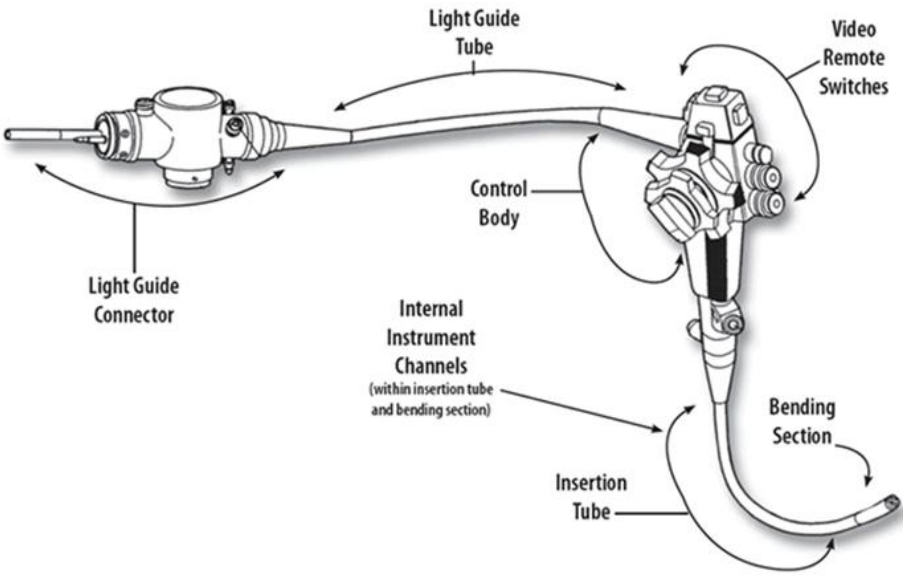

Figure 2.6 Structure of the flexible endoscope [13]

The anatomical building of the flexible endoscope is the external shell, comprised of five fundamental parts: The connector of the light guide, control body, the tube of the light guide, bending section and insertion tube [12].

The connector of the light guide: It is the hard end of the sphere in order for links to the light source or cart system of video. It is the sphere part most remote from the forbearing [13-14].

The tube of the light guide: occasionally named the universal cord, this empty tube links the light guide to the control unit [13-14].

Insertion Tube: It is the long object put in the body during regular use [13].

Bending Section: It is situated away from the center end of the insertion tube, this part is builded of strong articulating steel ribs attach with rivets together to shape a flexible skeleton [13-14].

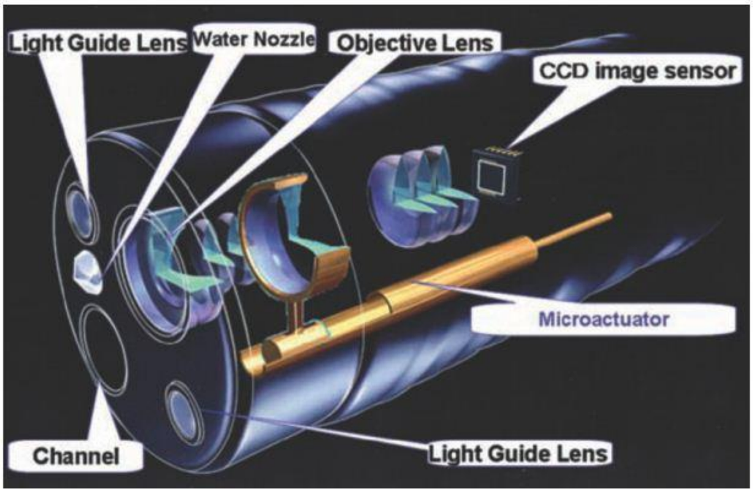

Figure 2.7 Flexible endoscopy distal end [14]

2.1.3 Cold Light Sources

Direct viewing in the orifices and internal cavities of the body by endoscopy requires a light source [15]. A light source, also going by the name of light projector, LED light source, or cold light source, is a disconnected cold light projector in order for produces light using powerful lamps; the light then exits at the sheath and illuminates the cavity to be inspected. Lamps include LED, halogen, xenon and incandescent lamps [16].

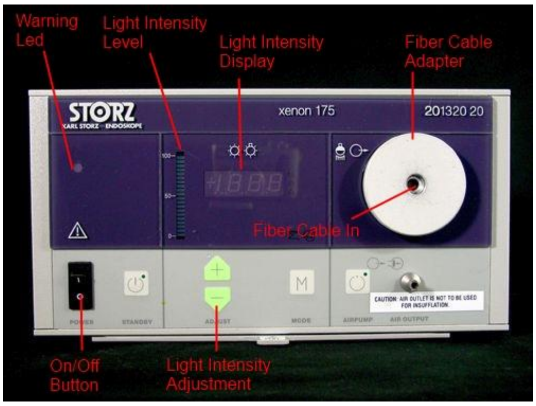

Figure 2.8 Xenon cold light source

2.1.3.1 Light Guide

The illumination is transfered to the endoscope by a elastic fiber-optic light lead, among 0.5-1.0 cm in outer diameter and 180 and 250 cm in length. This is basically cool in temperature like majority of the lamp temperature is not conveyed to the laparoscope. Quality of being poisonous of light is, hence, not a concern [9].

Figure 2.9 Fiber light cable (a) L:180cm, ϴ: 5mm (b) Infact fibers (c) Broken fibers

2.1.3.2 Halogen Cold Light Source

A halogen lamp, or quartz iodine light bulb, is an incandescent light bulb that has a small quantity of a halogen like bromine or iodine supplemented. The union of the halogen gas and the tungsten wire manufacture chemical reaction which deposits again condensed tungsten back on the wire, expanding its lifelong and preserving the clearnes of the envelope. Due to this, a incandescent lamp may be running at a costly temperature than a normal gas-filled lamp of alike power and service life, presenting light of a loftier visible light and color temperature [17].

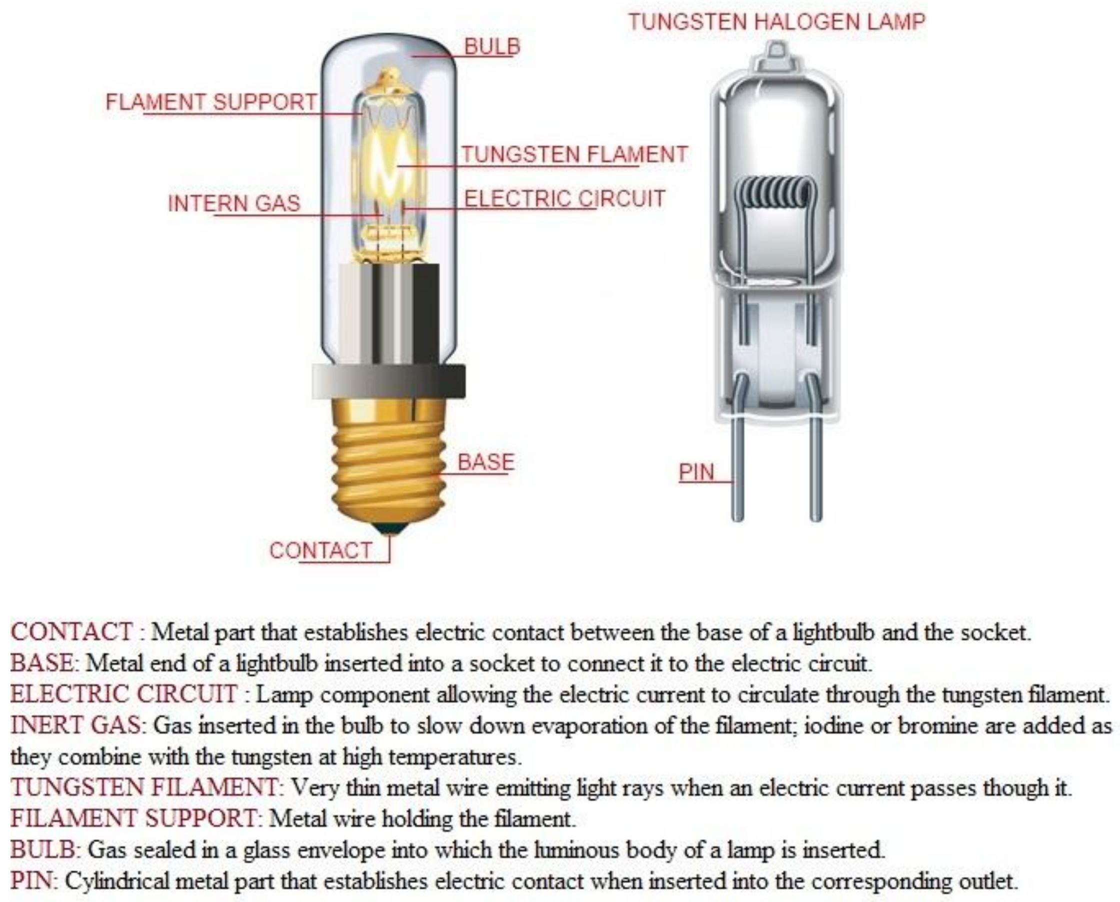

Figure 2.10 Tungsten halogen lamp [18].

The halogen lamp is an improved form of incandescent lamp. The filament is occured of malleable tungsten and located in a gas filled bulb. This is similar to normal tungsten lamp. However, the gas contained in the halogen lamp has a high pressure (8-7 ATM). The glass bulb is produced of aluminosilicate, high-silica glass or melted quartz. This bulb is mightier than regular glass to withstand the high pressures. Thanks to its small size and high light output of halogen lamps are used in film and television lighting, and has set the standard in this area. Today, halogen lamps are being replaced with LED lamps. If efficiency increase in halogen lamps can increase its sales [19].

Halogen lamps have a tungsten filament like regular incandescent lamps. However the halogen lamp is much smaller than incandescent (same wattage) lamps. The halogen lamp includes a halogen gas in the bulb. The halogen gas is a significant material that decelerates the thinning of the ductile tungsten filament and prevents the deformation. For these reasons, extends the life of the bulb. Halogen gas, tungsten filament provides a secure way of working at higher temperatures. Therefore, the light intensity is increased [19].

There are five halogen elements in the periodic table: fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). In the construction halogen lamp only bromine (Br) and iodine(I) are used [19].

Table 2.1 Adventeges / disadvantiges halogens lamps [19]

ADVANTAGES	DISADVANTAGES
Halogen lamps are small, lightweight.	Extremely hot (easily capable of causing severe burns if the lamp is touched).
Does not use mercury like CFLs (fluorescent) or mercury vapor lights.	The lamp is sensitive to oils left by the human skin, if you touch the bulb with your bare hands the oil left behind will heat up once the bulb is activated, this oil may cause an imbalance and result in a rupture of the bulb.
Better color temperature than standart tungsten (2800-3400 Kelvin), it is closer to sunlight. (CRI > 85)	Explosion, the bulb is capable of blowing and sending hot glass shards outward. A screen or layer of glass on the outside of the lamp can protect users.
Longer life than a conventional incandescent.	Not as efficient as HID lamps (Metal Halide and HPS lamps)
Instant on full brightness, no warm up time, and it is dimmable.	Endoscopic cold halogen lamp life smaller than xenon (or LED)

2.1.3.3 Light Emitting Diodes (LEDs) Light Source

A LED essentially is a P-N junction semiconductor diode that send out light in what time a current is implement anyway the device [20].

LED was present for the first time as a feasible electronic basic discrete device in 1962 by Nick Holonyak Jr. An LED is a semiconductor that consists of a p-n junction diode. It composed of a small piece of semiconducting matter deal with to create a construction called a (p-n) junction. When linked to a power supply, current to start flow from the p-side (anode) to the n-side (cathode). Charge-carriers stream into the intersection. When an electron encounters a gap, it descend into a weak energy level and releases energy in the shape of a photon [21].

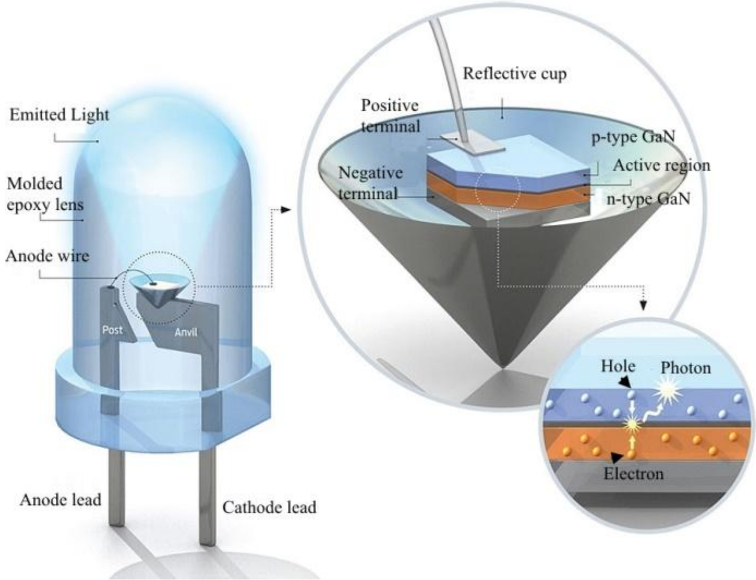

Figure 2.11 Traditional indicator light emitting diodes (LEDs) [21]

Light-Emitting Diodes (LEDs) Structure

To do it to pattern an LED is to put three semiconductor layers on a substrate. Between two type semiconductor layers, an constantly moving region send out light when an hole and electron combine again. Taking everything into account the p-n union to be a diode, then when the diode is forward biased, electrons and holes are urged forward the active space. The light is manufactured by a solid state procedure named electroluminescence [22].

Principle of LED Working

The LED is made up of a chip of semiconducting substance sedated with mixed to make a p-n junction. Compared to in other diodes, current sterams absolutely from anode, to cathode, but not in the opposite direction. Electrons and holes move along the junction from electrical conductor with different voltages [23].

The length of a wave of the light emitted, and therefor its color rely on the energy gap of the substances shaping the p-n junction. In germanium or silicon diodes, the holes and electrons combine again by a non-radiative passage, what manufactures no optical discharge, since these are circuitous band gap sustances. The materials utilized for the LED have a direct energy gap with intensities similar to near-infrared, observable, or near-ultraviolet light [23].

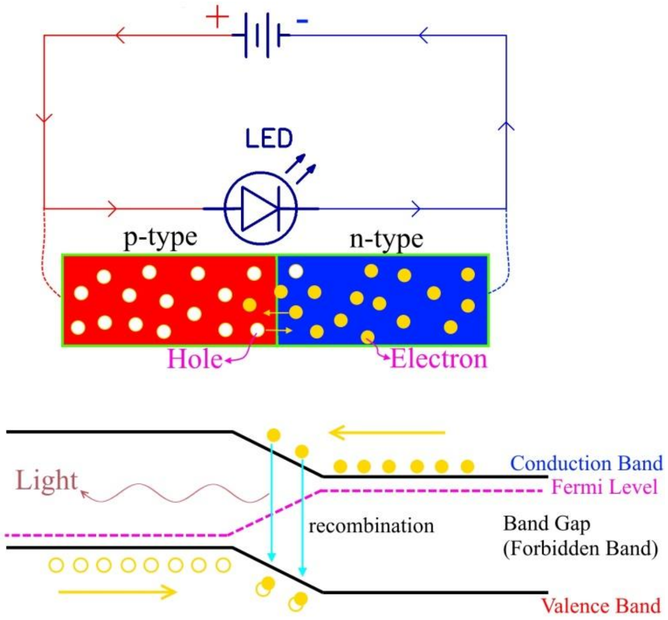

Figure 2.12 The inner workings of an LED, circuit (top) and band diagram (bottom)

Electrical Properties of LED

In the area of an not biased p-n junction, electrons originating from donors on the n-type side pour out over to the p-type side where they encounter many holes with which they recombine. A similar procedure happens with holes. Therefore, a region near the p-n junction is exhaust of free carriers. This region is be acquainted with the depletion region [24].

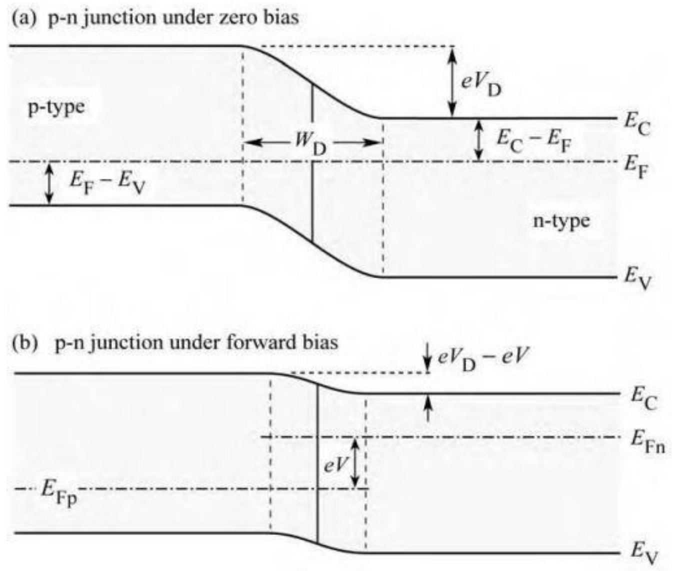

Figure 2.13 P-N junction under (a) Zero bias (b) Forward bias [24]

In the without of free carriers in the depletion layer, the only charge in the depletion layer is from ionized giver and acceptors [24]. The current–voltage (I–V) characteristic of a p-n junction was improved by Shockley.

The mathematical statement depicting the I–V curve of a diode is and so mentioned to as the Shockley equation [24].

I–V characteristic of the diode can be inscribed as:

$$I = I_S(e^{eV/kT} - 1) \quad (2.1)$$

$$I_S = eA\left\{\left(\sqrt{\frac{D_P}{\tau_P}}\frac{\eta_i^2}{N_D}\right) + \left(\sqrt{\frac{D_n}{\tau_n}}\frac{\eta_i^2}{N_A}\right)\right\} \quad (2.2)$$

Several diode I–V characteristics of semiconductors made from different materials are shown in figure along with the bandgap energy of these materials. The empirical beginning voltages bring in the figure, and the similarities with the energy gap energy of these substances, indicates that the band gap and the minimum gate-to-source voltage surely agree reasonably well [24].

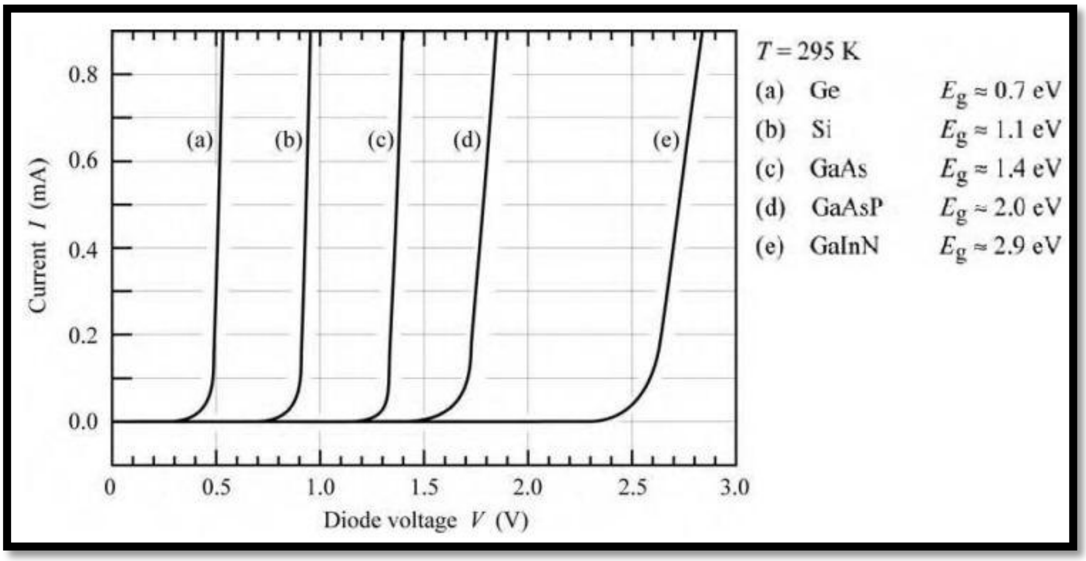

Figure 2.14 Current-voltage characteristics of p-n junctions made from different semiconductors [24]

Regularly a diode has undesirable or parasitic elements. The effect of a resistance is shown in figure (a). A series resistance may be induced by immoderate touch resistance. A parallel resistance may be induced by every canal. This evade may be made happen by harmed regions of the p-n intersection [24].

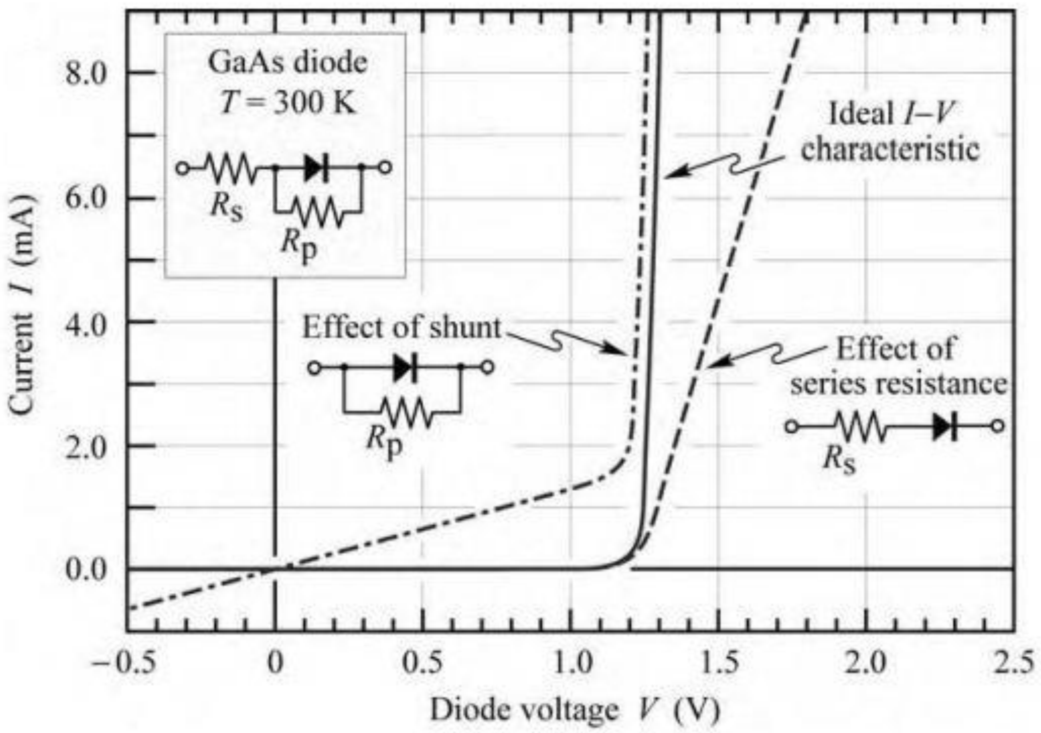

Figure 2.15 Effect of series and parallel resistance on I-V characteristic [24]

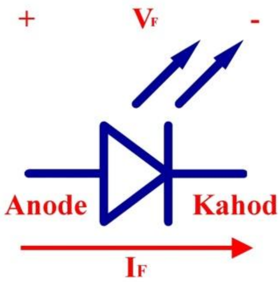

Figure 2.16 LED symbol (I_F and V_F)

2.2 Illumination Fundamentals

2.2.1 Light and Electromagnetic Radiation

To an engineer Relating to the science of optics, light is clearly a extremely small part of the electromagneticspectrum, between infrared and ultraviolet radiation. The observable part of the electromagnetic spectrum stretchs from about 700 to about 400 nanometers (nm), as shown in bottom figüre [25].

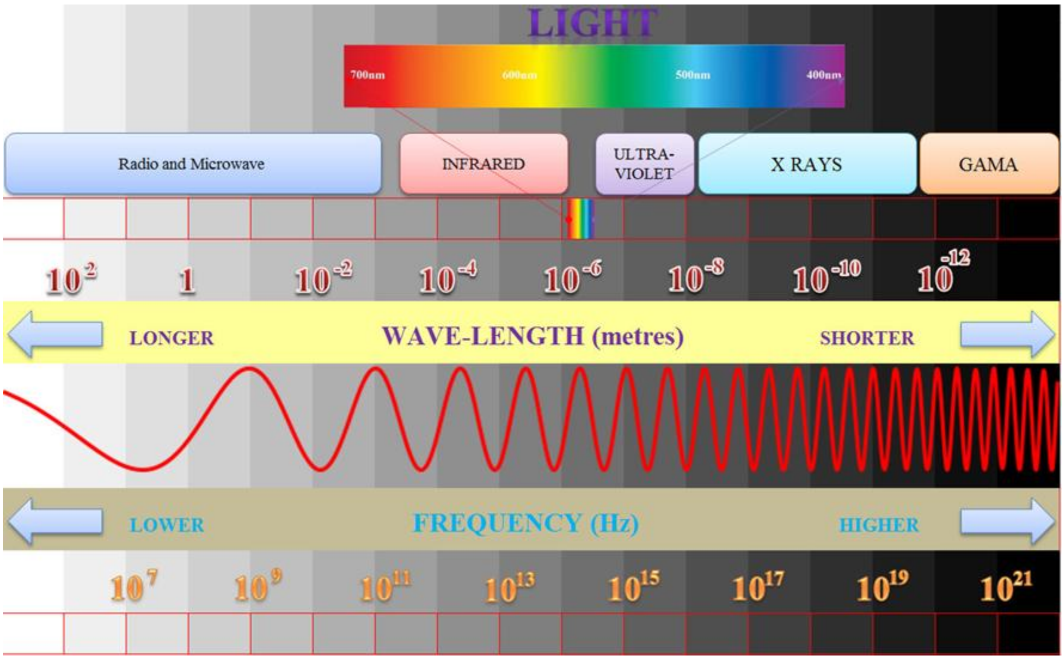

Figure 2.17 The electromagnetic spectrum

2.2.2 Principles of General Photometric and Radiometric

Radiometry is the thorough investigation of optical radiation light, radiation, ultraviolet, and infrared beam. Photometry, from the other point of view, is involved by peoples' seen response to light [25]. Radiometry is involved with the sum up energy component of the radiation.

The following table presents the usual radiometric and photometric quantities, together with their units and symbols [25].

Table 2.2 Photometric and radiometric quantity - units [25]

	Radiometric		Photometric	
Quantity	**Symbol**	**Units**	**Symbol**	**Units**
Wavelength	λ	nanometer (nm)	λ	nanometer (nm)
Radiant & luminous energy	Q	watt-seconds (W-s)	Q_v	lumen-seconds (lm-s)
Radiant & luminous energy density	U	watt-seconds/m³ (W-s/m³)	U_v	lumen-seconds/m³ (lm-s/m³)
Radiant & luminous flux (power)	Φ	watts (W)	Φ_v	lumens (lm)
Irradiance & illuminance	E	watts/cm² (W/cm²) or watts/m² (W/m²)	E_v	lux (lx; lm/m²) or footcandle (fc; lm/ft²)
Radiance & luminance	L	watts/m²/steradian (W/m²/sr)	L_l	lumens/m²/steradians (lm/m²/sr)
Radiant & luminous intensity	I	watts/steradian (W/sr)	I_v	candela (cd; lm/sr)

2.2.2.1 Spectral Response

The eyes of mankind is further delicate to some length of a waves than to others, already within the tight spectrum of visible light. The sensitivity depends on the orientation of the light intensity in the environment of the human eye [25].

2.2.2.2 Energy Density

Radiant and luminous energy, symbolized with the symbols Q_V and Q, regardfully, are the means of all the energy absorbed at a special the energy contained in a uncommon radiation field. While luminous energy is calculated in lumen-seconds Radiant energy is calculated in watt-seconds. Energy density, symbolized as U and U_V, are the quantity of energy per unit amount, calculated in either watt / seconds /m^3 or lumen-seconds/m^3 [25] .

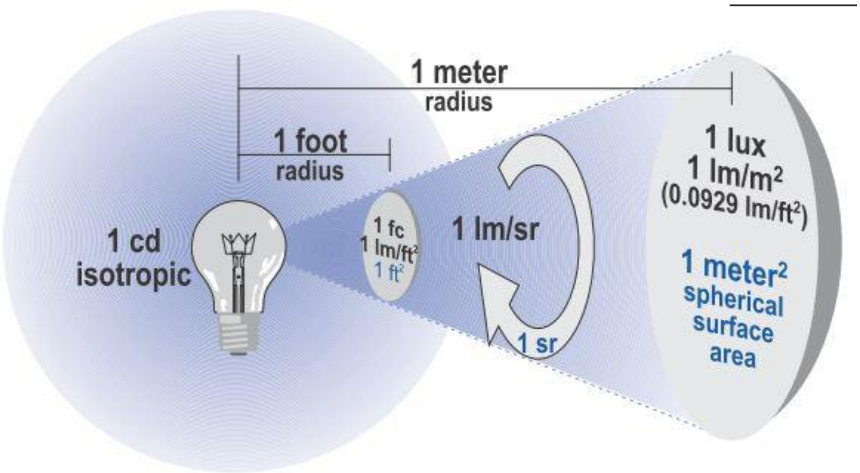

Figure 2.18 Illuminance [25]

2.2.2.3 Luminance and Radiance

Luminance (L_V) is the intensity of light per unit solid angle, calculated in lm/m^2 /sr. This menas that, luminance is the compactness of visible radiation [25].

Radiance, symbolize by the letter L, is the brightness per unit solid angle. It is calculated in W/m^2 /sr [25].

2.2.2.4 Radiant and Luminous Intensity

Radiant intensity, symbolized with the letter I, is the quantity of power glowed per unit solid angle, calculated in W/sr. Luminous intensity is the quantity of observable power per unit solid angle, calculated in candelas (cd, or lm/sr) [25].

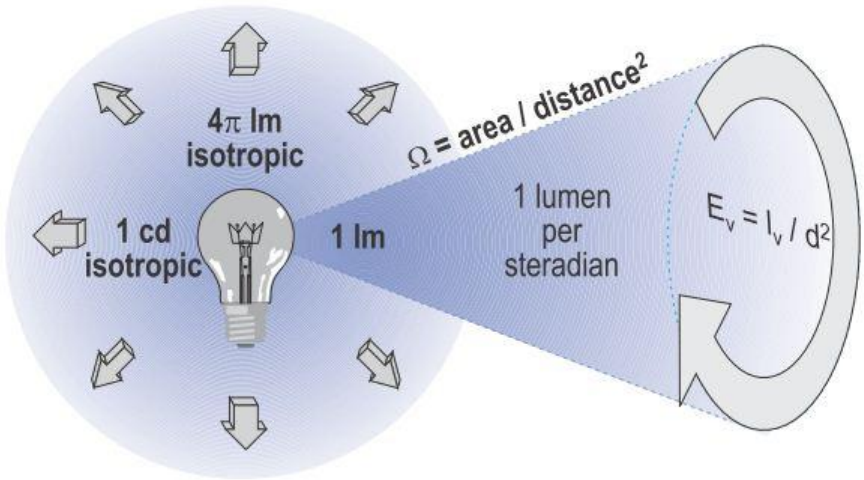

Figure 2.19 Luminous intensity [25]

CHAPTER 3

ENDOSCOPIC LED LIGHT SOURCE

3.1 The Hardware Configuration of the System

We are studying our thesis project under four main titles as HPLED, battery, electronic printed circuit board and the mechanical design of the outer casing as the hardware of our project.

3.1.1 The High Power LED (HPLED) Used Within the System

High Power LED and the power source directly affect the electronic system to be used. Thus, the LED and the type of the power source to be used within the system must be determined prior to the electronic design.

As the first step, within the framework of our thesis project, two cold light sources equivalent and similar to the light source to be designed were supplied. The LED models used in this light source were determined. HPLED analyses were performed on the basis of the datasheet information belonging to these models. HPLED catalogue and datasheet analyses belonging to various firms (Cree, Philips, Omron, Vishay, Bridgelux, etc.) were made. As the result of the analyses, the HPLEDs with the properties approximate to the equivalent light sources were delivered from abroad and from within the country. In order to be able to measure and observe the sufficiency and performance of the cold light sources and LEDs obtained, two experimental and observational stationary mechanisms were established. The first experimental mechanism was the measurement of the light intensity from specific distances after the LED light had been transmitted through the endoscopic telescope. In the second experimental and test mechanism, the sufficiency of the light source was quantitatively put forward by shooting the images from specific distances by means of a telescope through which the light source is used. The same system was also used along with the obtained leds on condition that the optic mechanism would remain the same. During the LED trials, the examination was performed under the power source and the constant current conditions, after which the results were recorded.

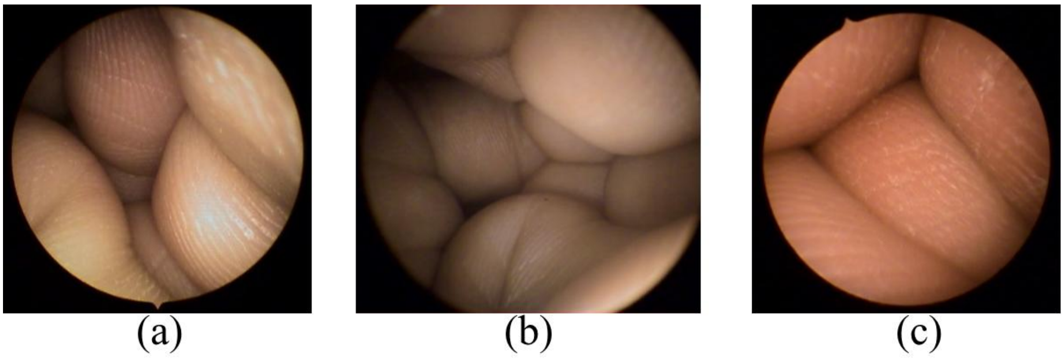

Figure 3.1 Comparison light source (a) Our LED (b) ELS LED (c) Halogene

The color rendering index (CRI) and the other parameters were compared proportionally through the images shot (Figure 3.1) and the LED cold light sources supplied. In addition, these parameters were compared with the datasheet information of the manufacturer. As the result of these comparisons, the performance of the LED we had used was observed and proved to be superior to its equivalent.

As seen in the figure below (Figure 3.2), the forward voltage falling over HPLED changes in a directly proportional way by depending on the current.

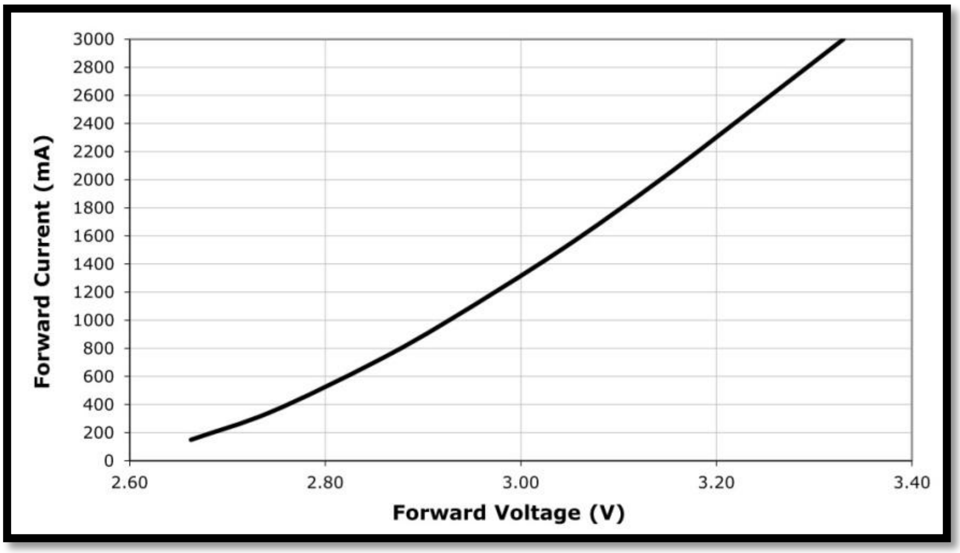

Figure 3.2 HPLED electrical properties (Tj = 85 °C) [26]

As seen in the following figure (Figure 3.3), there is a direct proportion between the current flowing over the LED and the light intensity it provides. We adjust the LED luminosity by changing the current via the electronic circuit system we designed.

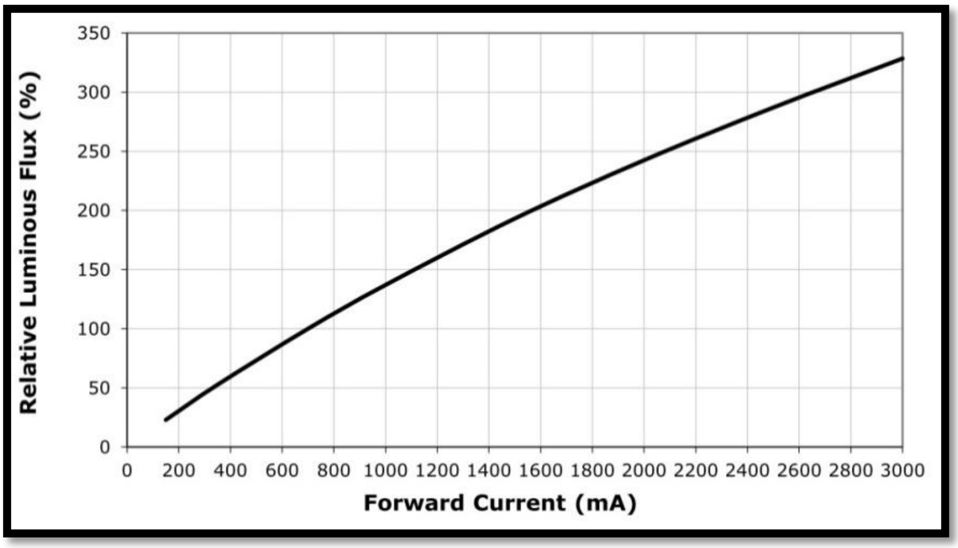

Figure 3.3 HPLED relative flux vs. current (Tj = 85 °C) [26]

Below is a characteristic table (Table 3.1) belonging to HPLED used in our thesis project. Our CRI value belonging to HPLED used in our thesis project is 90. The color temperature (CCT Range), on the other hand, is 3200K [26].

Table 3.1 HPLED characteristics info applied [26]

Characteristics	Unit	Typical	Maximum
Thermal resistance, junction to solder point	°C/W	2.5	
Viewing angle (FWHM)	degrees	125	
Temperature coefficient of voltage	mV/°C	-1.6	
ESD withstand voltage (HBM per Mil-Std-883D)	V		8000
DC forward current	mA		3000
Reverse voltage	V		-5
Forward voltage (@ 700 mA, 85 °C)	V	2.85	3.15
Forward voltage (@ 1500 mA, 85 °C)	V	3.05	
Forward voltage (@ 3000 mA, 85 °C)	V	3.3	
LED junction temperature	°C		150

3.1.2 Power Supply Used Within the System (Battery)

Power source is one of the most important parts of every electronic circuit. In our thesis project, our most significant criteria in the selection of the power source for our the device, the sample of which we were going to take, were its lightness, sizes, exposure time and easy portability. It was required that there be no cable connector to be able to carry our device easily. Hence, we had to select a battery. The exposure time of our device is of importance during the examination and operation. There must be as much amount of energy as possible to be stored by the battery for a long-lasting exposure time of our device. The rechargeable batteries are of great significance in terms of ensuring the long-term required power and reducing the costs. Market researches in compliance with these criteria were carried out for the power source (battery) we used in our thesis project. As the result of this research, it was decided that 3.7V 3400mAh Li-on (18650) battery coded NCR18650B, which was manufactured by Panasonic company, was appropriate for the project.

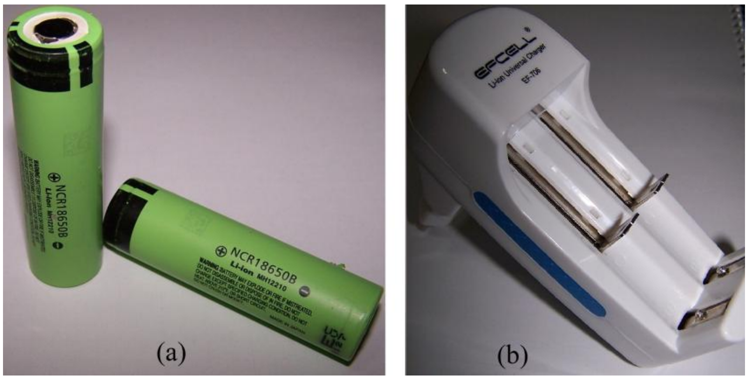

Figure 3.4 (a) Battery (b) Charger

The sizes of the battery coded NCR18650B, which was used in our thesis project, were 64.93 X 18.2 (mm), and it weighed about 45g. Its capacity was 3350mAh on the average, with 3.6V nominal voltage. Its dead weight was 4.2V when charged. It can operate on a temperature scale of -20 ~ 50°C. It can be charged with a constant current or a constant voltage source (up to 1600mA) [27].

In the figure below (Figure 3.5), the discharge rate of the battery is given. As also seen in the figure, as the battery is discharged, so does the battery voltage diminish in proportion to this. The increase in the discharge current also increases the voltage drop of the battery.

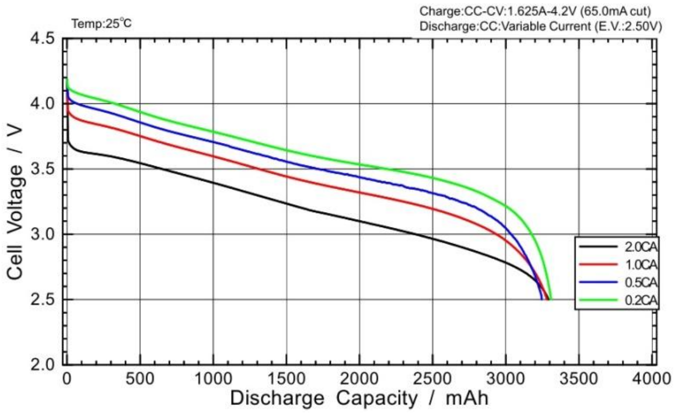

Figure 3.5 Discharge characteristics for NCR18650B [27]

The fact that the battery voltage was 4.2V-2.7V and the HPLED bias was approximately 2.85V-3.3V became quite an important factor in determining the topology of the circuit we were going to devise.

3.1.3 The Electronic Design of the System

3.1.3.1 LED Equivalent Circuit

LED can be defined as a constant voltage load. As seen in the figure below (Figure 3.6), the electronic equivalent can be modelled through a perfect zener diode and an ESR (Equivalent Series Resistance). LED starts to give off light once this barrier voltage of the LED has been overcome. This voltage drop over the LED may differ. The semiconductor materials are not that good conductors. They become semiconductor materials in LED and show resistance (ESR) to the current. This means that the voltage drop increases in proportion to the current increase passing over the LED. The ESR (Equivalent Series Resistance) is around 20-30 Ohm in low-power LEDs but around 1-2 Ohm in high-powered LEDs. The ESR measurement is performed when the difference in the current increase changes the forward voltage drop. As for the HPLED we selected, when the forward voltage goes from 3.0V up to 3.2V (0.2V), the current flowing over it rises from 1300mA up to 2300mA (1000mA) [26]. Hence, ESR reaches (0.2V/ 1000mA) 0.2Ohm.

The barrier voltage of the LED drops when the temperature increases. The barrier voltage of the HPLED we selected shows a 1.6mV -decrease per each degree [26].

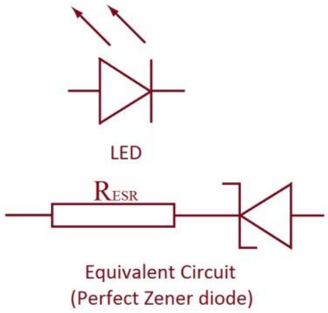

Figure 3.6 Equivalent circuit for an LED

3.1.3.2 Driving LEDs and Controlling Methods

Voltage Source

When the LED with a constant voltage load is driven by a constant voltage source, there may be some inconveniences to this due to the fact that the difference between the load voltage and the constant voltage source drops over the ESR. The ESR of HPLEDs is a minimal value. Therefore, the minimum changes in the constant voltage source or in the forward voltage drop of the LED lead to maximum changes within the current.

If the intensity within the voltage source and the forward voltage drop of the LED is known, the current changes, then, can be calculated [28].

$$I_{MIN} = \frac{V_{SOURCE\_MIN} - V_{F\_MAX}}{ESR} \qquad (3.1)$$

$$I_{MAX} = \frac{V_{SOURCE\_MAX} - V_{F\_MIN}}{ESR} \qquad (3.2)$$

The ESR in this equivalence is fixed. In the event that the ESR is high, the maximum and minimum difference in the current decreases, as it can also be seen from the equivalence. Minimum difference in the current ensures stability.

Passive Current Control

As in all the other LEDs, we should also restrict the current passing over the HPLEDs, or else, the LED cannot bear the current passing over it and breaks down. The simplest LED driver can be made with the help of a series resistance over the LED.

We can reduce the effect of the change in the voltage source and in the LED voltage with a series resistor [28].

$$I_{MIN} = \frac{V_{SOURCE\_MIN} - V_{F\_MAX}}{REXT} \quad (3.3)$$

$$I_{MAX} = \frac{V_{SOURCE\_MAX} - V_{F\_MIN}}{REXT} \quad (3.4)$$

The negative effect of the temperature shows itself in badly-designed circuits. In the following figure (Figure 3.7), a simple driver circuit is given. We can explain the relationship between the temperature and the LED current as follows: In the circuit is a 5V-constant voltage source and a piece of series LED over 2R8 resistor. When the initial energy is provided for the circuit, a 0.7A current passes over the LED. The LED starts to warm up in proportion to the power spent over it. The forward voltage falling over the LED due to the temperature increase drops from 3.15V down to 2.85V. In this case, in accordance with OHM Law, the current passing over the LED increases and rises up to 0.75A. While the rising current heats up the LED more and more, the voltage over the heated LED drops more, as well. As the result of this cycle, the LED breaks down unless precaution is taken.

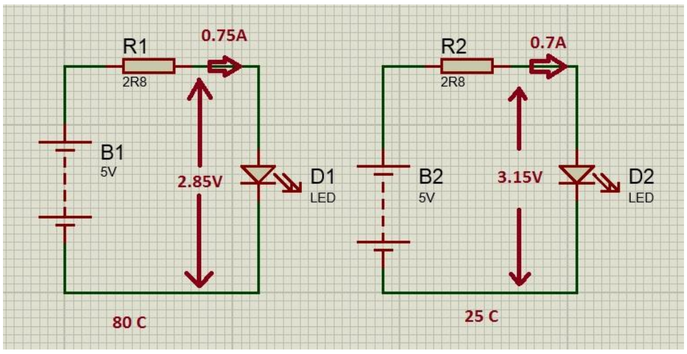

Figure 3.7 Temperature-current relationship in LEDs.

Active Current Control

Current control with a series resistor is not a good method at all, especially when there are changes in the voltage source. In the active current control (Figure 3.8), the current flowing over the LED is controlled by feedback, and the current regulation is done. The active current control can be designed with the elements, such as mosfet (metal oxide semiconductor field-effect transistor), transistor and op-amp.

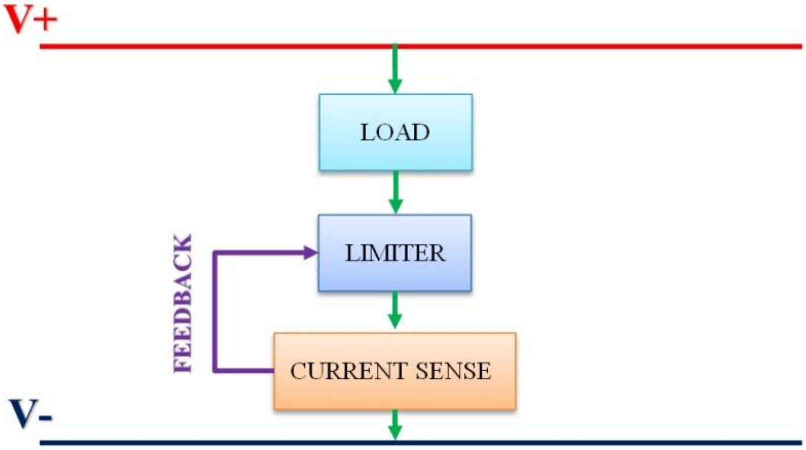

Figure 3.8 Current limiter functions

Current Source

LED behaves like a constant voltage load; for this reason, it can be connected to the constant current source directly. The forward voltage drop of the LEDs driven by the current source and the amplitude of the ESR resistor do not matter. When a few LEDs are connected in parallel to each other, the voltage regulation (driver) is preferred. If LEDs are connected in series, the constant current regulation (driver) is preferred to be used. In our thesis project, the constant current driver was preferred since we used an HPLED. The constant current source and the LED driver can be made with the help of two structures: as linear and switched. We determined the appropriate methodology for our thesis project by analyzing these two structures below.

3.1.3.3 Linear and Switching Mode Drivers

Simply, the linear and switched regulators are seen in figure 3.9. We can say that the linear regulator is simply a variable resistance. The resistance of the regulator changes by depending on the load, and the voltage value at the output is already regulated. To put it in simple terms, the switched regulator, on the other hand, can be represented as a simple switch. The desired voltage is obtained by changing the period of time when the switch is off.

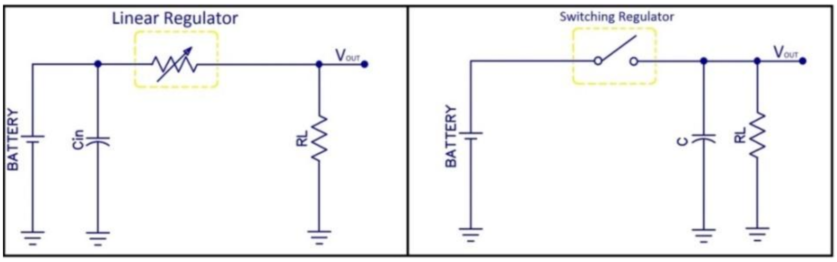

Figure 3.9 Basic linear and switching regulator

Switch mode drivers are particularly preferred due to their high efficiency in the power transformation in high-powered applications. They are more complex than the linear regulators and are more costly. We used a switch mode regulator in our project in order to be able to achieve high efficiency. We also determined the topology we were going to apply in our thesis project by examining the varieties of switch mode regulators.

Buck- Based LED Drivers

Buck topology is used as a step-down in practices. The output voltage must not be more than 80% of the supply voltage.

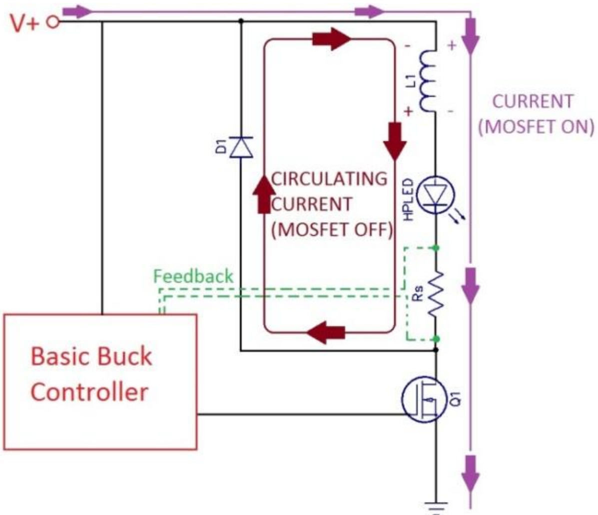

Figure 3.10 Buck LED driver

In the above figure (Figure 3.10), a simple buck converter is seen. In this circuit, the mosfet is used for the purpose of switching. When mosfet is ON, the current flows through the L1 coil and the series HPLED and Rs resistor. L1 coil stores energy by slowing down the increase of the current. When mosfet is on OFF position, on the other hand, the energy over the L1 coil is discharged over HPLED, Rs and D1 diode. The current passing over the Rs resistance here is controlled by buck controller, and the HPLED current is tried to be kept fixed. The current flowing over the LED oscillates at minor values.

Boost Converters

The output voltage in the Boost converter is used when it makes 1.5 times as much as the supply voltage. In figure 3.11, a boost converter is simply seen. When mosfet is ON, the L1 coil (its anode (positive pole) being on top) stores magnetic energy. When mosfet shifts to OFF position, on the other hand, the bias on the L1 coil turns upside down and the lower part becomes positive. In this case, the battery and the coil becomes like a series voltage source, right after which it charges the C_{out} capacity over D1 diode. If the switching process is done over the coil without the energy discharge, it becomes more than the input voltage. As the initial voltage of the battery used in our project (4.2V) is greater than the LED voltage (2.85V), it is not appropriate for our project in this topology.

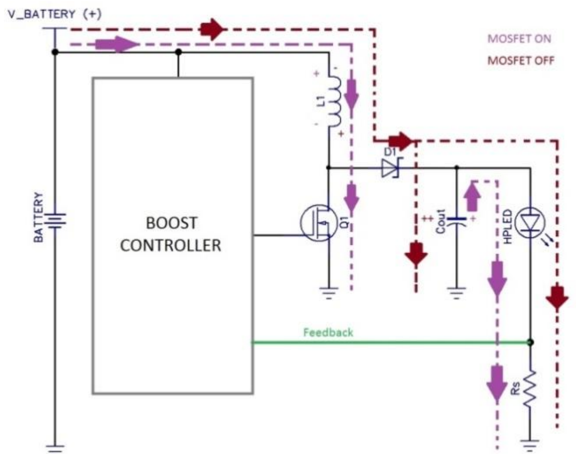

Figure 3.11 Simplified boost LED driver.

Boost-Buck Converter

Boost-Buck converter topology, first of all, involves Boost and Buck topologies. In this case, the input voltage may be less or greater than the output voltage.

The battery used in our project was, at first, around 4.2V, and it is greater than the bias voltage (2.85V) of HPLED. The voltage of the battery on load diminishes in time and drops further down when compared with HPLED bias voltage. Hence, this topology is convenient for our project. Our project was performed by using a different type of this topology, which is referred to as SEPIC Buck Boost converter. Thus, we are going to analyze this topology at full length.

SEPIC Buck-Boost Converters

The input voltage in SEPIC (Single Ended Primary Inductance Converter) topology can also be less or greater than the output voltage. The design of this topology can be made as a constant current source or a constant voltage source.

SEPIC topology has the same reference ground and the same polarity. The polarity differs in other boost buck topologies.

In the following figure (Figure 3.12), SEPIC topology is simply seen. The input and output are isolated from each other via the CS capasitor.

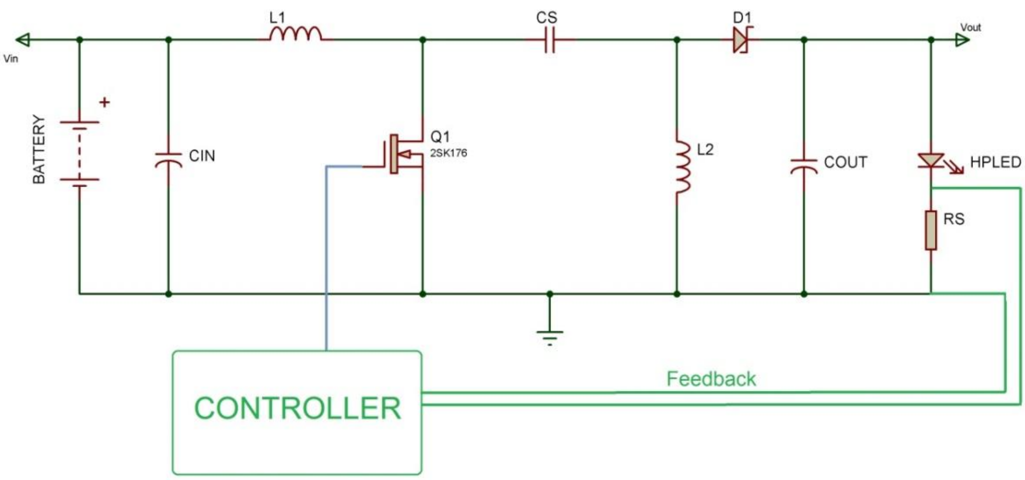

Figure 3.12 SEPIC topology

In Figure 3.13, Q1 Switch is seen to be ON (short circuit). L1 coil is charged by the input source throughout this period. The energy in the CS capasitor is loaded onto the L2 coil. The load current is provided by the output capasitor (COUT) during this time. L1 and L2 coils have no connection with the load. Since the CS capasitor does not pass the DC current, it is equal to the input voltage in the beginning.

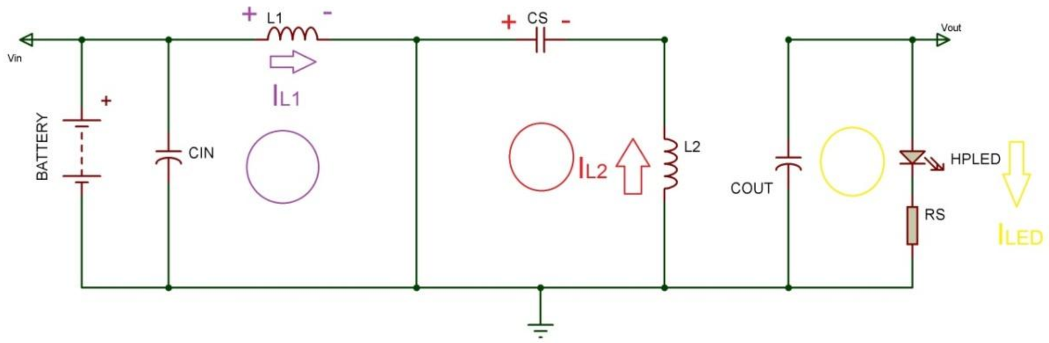

Figure 3.13 SEPIC converter current flow during Q1 on-time

In the following figure 3.14, Q1 switch is seen to be OFF (open circuit). L1 coil charges the CS capasitor. I_{L1} and I_{L2} currents, on the other hand, provide the load current.

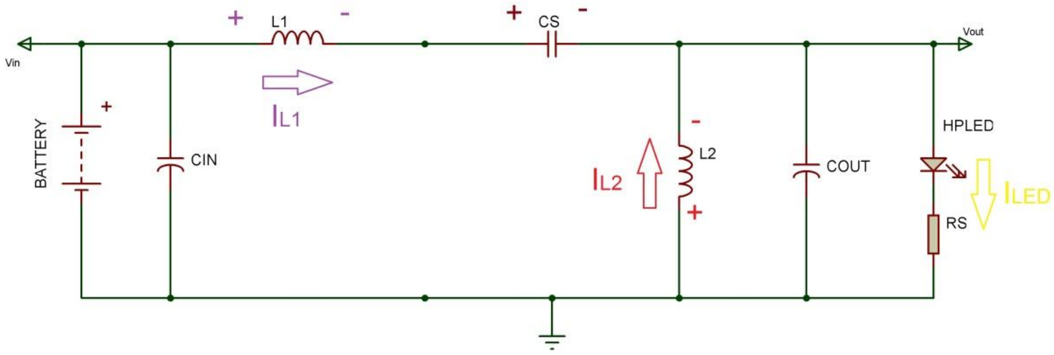

Figure 3.14 SEPIC converter current flow during Q1 off-time

3.1.3.4 Theory of Operation

Li-ion batteries have attracted attention due to their high energy density in portable applications. We also used these batteries to meet the energy requirement of our thesis project for a long time. The open voltage potential of the battery 18650 we used at full charge is 4.2V. This voltage during the discharge drops down to 2.7V.

The forward bias of the HPLEDs (V_F) we used within the scope of our project varies according to the current and the temperature. The forward bias of the HPLED can be 2.85V at the lowest and 3.15V at the highest. These values will also be the output voltage (V_{OUT}) of our LED driver circuit. The criteria we were supposed to be careful about and take into consideration at the stage of the electronic design have been shown in table 3.2.

Table 3.2 SEPIC LED driver specification

Characteristic	Symbol	Value	Unit
Input Voltage Range (V_{IN})	$V_{IN(MAX)}$	4.2	V
	$V_{IN(MIN)}$	2.7	V
Output Voltage Range (V_{OUT})	$V_{OUT(MIN)}$	2.85	V
	$V_{OUT(MAX)}$	3.15	V
Output Current Range ($I_{OUT} = I_{LED}$)	$I_{OUT(MAX)}$	770	mA
	$I_{OUT(MIN)}$	750	mA
Switching Frequency	f_{SW}	1600	KHz
Diode Forward Voltage	V_{DIODE}	0.3	V

The voltage of our battery recharged at the start (V_{IN}) is greater than the desired output voltage (V_{OUT}). In time, the battery voltage drops further down the output voltage we desire. According to these data, the most appropriate topology for our thesis project is the SEPIC Buck Boost topology that we had previously studied. In determining the LED driver circuit elements we designed with the help of SEPIC topology at the stage of the electronic design, the values shown in table 3.1 were used. The switching frequency here is related with the switching control element we had selected. The increase in the switching frequency minimizes the element sizes. Since the product of our thesis project would be portable, the tiny size of the electronic circuit was of importance for us. For this, we researched into the switching control integrated circuits (IC) used in the ready-made SEPIC topology. It followed from the studies we had conducted that the most convenient circuit for our thesis project was the integrated circuit LM3410 manufactured by the Texas Instrument Company.

SEPIC LED Driver Integrated Circuit

The integrated circuit LM3410 is the constant current LED driver integrated circuit that operates at 525KHz/1.6MHz frequencies. The switching frequency is internal, with two different models (LM3410Y, LM3410X). Our integrated circuit has an NMOS switching element with 170mOhm internal resistance that operates with a maximum current of 2.8A. The input voltage range is 2.7V and 5.5V. The output voltage range is between 3V and 24V. It has a rather lower power exertion on standby. As for the efficiency, it reaches over 80% [29].

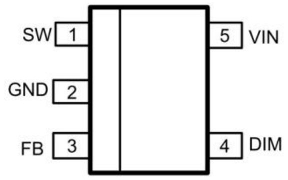

Figure 3.15 LM3410 IC connection diagram 5-Pin SOT-23 (Top) [29]

Table 3.3 LM3410 SEPIC LED driver pin descriptions [29]

Pin	Name	Function
1	SW	Output switch. Connect to the inductor, output diode.
2	GND	Signal and power ground pin. Place the bottom resistor of the feedback network as close as possible to this pin.
3	FB	Feedback pin. Connect FB to external resistor divider to set output voltage.
4	DIM	Dimming and shutdown control input. Logic high enables operation. Duty Cycle from 0 to 100%. Do not allow this pin to float or be greater than VIN + 0.3V.
5	VIN	Supply voltage pin for power stage, and input supply voltage.

The integrated circuit LM3410 has three different types of packages. We used 5-Pin SOT-23 package seen above since it has an easier assembly. In table 3.3, on the other hand, the connection pins and their functions have been shown. As for the electrically operating voltages, the VIN pin should be between 2.7V and 5.0V, the DIM pin should be between 0V and VIN, and the SW pin should be between 3V-24V. Voltage must be exerted over VIN and DIM pins without exceeding the limit of -0.5V to 7.0V in order not to cause the integrated circuit to break down. On the other hand, the FB voltage should be between 0V and 3.0V. Separately, it is required that the DIM voltage not exceed the VIN voltage more than 0.3V. The operating temperature, on the other hand, could be between -40°C and 125°C [29].

In a simpler sense, we can see the block structure of the integrated circuit in the following figure (Figure 3.16). As can also be seen from the block structure, the integrated circuit comprises an oscillator of 525KHz or 1.6Mhz. It minimizes the sizes of the capasitors and coils to be used at high frequency. Hence, the size of the circuit is minimized.

LM3410 gains control of the LED current via a current- mode control. As is seen from the block structure, our integrated circuit involves an NMOS switch [29]. Our integrated circuit regulates the LED current by using the NMOS switch. The LED current is regulated by the duty rate variable with the constant frequency.

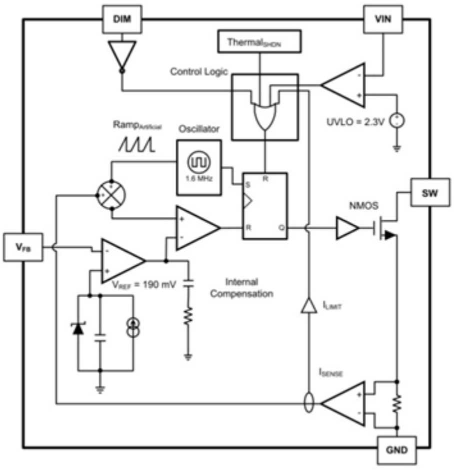

Figure 3.16 LM3410 LED driver internal block diagram [29]

As seen in figure 3.17, the voltage falling over the series resistance and the LED is benefited from in order to adjust the maximum current passing over the LED. The voltage falling over this resistor (R_S) is connected to the V_{FB} pin of our integrated circuit as the feedback.

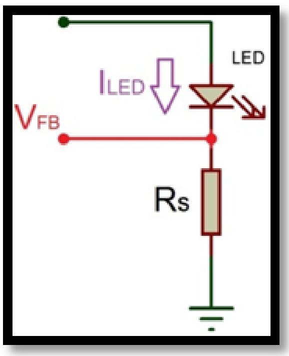

Figure 3.17 Setting LED current

According to the maximum LED current we determined, we can calculate the R_S feedback resistance with the following formula [29]:

$$I_{LED} = V_{FB} / R_S \qquad (3.5)$$

As the datasheet information, the V_{FB} is fixed 190mV.[29]. The maximum current we desired is 750mA on the average. The resistance to be used from here is found as (190/750) 0.253Ohm. The power exerted in the resistor, on the other hand, reaches approximately 0.14W.

As the result of these data, we used, in our project, the product of "Rohm Semiconductor" company, which is referred to as MCR50JZHFLR250 model, being at 250mOhm value and operating at 1/2W power with 1% tolerance.

The LED current can be changed by exerting PWM (Pulse-Width Modulation) signal on the DIM pin located within our LM3410 integrated circuit. In this way, the LED luminescence can be enhanced and reduced by changing the duty rate at the constant frequency. In our thesis project, we allow the current over the LED to change between 0 and 750mA by changing the duty rate between 0% and 100%. The PWM frequency can be selected between 1 Hz and 25KHz. The duty rate must be 100% in order to allow the LED to give off maximum light [29].

When the temperature of the integrated circuit reaches 165°C, the integrated circuit cannot perform the switching process. This is the thermal shutdown characteristic of the integrated circuit. When the temperature drops down to 150°C, the integrated circuit starts to operate again [29].

Since the circuit sizes are minimized at a high frequency, we preferred to use in our project the LM3410X integrated model that is able to perform 1.6MHz switching process.

SEPIC Design Methodology

At the stage of the electronic design, we determined our HPLED driver circuit topology, after which we selected the switching and controlling elements. Now we are going to specify the other circuit elements to be used, along with their capacity, inductance and current values.

In switching process, the duty rate is a major factor. Thus, we have got to calculate the duty rate in the first place [30]. If the duty rate proves to be more than the maximum duty rate, then the cyclic process does not take place.

$$D_{MIN} = \frac{V_{OUT}+V_{DIODE}}{V_{IN(MAX)}+V_{OUT}+V_{DIODE}} \tag{3.6}$$

$$D_{MAX} = \frac{V_{OUT}+V_{DIODE}}{V_{IN(MIN)}+V_{OUT}+V_{DIODE}} \tag{3.7}$$

The minimum value of our input voltage ($V_{IN(MIN)}$) is 2.7V, while the maximum value ($V_{IN(MAX)}$) is 4.2V. As for the outlet voltage, we selected the maximum value, 3.15V, as the worst mode. The reverse bias of the diode we are going to use within the circuit must be more than the maximum sum of the input and output voltages. The diode current, on the other hand, must be compatible with the maximum output current. In other words, the diode used in our thesis project must be able to withstand (4.2+3.15) 7.35V reverse bias and 0.8A current. In accordance with these values, we used the diode numbered DFLS120L-7 model by Diodes Incorporated Company. Its reverse bias is 20V, and it can withstand a 1A current. The forward bias (V_{DIODE}) was taken as 0.3V by referring to its datasheet. The maximum and minimum duty rate can be calculated along with this value.

$D_{MIN} = \frac{3.15+0.3}{4.2+3.15+0.3} = 0.45$ and,

$D_{MAX} = \frac{3.15+0.3}{2.7+3.15+0.3} = 0.56$ is found.

In order to find the coil value used in our electronic circuit:

The coil value to be used within the circuit determines the current fluctuation. As the coil value increases, the current fluctuation decreases. However, the increase in the coil value maximizes the size of the coil hence, the size of the circuit to be created. Separately, minimizing the current wave far too much weakens the control signal. The fact that this current fluctuation level is between 40% or 20% of the maximum current provides the best results [31]. We have to find the current fluctuation within the coil (ΔI_L) before finding the coil value.

$$\Delta \mathrm{I}_L = I_{IN} \times \%40 = I_{OUT} \times \frac{V_{OUT}}{V_{IN(MIN)}} \times \%40 \tag{3.8}$$

$\Delta \mathrm{I}_L = 0.76 \times \frac{3.15}{2.7} \times \%40 = 0.354A$ is found.

$$L_1 = L_2 \geq \frac{V_{IN(MIN)}}{\Delta \mathrm{I}_L \times f_{sw}} \times D_{MAX} \tag{3.9}$$

$L_1 = L_2 \geq \frac{2.7}{0.354 \times 1600000} \times 0.56 \cong 2.66\mu H$ is found.

One of the important factors in selecting the coils is the peak currents within the coils.

$$I_{L1(PEAK)} = I_{OUT} \times \frac{V_{OUT}+V_{DIODE}}{V_{IN(MIN)}} \times (1 + \frac{\alpha}{2}) \tag{3.10}$$

$I_{L1(PEAK)} = 0.76 \times \frac{3.15+0.3}{2.7} \times (1 + \frac{\%40}{2}) \cong 1.1A$ is found.

$$I_{L2(PEAK)} = I_{OUT} \times (1 + \frac{\%40}{2}) \tag{3.11}$$

$I_{L2(PEAK)} = 0.76 \times 1.2 \cong 0.912\ A$ is found.

To use a coil in our thesis project in the way that it would meet all these properties, we selected the coil coded DR73-4R7-R with the inductance value of 4.7uH and a current value of 3.09A, manufactured by Eaton Bussmann Company.

To find out the value of the coupling capacitor:

Selecting a small or a large coupling capasitor makes the circuit become unstable. The coupling capasitor value is selected according to the voltage change over this capasitor. The change in the coupling capasitor must be between 2% and 5% of the minimum value of the input voltage. A ceramic or a tantalum capasitor with the minimum ESR resistance should be used [30-31].

$$C_S > \frac{I_{OUTmax} \times D_{MAX}}{0.05 \times V_{IN(MIN)} \times f_{sw}} \tag{3.12}$$

$C_S > \frac{0,76 \times 0,56}{0,05 \times 2,7 \times 1600000} \cong 2\mu F$ is found.

$$I_{CS(RMS)} = I_{OUT} \times \sqrt{\frac{V_{OUT}+V_{DIODE}}{V_{IN(MIN)}}} \tag{3.13}$$

$I_{CS(RMS)} = 0,76 \times \sqrt{\frac{3,15+0,3}{2,7}} \cong 0,86A$ is found.

$$ESR_{CS} < \frac{0,01 \times V_{IN(MIN)}}{I_{L1(PEAK)}} \tag{3.14}$$

$ESR_{CS} < \frac{0,01 \times 2,7}{1,1} \cong 0,024\ Ohm$ is found.

In the light of these data, we selected the product of TDK Corporation Company, which is coded C2012X5R1E225K125AC with the value of 2.2uF capacity. The ESR value of this capasitor is less than 0.01 Ohm at 1MHz.

For the MOSFET of the LM3410 integrated circuit:

$$I_{LM3410(PEAK)} = I_{L1(PEAK)} + I_{L2(PEAK)} \tag{3.15}$$

$I_{LM3410(PEAK)} = 1{,}1 + 0{,}9 \cong 2$ A is found.

$$I_{LM3410(RMS)} = I_{OUT} \times \sqrt{\frac{(V_{OUT}+V_{IN(MIN)}+V_{DIODE})\times(V_{OUT}+V_{DIODE})}{(V_{IN(MIN)})^2}} \quad (3.16)$$

$I_{LM3410(RMS)} = 0{,}76 \times \sqrt{\frac{(3{,}15+2{,}7+0{,}3)\times 3{,}15+0{,}3)}{(2{,}7)^2}} \cong 1{,}29A$ is found.

Since the current value does not exceed 2.8A, it appears to be appropriate.

For the Output Capasitor:

It can be considered normal when the fluctuation voltage is 2% of the output voltage. [31]. In other words, the V_{ripple} value can be taken as 0,063.

$$C_{OUT} > \frac{I_{OUTmax}\times D_{MAX}}{0.5\times V_{ripple}\times f_{sw}} \quad (3.17)$$

$C_{OUT} > \frac{0{,}76\times 0{,}56}{0.5\times 0{,}063\times 1600000} \cong 8{,}45\ \mu F$ is found.

$$ESR_{OUT} < \frac{0{,}5\times V_{ripple}}{I_{L1(PEAK)}+I_{L2(PEAK)}} \quad (3.18)$$

$ESR_{OUT} < \frac{0{,}5\times 0{,}063}{1{,}1+0{,}912} \cong 15{,}6\ mOhm$ is found.

The product coded CL31B226KPHNNNE manufactured by Samsung Electro-Mechanics America Inc. Company was used. This capasitor has a value of 22uF capacity and 5mOhm ESR. One of these capasitors was also used as the input capasitor in the same way. In this way, we have determined the values of the elements to be used in our SEPIC topology design.

3.1.3.5 Microcontroller

In order to provide the interaction with the interface in our thesis project, the 8-bit flash-based 12HV752 model microcontroller by the Microchip company was used. This microcontroller has an internal oscillator that can be selected through the software (8MHz,4MHz,1MHz or 31KHz). With 8 pieces of pins, this microcontroller can operate at a range of 2.0V- 5.0V. It has a memory of 1024x14 bit. With a 5- bit I/O pin, the microcontroller has peripheral features, such as 10-bit ADC, 5-bit DAC, timer, capture, compare, and a PWM (CCP) module [32]. In our thesis project, we use the PWM module from among these peripheral features. The major reasons determining the use of the microcontroller in our thesis project have been the minimum power consumption, the number of pins, the PWM module and the price.

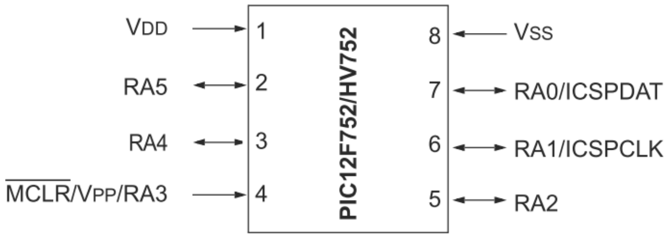

Figure 3.18 PIC12F752/HV752, 8-pin diagram [32]

3.1.3.6 Schematic Design

In our thesis project, two different circuits were created as the printed circuit board. The first circuit was designed for the LED driver circuit, whereas the second one was designed for the purpose of creating an interface along with the battery. From now on, I will name the first circuit as the LED Driver circuit and the second one as the battery interface circuit. The microcontroller and the interface connection common within these two circuits provide resilience during the design.

LED DRIVER CIRCUIT SCHEMATIC

We created the LED driver design through the SEPIC topology we had specified unique to the HPLED and the battery to be used. For the control and the management of this design, on the other hand, LM3410 IC was used.

In the following figure (Figure 3.19), the HPLED driver circuit schematic is seen. Those seen as U1 and U2 are the LM3410 integrated circuits, as seen in our material list in table 3.14. The reason why two pieces were used is that two casings of different structures (5-pin SOT-23 and 6 –pin WSON) could be used at the same time. WSON casing was used due to the consideration that it was appropriate for mass production. The manual assembly and solder of this casing is rather difficult, therefore, we used the structure with SOT-23 casing for the experimental and testing stages.

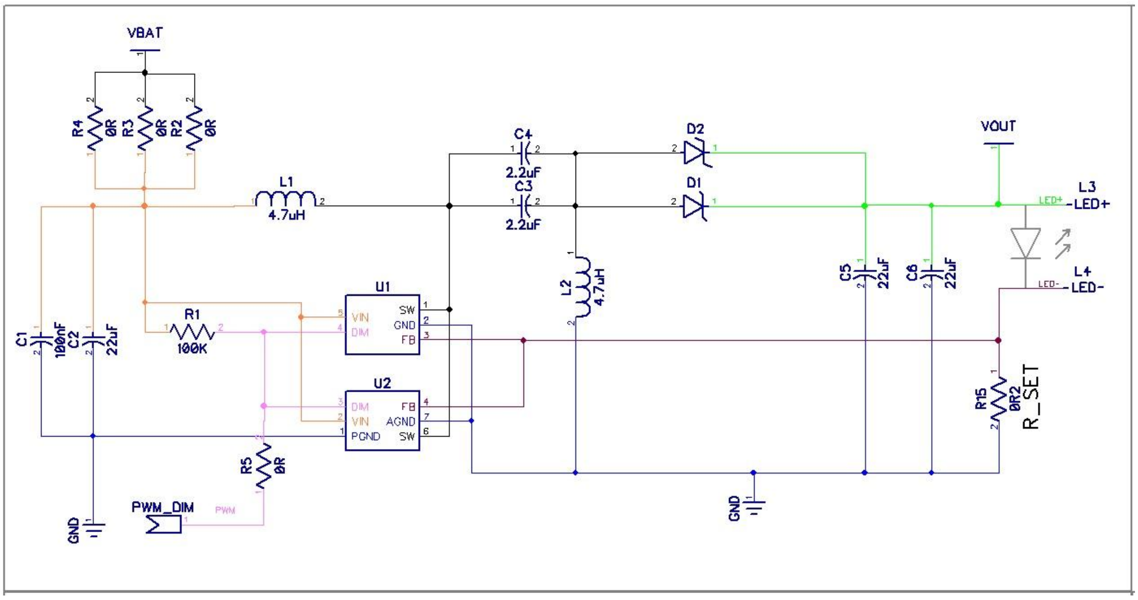

Figure 3.19 HPLED driver schematic

The LED current is controlled by PWM signal and DIM pin. The LED luminescence can be enhanced and reduced by changing the duty rate between 0% and 100%. When the duty rate is 100%, the LED current is at its maximum. We performed a pull-up by means of R1 resistance in order to be able to exert a PWM signal on the DIM pin.

We used R2, R3 and R4 shunt resistances to isolate the LED driver circuit supply from the other circuit structure. In this way, testing the LED driver circuit was easier and more reliable. Moreover, this process became functional in preventing the LED driver circuit from being affected while performing the microcontroller programming. Thus, it allowed us to perform the tests and experiments easily during the program editing process.

We also used it to be able to deactivate R5 shunt resistance and PWM signal. The R5 shunt resistor made it easier for me to be able to use the signal generator. It became useful during the tests and experiments I performed with the LED driver circuit.

R1 resistance is the feedback resistance (R_S). As seen in table 3.4, we used the resistor of Rohm Semiconductor Company, which was numbered MCR50JZHFLR250 model with 0.25Ohm, 0.5W and 1% tolerance along with a 2010 (5025 Metric) packet form [35]. In this way, the LED current was restricted and allowed to be at a maximum of 0.76A.

We used the C1 capasitor to prevent the supply input of the integrated circuit from power fluctuations by placing it in the input section of LM3410 integrated circuit.

C2 capasitor is the input capasitor (CIN) that has to be used in SEPIC topology. A larger capasitor with a lower ESR value that is greater than 10V with the value of 22uF can be used. For this process, a tantalum capasitor with a lower ESR value and a high AC ripple current value can also be selected.

C3 and C4 are coupling (CS) capasitors. A ceramic capasitor with 2.2uF value or two ceramic capasitors with 1.5uF value can be used. We used the product of TDK Corporation Company coded as C2012X5R1E225K125AC with 10% tolerance in 2.2uF (25V), 0805/ (2012 Metric) packet [34]. One of the reasons why we used two pieces in the schematic was to see the change taking place in the course of the experiments and tests by using them in parallel to each other.

C5 and C6 are output capasitors (C_{OUT}). The ESR value of the output capasitor must be lower than 15.6mOhm, while its capacity value must be greater than 10uF (10V). The ESR value is minimized by connecting the two capasitors in parallel to each other. We used the product coded CL31B226KPHNNNE manufactured by Samsung Electro-Mechanics America Inc. Company, with the value of 22uF (10V) and 10% tolerance along with X7R temperature characteristic within 1206/(3216 Metric) packet [33].

L1 and L2 coils were used to restrict the current fluctuation. As we had calculated beforehand, the coil value must be greater than 2.66uH, whereas the current value must be more than 1.1A. By taking these points into consideration, the coil of Eaton Bussmann Company which was coded DR73-4R7-R with 4.7uH inductance and 3.09A RMS current value was used, as will be seen in table 3.4. The coil tolerance was 20%, with a value of 28 mOhm DCR .

D1 and D2 diodes within our circuit have the same function. One of these diodes can be used in the process. We used it in this way so as to be able to try diodes with different types of casing. The diode mentioned should be schottky diode. As is seen in the materials list, we used the diode of Diodes Inc. Company, coded DFLS120L, in our thesis project. Separately, the diode coded PMEG3020EP manufactured by NXP Semiconductors Company can also be used as an alternative to higher currents. The less the forward voltage drop of the diode, the better it will be.

We added two pads as LED+ and LED-, thanks to which a connection to the LED with two cables can be made.

The connection of the microcontroller to PWM is made via PWM_DIM connector.

We added a pad into our circuit to be able to make power connections within the schematic circuit seen in figure 3.20. Positive (+) with P1 and V_{BAT} pads and ground (-) with G1,G2,G3,G4 and G5 pads can be used for power connections. We used C7 in the lower part of the printed circuit. This capacity can be used as an alternative input capacity within our circuit.

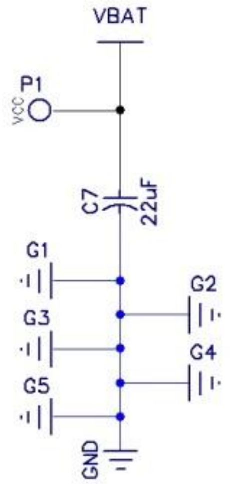

Figure 3.20 Power connection

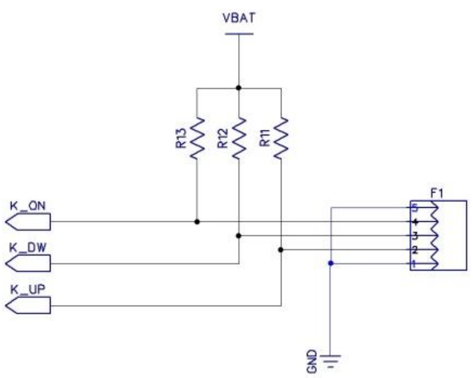

Figure 3.21 Light control interface schematic

In figure 3.21, the connection schematic for the interface used for HPLED light control is seen. The element seen with the reference code F1 is the flat flex type surface mount connector with 1mm pin pitch. With this connector is a membrane switch connection made. In order to turn the connector upside down, 1st and 5th pins of F1 connector were connected to the ground (GND). It was used to pull-up the buttons connected to the connector through R11, R12 and R3 resistors. K_ON, K_DW and K_UP pin connection is made to the microcontroller. These pins are constantly controlled in the microcontroller, and whether or not the buttons are pushed is controlled in this respect. Unless the button is pushed, the microcontroller performs the reading as logic 1 (high). When the button is pushed, the reading is done in the form of logic 0 (Low).

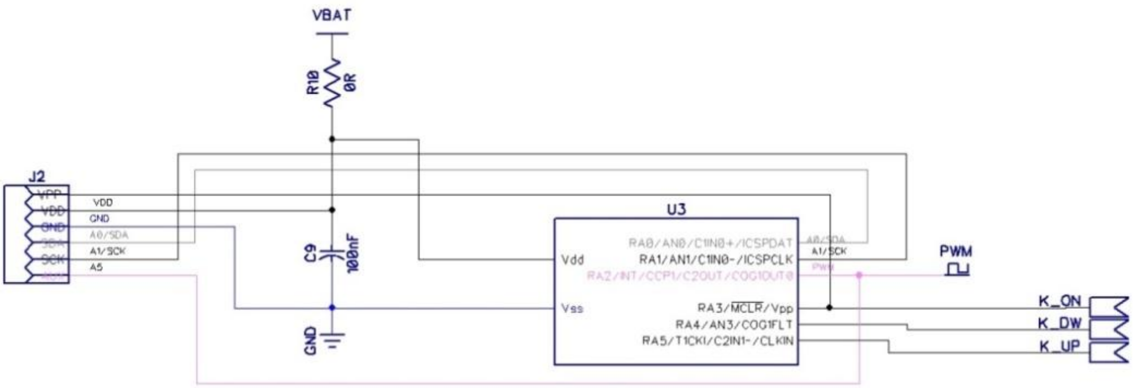

Figure 3.22 Microcontroller and programmer interface

In figure 3.22, the microcontroller and the schematic structure used in the programming of microcontroller can be seen. U3 integration is a PIC12HV752 microcontroller with 8 pins and a SOIC-8 casing. The microcontroller was used for the purpose of maximizing and minimizing the LED light through PWM signal and to perform the button control that is the user interface.

R10 was placed to cut the shunt resistance and battery energy.

C9 capasitor was added to prevent the microcontroller from being affected by power fluctuations.

It is the interface for microcontroller programming through J2 connector. Once our program has been written and compiled, it is converted into a hex code. This hex code is written within the microcontroller via our Pickit 3 programmer connected through J2 connector.

Table 3.4 LED driver circuit bill of materials

Index	Reference Design	Digikey Part Number	Description	Manufacturer Part Number	Quentity
1	U1	LM3410XMF/NOPBCT-ND	IC DRVR WT/OLED BCKLT SOT23-5	LM3410XMF/NOPB	1
2	U2*	LM3410XSD/NOPBCT-ND	IC LED DRVR WT/OLED BCKLGT 6WSON	LM3410XSD/NOPB	0
3	U3	PIC12F752T-I/SN-ND	IC MCU 8BIT 1.75KB FLASH 8SOIC	PIC12F752T-I/SN	1
4	C1,C9	399-1171-1-ND	CAP CER 0.1UF 50V 5% X7R 0805	C0805C104J5RACTU	2
5	C2,C6,C7	1276-2769-1-ND	CAP CER 22UF 10V 10% X7R 1206	CL31B226KPHNNNE	3
6	C3,C4**	445-7629-1-ND	CAP CER 2.2UF 25V 10% X5R 0805	C2012X5R1E225K125AC	1
7	L1,L2	513-1133-1-ND	FIXED IND 4.7UH 3.09A 29.7 MOHM	DR73-4R7-R	2
8	D1	DFLS120LDICT-ND	DIODE SCHOTTKY 20V 1A POWERDI123	DFLS120L-7	1
9	D2***	568-7402-1-ND	DIODE SCHOTTKY 30V 2A SOD128	PMEG3020EP,115	0
10	R1	P100KCCT-ND	RES 100K OHM 1/8W 1% 0805 SMD	ERJ-6ENF1003V	1
11	R2,R3,R4,R5,R10	P0.0ACT-ND	RES 0.0 OHM 1/8W JUMP 0805 SMD	ERJ-6GEY0R00V	5
12	R11,R12,R13	P10.0KCCT-ND	RES 10K OHM 1/8W 1% 0805 SMD	ERJ-6ENF1002V	3
13	R15	RHM.25UCT-ND	RES 0.25 OHM 1/2W 1% 2010 SMD	MCR50JZHFLR250	1
14	F1	A101415CT-ND	CONN FPC/ZIF 5POS 1MM VERT SMD	1734248-5	1
* U1 is the equivalent of the U2. If you use U1, you should not use U2.					
** C3 and C4 may be used as 1.5uf or only C3 may be used as 2.2uF.					
*** D1 is the equivalent of the D2.					

BATTERY INTERFACE SCHEMATIC

The schematic we used for our battery interface is as seen in figure 3.23. We tried to create resiliency within this system where we used the parts (B) and (C) additionally. In this way, it became possible for us to utilize our system in both ways. If we use the microcontroller within this card, then we also need to use the control interface in this card. During the experiments and tests, we determined that using the microcontroller and the control interface in this card would be more convenient in terms of positioning. We operated the system by making connections to the LED driver with three cables.

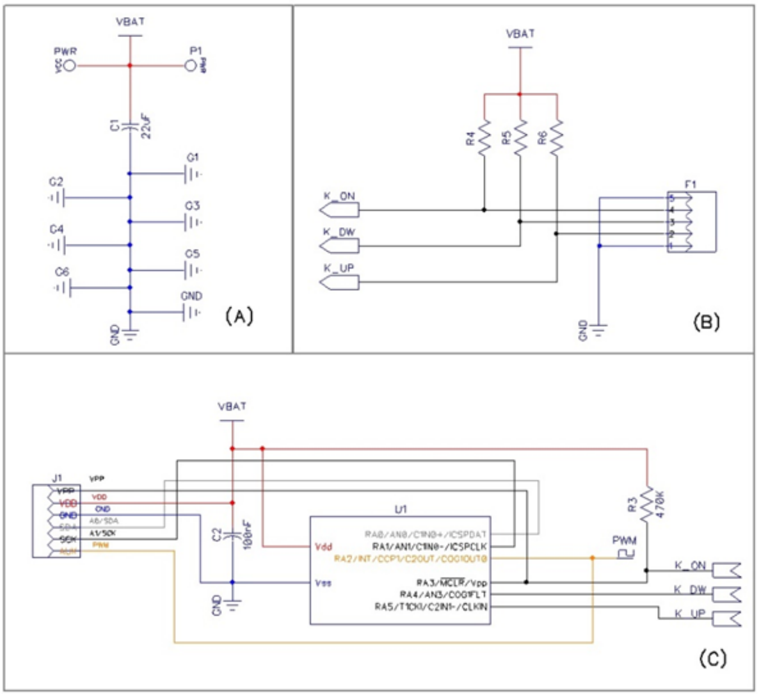

Figure 3.23 Battery interface schematic

Since the elements used in the battery interface circuit seen above are common with the LED driver circuit, there is no need to go into detail in this respect. The main reason for performing this circuit was to allow the battery to get connected to the circuit via a spring.

Table 3.5 Battery interface bill of materials

Index	Reference Design	Digikey Part Number	Description	Manufacturer Part Number	Quentity
1	U1	PIC12F752T-I/SN-ND	IC MCU 8BIT 1.75KB FLASH 8SOIC	PIC12F752T-I/SN	1
2	C1	1276-2769-1-ND	CAP CER 22UF 10V 10% X7R 1206	CL31B226KPHNNNE	1
3	C2	399-1171-1-ND	CAP CER 0.1UF 50V 5% X7R 0805	C0805C104J5RACTU	1
5	R4,R5,R6	P10.0KCCT-ND	RES 10K OHM 1/8W 1% 0805 SMD	ERJ-6ENF1002V	3
6	F1	A101415CT-ND	CONN FPC/ZIF 5POS 1MM VERT SMD	1734248-5	1

3.1.3.7 Layout Design

LED DRIVER LAYOUT DESIGN

LED driver printed circuit had a double-layered design, and the samples were performed. Our printed circuit board sample was manufactured by using an FR-4 material. There is also a material lay-out on double sides. The copper thickness in our printed circuit board sample is 35u/35u. The printed circuit board thickness (PCB thickness) was performed as 1.6mm. Our printed circuit card has a diameter of 30mm in the form of a circle. The solder mask colour is green, and the silk screen colour is white.

In figure 3.24, the design of the LED driver printed circuit card is seen. First of all, we made a lay-out of the elements in designing the printed circuit card. We placed the circuit elements as close as possible to one another. The FB(feedback) pin of LM3410 integration (U1,U2) has a high impedance. We formed the route from the FB pin to the R15 resistor quite short so as to prevent noise interaction, noise occurrence and false regulation. The lower part of LM3410 integration in the Bottom Layer was made as GND. A via was placed at the bottom layer to be able to minimize the temperature of the U2 integration. Thanks to these vias, we aimed to minimize the temperature by performing copper melding at the bottom side. We placed the microcontrollers and connectors at the bottom layer, which proved to be effective in minimizing the printed circuit.

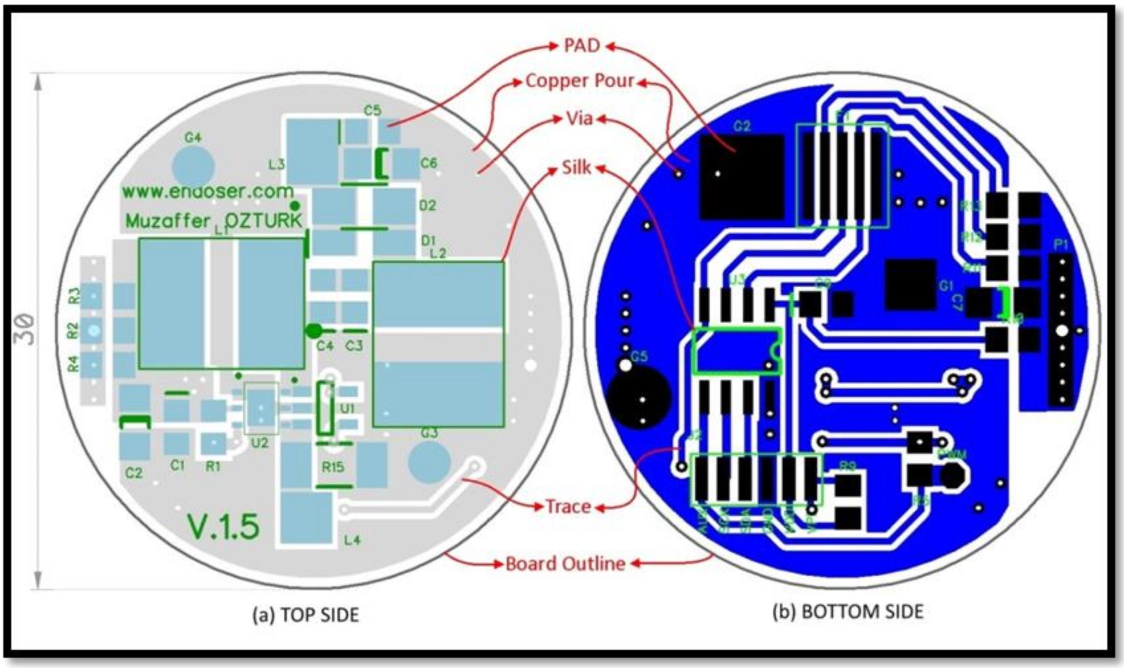

Figure 3.24 LED driver layout design (a) Top side (b) Bottom side

In figure 3.25, our printed circuit, the sample of which was produced, is seen. In the figure, LED connection points and “BATTERY INTERFACE” card along with the connection points are shown. These connections are made via cables.

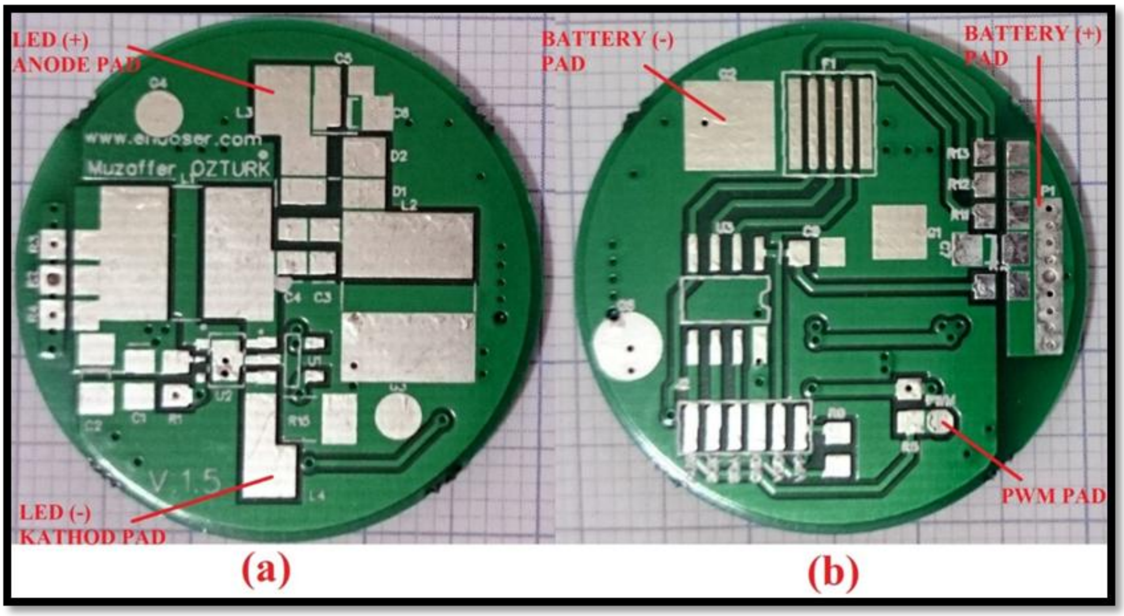

Figure 3.25 LED driver printed circuit board picture (a) Top side (b) Bottom side

BATTERY INTERFACE LAYOUT DESIGN

The battery interface printed circuit was created by using an FR-4 material in double-layered form. There is a material layout on the top side and only a spring at the bottom. Our printed circuit card is in the form of a circle with 20mm-diameter.

In figure 3.26, the design of a battery interface printed circuit card is seen. We first specified the material layout in the design of this card, as well. As can be seen from the bottom side of the card, two pieces of pads have covered the bottom side of the printed circuit board. Here, the positive (+) voltage of the battery is connected to the pad in the middle by means of a spring. The negative (-) voltage of the battery, on the other hand, is connected to the outer casing made of aluminium and to the other outer pad. The pads and vias over the board outline, half of which have remained outside, were used for this connection.

The connection with the LED driver card is performed via three cables (VBAT,GND and PWM). Unless we use the microcontroller in this card, none of the materials are used within this card, and then the connection is provided with the LED driver card through two cables (VBAT, GND).

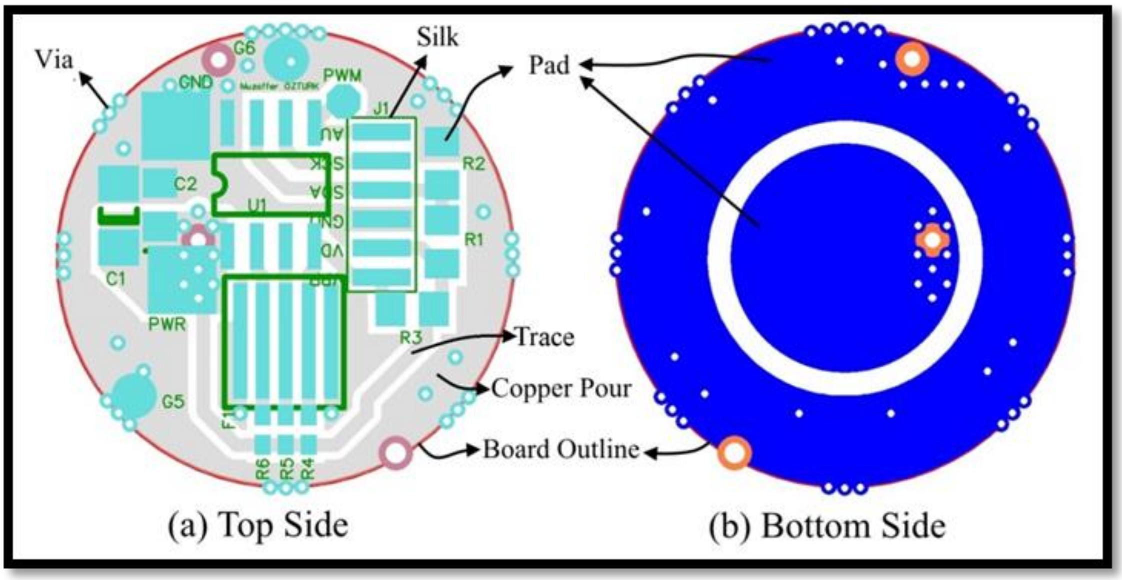

Figure 3.26 Battery interface (a) Top side (b) Bottom side

In figure 3.27, a battery interface circuit, the printed circuit sample of which (PCB) was produced, is seen. When we use the microcontroller (U1) over this card, we should also use the materials, C1,C2, R4, R5, R6 and F1.

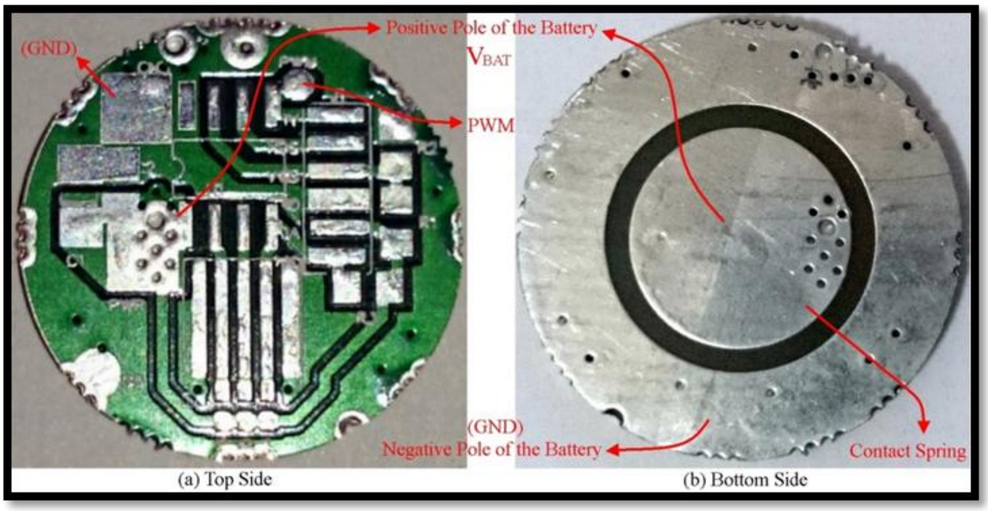

Figure 3.27 Battery interface picture (a) Top side (b) Bottom side

3.1.4 The Mechanical Design of the System

In our thesis project, we performed a line drawing (two-dimensional drawing) at the stage of the mechanical design of the system by taking into consideration the materials to be used for this process. The factors we paid attention to during the design drawing process were as follows: The size of the battery to be used, light density control interface (membrane switch), button connection point, telescope connection, LED cooling, and the compatibility of LED with the telescope connection.

In figure 3.28, the line drawing of the system design is seen. In this figure, all the parts within the design are termed and shown in that way. As for the dimensions; they have 121mm length and 38.5mm- diameter.

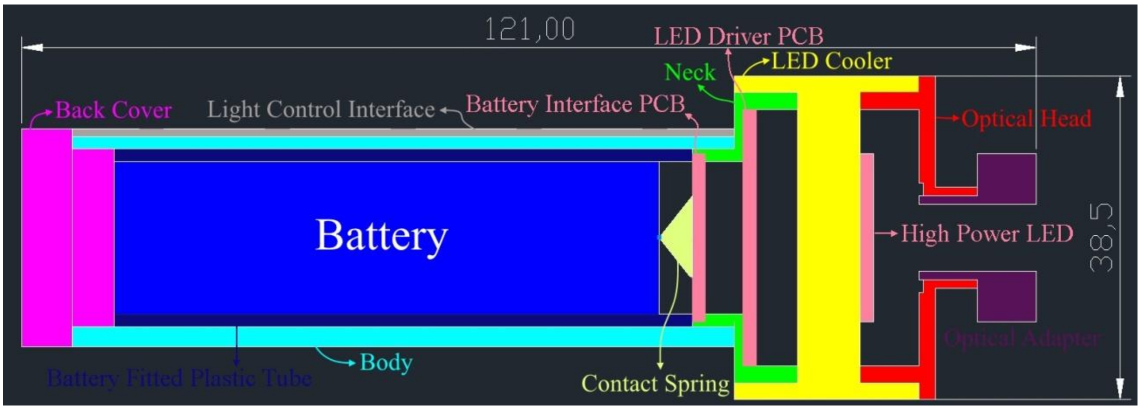

Figure 3.28 Two-dimensional (2D) mechanical design

The battery interface PCB, LED driver PCB, high power LED PCB, contact spring and battery comprise the electronic hardware parts of our system. The mechanical and electronic pieces of these parts were described in detail in the previous chapters. In our mechanical system, the endoscopy telescope is connected with an optical adapter piece. The optical lens placed in the light post section of the endoscopic telescope is positioned right in front of HPLED. The proximity of HPLED to the light post enhances the entry of light into the fibers within the telescope. We did not apply a lens since the loss of light was less when these two were proximate to each other (1mm-2mm). The light intensity was determined to have increased once the transparent layer over HPLED was removed. Yet, HPLED may break down while removing this layer.

We shall separately analyze the parts comprising the mechanical system of our project.

3.1.4.1 Light Control Interface

To be able to control the light intensity, the membrane switch with three buttons seen in figure 3.29 (a) was used. The bottom surface is adhesive and is used by sticking it to the body of the design. The surface where the membrane is to be fixed should be smooth and clean. The button connection to the (F1) FPC connector located in the battery interface printed circuit board is made by entering a thin space in the neck seen in the mechanical design.

We used two common points (GND) at the beginning and at the end in order to provide convenience at the stage of the design. Thus, we allowed the button connections to be of a more flexible quality. This structure has been quite beneficial in the connector changes applied.

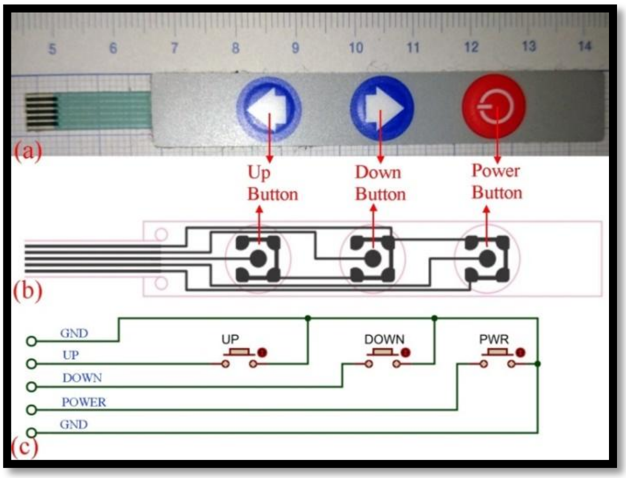

Figure 3.29 Light control interface (a) Picture (b) Circuit design (c) Schematic

Some of the reasons why we used the membrane switch in our project are that it is a long-lasting material; it is not affected by water, humidity or dust, it has a simple and useful assembly; it is thin enough and cost-effective, as well. The embossed quality of the membrane switch boosts the feeling of touching the keys.

3.1.4.2 Back Cover

In figure 3.30, the side view, front view, 3D and the image of the back cover is seen. The cathode (negative pole) of the battery contacts the mid-section of the back cover. It is required that the ground (GND) be in connection with the battery interface printed circuit board (PCB) in order for the cycle to be completed in our electronic system. The aluminium cover is connected with the body and the mechanical neck. The mechanical neck and the battery interface card becomes electrically short-circuit and completes the cycle thanks to the semi-vias on the side.

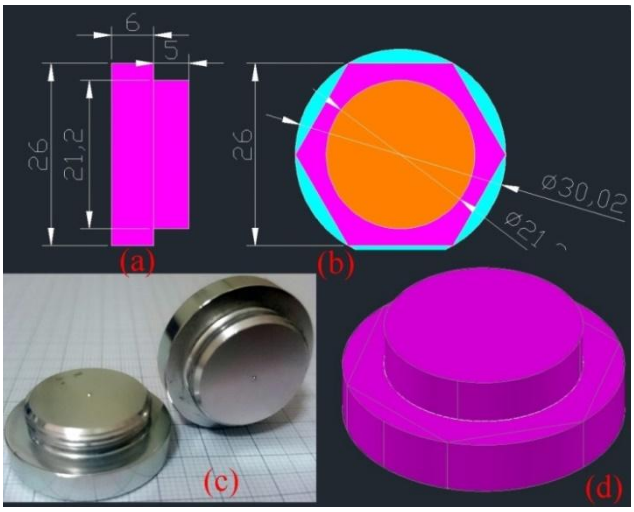

Figure 3.30 Back cover (a) Side view (b) Front view (c) Picture (d) 3D view

The back cover is mounted on the body part with the cog that opens up on it. We also considered the back cover to get integrated with the body by making the outer diameter hexagonal however, this process could not be performed due to the reasons resulting from manufacture.

3.1.4.3 Mechanical Body

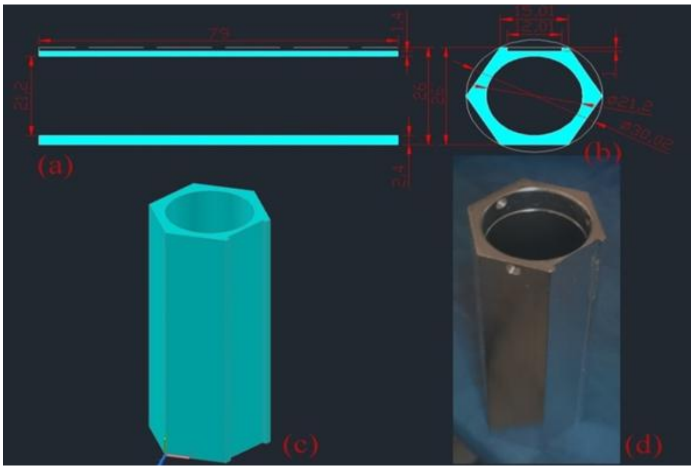

Figure 3.31 Mechanical Body (a) Side view (b) Front view (c) 3D view (d) Picture

In our thesis project, we designed the body of our mechanical system in hexagonal form as seen in figure 3.31. The reason for this was to create a smooth and useful platform for the membrane switch. The place where the membrane switch would be placed was made as deep as its own thickness. Thus, when the membrane switch is attached, the body appears to be compact. The body is connected with the back cover and the neck. The body and neck connection is performed by using three pieces of metric-3 screws.

3.1.4.4 Battery Fitted Plastic Tube

The plastic tube seen in figure 3.32 was used in order to prevent the battery from swinging within the body. The fact that this part was made of aluminium became useful since it would increase the weight of the device. Separately, by preventing the battery body from getting in contact with the mechanical body, the leakage currents are avoided. The mechanical system is placed within the body. It was bought as ready-made and was used in our project.

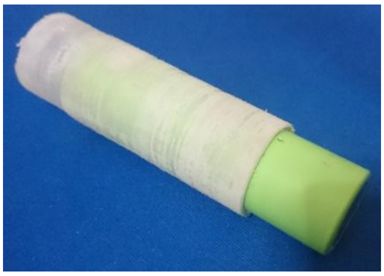

Figure 3.32 Battery fitted plastic tube

3.1.4.5 Mechanical Neck

In the following figure (Figure 3.33), the mechanical neck used in our mechanical system is seen. The battery interface printed circuit board (PCB) and LED driver printed circuit board (PCB) are placed onto this piece. The FFC cable belonging to the membrane switch makes a connection with the help of a connector (F1).by entering from the space within this piece.

The battery interface printed circuit card is mounted within the area which makes 20mm-diameter of the mechanical neck piece by getting compressed through the solder. The mechanical neck and the battery interface card must be electrically in transmission. This transmission can easily be performed thanks to the semi-vias and pads on the side of the battery interface printed circuit. On the other side of the mechanical neck piece, a LED driver printed circuit is placed on the area with 30.5mm diameter.

The mechanical neck section is linked with the mechanical body and LED cooling cores. Both connections are made via 3 pieces of metric three screws.

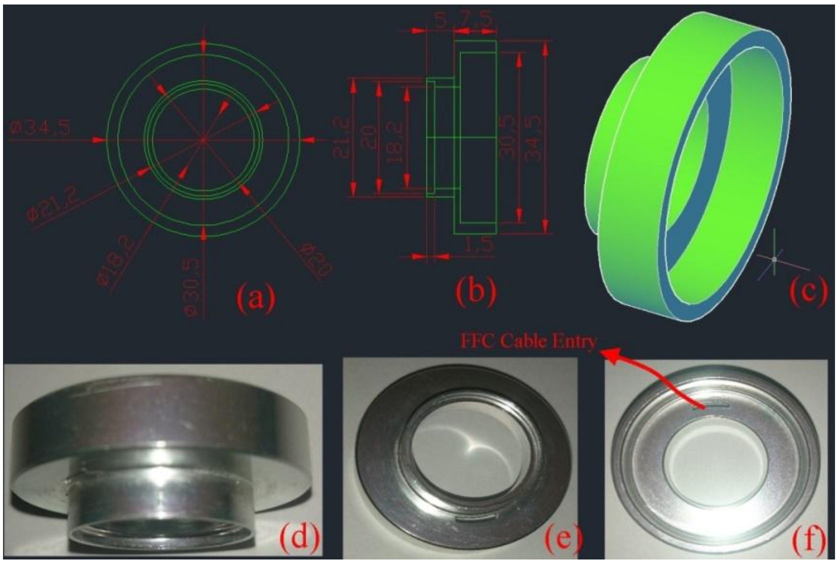

Figure 3.33 Mechanical neck (a) Front view (b) Side view (c) 3D view (d) Side picture (e) Back view (f) Front view

3.1.4.6 LED Cooler

In the following figure (Figure 3.34), LED cooling core comprising the mechanical system of our thesis project is seen. A thermally conductive double-sided tape is fixed on the bottom aluminium part of HPLED (with the stellate (star-shaped) printed circuit with an aluminium bottom part), and then it is mounted on the LED cooling core with a screw. A thermally conductive paste can also be used instead of a double-sided tape. The high power LED warming up in this way is cooled through our LED cooling core. During the initial trials, the temperature of the LED cooling core was far too much. For this reason, two cogs with a depth of 7.5mm were opened up on the LED cooling core to allow for a better cooling process. Along with these opened cogs, the surface area was expanded to allow for a better cooling process and became effective in minimizing the temperature.

There are six metric three screw connections in the mechanical LED cooling core. Four of these are used for getting fixed on the HPLED cooler, while two of them are used for the cable connection. The power connection cables of HPLED pass from the holes on the mechanical LED cooling core to the other side and are then connected to the LED driver printed circuit card.

Our LED cooling mechanical core is mounted with the help of a mechanical neck (with three pieces of metric-3screws) and an optical head (with the cog).

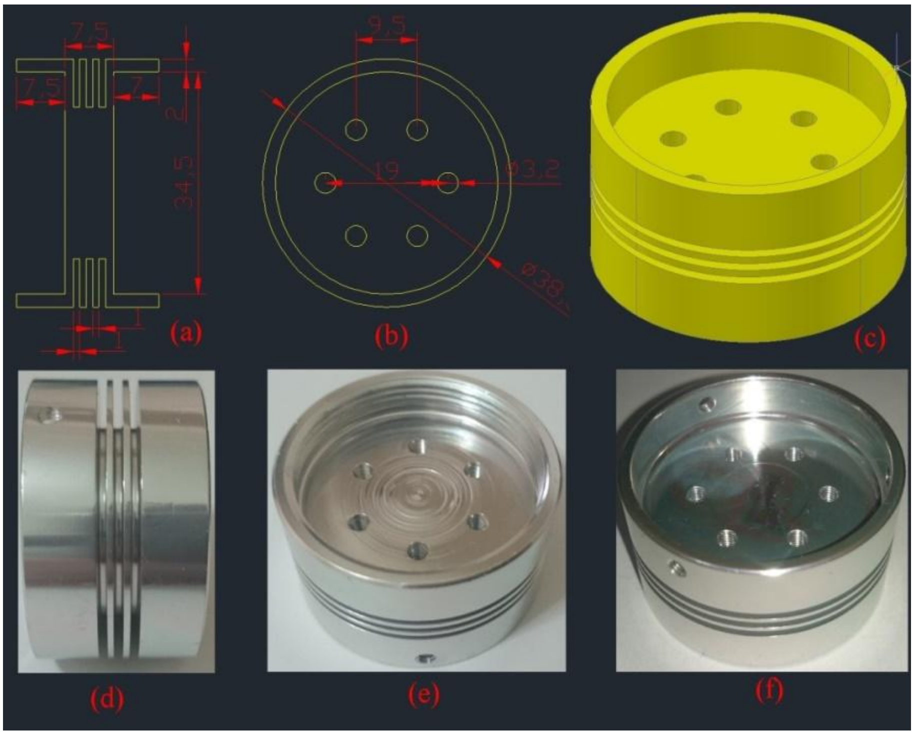

Figure 3.34 LED Cooler (a) Side view (b) Top view (c) 3D view (d) Side picture view (e) Top picture view (f) Bottom picture view

3.1.4.7 Optical Head

Our optical head piece that comprises the mechanical system of our thesis project is seen in figure 3.35. With the help of this mechanical piece, the necessary distance between the LED and the telescope is created. The closer the HPLED to the light input lens of the endoscopic telescope, the better results can be achieved. Hence, we devised this mechanical piece in order to adjust the necessary distance and to be able to make the telescope connection.

The optical head is mechanically connected to the cog and the LED cooler. It is integrated with the optical adapter piece from the other side.

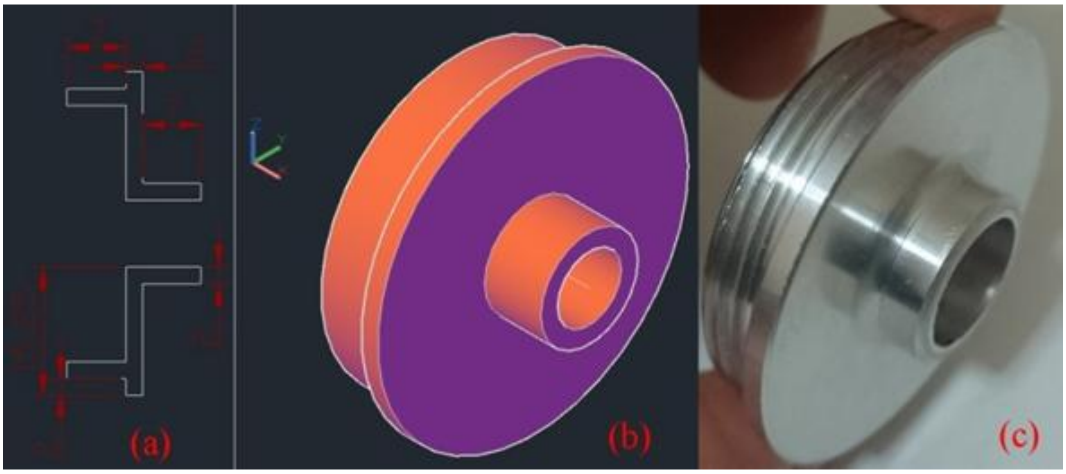

Figure 3.35 Optical Head (a) Side view (b) 3D view (c) Picture

3.1.4.8 Optical Adapter

A part of the mechanical system, the optical adapter piece can be seen in the following figure (Figure 3.36). This piece integrates with the optical head by means of a shinplaster. It can easily rotate around itself. In this way, the connection with the endoscopic telescope is made merely by compressing this piece without even overturning the whole device. The cog in the inner part of the optical adapter provides connection with the endoscopic telescope.

The notches on the diamond embossed section on the outer surface of our optical adapter were made for the purpose of rotating the piece manually and easily. This material was made of hard steel.

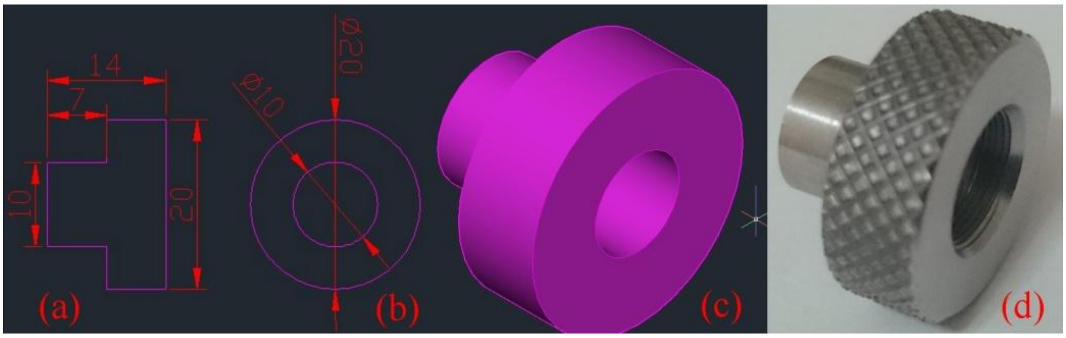

Figure 3.36 Optical adapter (a) Side view (b) Front viev (c) 3D view (c) Picture

3.2 The Software Configuration of the System

Through the software within the microcontroller, we check the HPLED light intensity by using the membrane buttons. We have three pieces of buttons, one for switching the device on/off (standby) and the other two for minimizing and maximizing the intensity of light.

We need to program the microcontroller in order to get the desired reactions. We used the C programming language to program the microcontroller. As a compiler, we used PCWHD Compiler developed by Custom Computer Services Inc. (CCS) company. to load the code compiled by the compiler into the microcontroller, PICkit 3 In-Circuit Debugger manufactured by the Microchip Inc. company was used.

Separate library files were prepared for the hardware used for allowing the software to become modular. Flexibility and modularity were achieved in our software by using these hardware library files in the applications software.

The library files written for the membrane button are BUTTON.H and BUTTON.C files. In this library are two functions identified. The BUTTON_init() function is called in at the outset of the program, and the pin settings of the microcontroller are performed. When the BUTTON_GetPush() function is called in, it controls the hold down (pressed) key of the membrane button. If the return value is ‘’1’’, then K_UP button is held down; if it is ‘’2’’, K_DOWN button is held down; and if this value is ‘’3’’, then K_ON button is held down. If no button is pushed/held down, the return value then is zero (NULL).

The library files written to control the LED driver card are “NPWM.H” and “NPWM.C” files. The PWM frequency can be changed by changing the “NPWM_PERIOD” value identified in the header file. We used the PWM signal at 1KHz frequency by processing this value as 124. The NPWM_init() function identified in this library is called in at the outset of the program, and the initial settings of the PWM module are performed. In our main program, on the other hand, we can set the duty rate as the parameter by using the NPWM_Set_PWM_Duty(duty) function.

We enabled the increase and the decrease in the LED light to function gradually by using the TIMER0 interrupt within the software. Our main software is diverged towards the interrupt function for a given period. Our interrupt function, at each call-in, performs a certain amount of increase or decrease by controlling the change for the PWM signal. Thus, the gradual change of the HPLED light is ensured. Settings for the interrupt were performed through the TMR0_init() function identified in TMR0.H and TMR0.C files. The necessary settings are performed over the microcontroller by calling this function in at the outset of the main program.

The registry addresses belonging to the PIC12HV752 microcontroller, and the data and macros used in general have already been identified in REG12HV752.H and PIC12HV752.H files.

The main setup and the main() function of the program are found in MAIN.C file. MAIN.H file included in the program in the MAIN.C file is the one in which the other required files are included within the program and the settings of the microcontroller are performed. All the initial settings have been gathered in the initialization() function identified in the MAIN.H file. All the initial settings are done by using this function at the outset of the main() function.

Thanks to the GetKey() function found in MAIN.C file, we can distinguish whether to hold down the keys for a shorter or a longer period of time. The return value of this function varies according to holding down the keys for a short or long time. A 10ms delay is made within the infinite cycle in the main() function. Following this delay, the GetKey() function is called in. The button control is performed through this function that is called in in 10 ms. This process is done as a system task (in any case).

In the MAIN.H file,TIMER0_ISR() interrupt function has been identified. An interrupt occurs at 10 ms intervals in the main function, and this function is performed. With this function, the duty rate changed in the main program (main()) is controlled. The increase and the decrease are slowed down in this way. The application of the PWM signal is only performed within this interrupt function.

3.2.1 Finite State Machines (FSM)

In the following figure (Figure 3.37), the finite state machine we had prepared for our main program is seen. In our finite state machine, as also seen in the figure, are six states identified. The state in which our program starts is the state of ST_STANDBY. In this state, the PWM signal duty rate, in other words, LED light intensity is zero. Whether or not the K_ON button is held down is controlled in this state. Unless the K_ON key is pushed, the ST_STANDBY state is guarded. When the ON/OFF (K_ON) button is held down, the program passes on to the ST_MAIN state, and the duty rate is set as 100%. LED gives off light with full efficiency.

ST_MAIN and ST_STANDBY states constitute the program theme. The intertwining of these states is done by holding down the ON/OFF (K_ON) button. The return of the other states to the ST_MAIN state takes place automatically. In the ST_MAIN state are the key controls performed. The change of state occurs according to the held- down key. When ON/OFF (K_ON) key is pushed in the ST_MAIN state, passing on to the ST_STANDBY mode over again is seen when the duty rate is pulled down to 0%.

During the ST_MAIN state, if the UP key is held down for a short time (K_UP), then a transition to the ST_UP state is made, whereas, if it is held down for a long time (K_UP_L), then the transition to the ST_LONGUP state is made. The duty rate in the ST_UP state is enhanced to a given normal extent (DUTY_AMOUNT). However, during the ST_LONGUP state, the duty rate is enhanced twice as much. An boost control is performed to prevent the duty rate from exceeding 100%. Without pushing any key, a return from either state to the ST_MAIN state is done once again.

When in ST_MAIN state, a transition to the ST_DOWN state is done by holding down the DOWN (K_DOWN) key for a short time, while a transition to the ST_LONGDOWN state is performed by holding the (K_DOWN_L) key for a long time. In the ST_DOWN state, the duty rate is minimized to a given normal extent (DUTY_AMOUNT). In the ST_LONGDOWN state, the duty rate is minimized twice as much (DUTY_LONG_AMOUNT). By performing a minimizing control, the duty rate is set down to the lowest level. Again, return from either state back to the ST_MAIN state takes place without even pushing any button.

You can find the software files in the appendix.

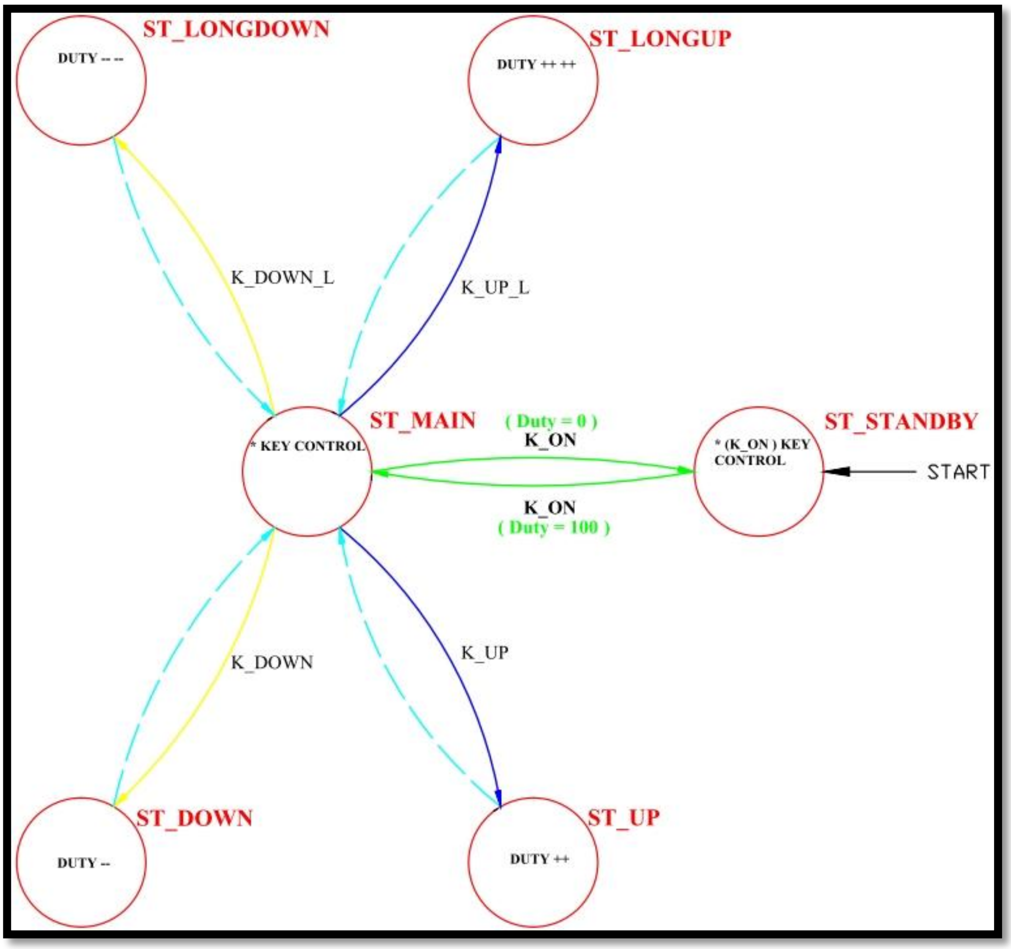

Figure 3.37 Finite State Machine (FSM)

CHAPTER 4

RESULTS

The subject of our project was the design of the LED light source used in endoscopy systems as well as its production. The prototype production unique to the project was implemented, and the project was completed.

Figure 4.1 Portable endoscopic cold LED light source

The portable endoscopic cold light source we created within the scope of our project has a number of advantages. Some of the advantages of the light source in question is that the compactness of its size does not require a lamp replacement, it has less energy consumption, it works more quietly than its equivalents, and it is less costly.

One of the success criteria targeted at the start of our project was the fact that the LED light source created within the scope of our project provided 90% more energy conservation than xenon and halogene lamps. The device, the prototype of which has been manufactured within the scope of our project, performs a power consumption of approximately 3-10W. Xenon and halogene lamps, on the other hand, have a power consumption of 180-300W. It follows from this information that more than 95% energy conservation is maintained.

Our prototype device costs about $150. The current portable LED light sources cost $650, while the fixed desktop cold LED light sources cost $2500, and xenon $4000, and halogene costs $1500 on the average. As is seen, the cost was reduced by 96% compared to xenon cold light sources, 90% when compared to halogene cold light sources, and by 77% compared to those in its own class (the LED cold light sources).

In line with the datasheet information used in our prototype device, the lamp life is seen to be over 50,000-60,000 hours, which is quite satisfying when compared to xenon lasting for 1000-500 hours and halogene lasting for 150-200 hours.

The colour rendering rate of our prototype portable device was designed and manufactured as 90 greater. Thus, the natural colors can be seen in the image captured on the camera.

In our prototype cold light source, the colour temperature is 3200K. The LEDs with more colour temperature give off light at a higher lumen. Since the increase in the colour temperature of the LED used here minimized the color rendering index (CRI) rate, it proved to be 3200K.

Our portable sample, an output of our project, weighs 175gr along with the battery. As for the size, the maximum diameter is 35mm, whereas the length is 122mm. Its portability, as will also be understood from its weight and size, is quite easy. It is of great use with its easy-to-use quality and ergonomic design.

The portable light source produced as a sample is compatible with the rigid telescopes of Storz-brand. The "Optical Adapter" we have described in our mechanical design can be made suitable for the brand re-designed and requested according to the other brands.

The cost and performance of our prototype device are quite high compared to its equivalents. It does not require an external hardware (fibre cable). The level of noise is quite low. It is ergonomic and useful in terms of size and structure. It is resistant to impacts. There is no heavy metal, such as lead and mercury within its structure.

Due to the fact that the LED emits heat along with the temperature during the use of the device for longer periods, the outer casing warms up a little. With the improvement studies we performed, this temperature was reduced down to 37-39 C°.

DISCUSSION

In this study, we aimed to design a portable and physically minimized led light source for endoscopy system. This device can be used instead of other light sources. The portability of the device with its lifetime feature is the first advantage over other classical cold light sources. The amount of used LED chips and other components makes us to have a cheaper than xenon and halogen cold light sources.

Our portable sample device, the output of our project, was compared with the other devices already being used on the market. Our portable device can give off light with only one battery for 90-120 minutes. Due to the shortness of its exposure time, it may not be appropriate for laparoscopic operations. Yet, a fortifier can be used as a spare light source. The short exposure time can be extended with a spare battery.

Separately, the desktop cold LED light source device, which is the second prototype product created during our R&D (Research&Development) studies performed in the course of our project within the scope of TUBITAK (scientific and technological research council of Turkey), was comparatively analyzed below with the other devices available on the market.

Apart from the portable devices, the other devices we compared have high level of noise since they contain a fan.

Except for the portable ones, the other devices in question require a fibre optic cable during the connection with the optics, which costs an extra $300-750. As there may be break-ups, splits and burn-ups in the fibre cable, various failures may occur. Since our portable cold light source, the sample of which we manufactured, does not require a fibre cable, it is quite an advantageous device.

In the production of xenon and halogene lamps, heavy metals like lead and mercury are found. There is no heavy metal in our portable sample device, an output of our project.

Table 4.1 Comparison device

NO	DEVICE	PRICE ($)	LAMP TYPE	LAMP LIFE (Hour)	POWER (Watt)	Color Rendering Index CRI	Color Temperature CCT (K)	SIZE (WxHxD)	WEIGHT (gram)
1	Illuminator LED	2000-2500	LED	60,000 h	100W	90	6500K	112x293x128	2300 g
2	Storz 20 1614 01-1 Cold Light Fountain Power LED 175	5000-7000	LED	30,000 h	175W	>80	6400K	305x165x235	4000 g
3	Storz 20 1331 01-1 Cold Light Fountain XENON 300	4000-6000	XENON ARK	500-1000 h	300W	>80	6000K	305x165x335	7960 g
4	Storz 20 1133 01 Cold Light Fountain HALOGEN 250	1750-2500	HALOJEN	150-200 h	250W	99	3400K	305x109x265	7000 g
5	Our Desktop Cold LED Light Source	500$ -750$	LED	60,000 h	75W	92	5600K	300x170x330	2500 g
6	Our Portable Cold LED Light Source	150$ -250$	LED	50,000 h	10W	90	3200K	(ØxH)35x122	175 g
7	ELS10 (Portable)	650$ -1000$	LED	10,000 h	3W -10W	??	??	(ØxH)27x89	90 g

Xenon and halogene lamps are susceptible to blows and strikes. Any physical impact may shorten the lamp life more and more. Such a situation is not seen in the devices using LED lamp.

The greatest difference between the portable light source, the output of our project, and ELS10 device used on the market is the battery tolerance time. While ELS10 can operate with a full battery at a maximum of 45 minutes, the portable device we created can be used for 90-120 minutes uninterruptedly.

Our project output is compatible with the endoscopic optic devices of different brands and models still being used in hospitals.

The price of the lamp used in xenon cold light sources varies between $700 and $1000. The lamp life of xenon is 500-1000 hours, which makes the price of the lamp $1,00-$1,4 per hour. The lamp life of halogene lamps used in halogene cold light sources is between 150 to 200 hours. The halogene lamp prices, on the other hand, vary between $75 -$150, which suggests that the user cost of the halogene lamp is $0,5 -$1,00 cost/hour. The lamp life of the LED lamp used in our prototype sample is 50,000 hours, and it costs about $20. The user cost/hour, however, makes $0,0004. The lamp life of the lamp we used in the desktop LED cold light source is 60,000 hours, and it costs $150. For this reason, its cost/hour makes about $0,0025.

CONCLUSIONS AND RECOMMENDATIONS

Cold light sources, which are currently used minimal invasive surgery procedures radiates over a wide spectrum range. These light sources ensures a colour close to the natural light of the day. Xenon and halogen lamps are high electric power but highly inefficient. Although these lamps 180-300W electrical power consumption of only 1W produce optical power. This cold light sources are very expensive. Approximately prices are between 5000 to 7000 dollars. Life of the lamp was too short and the prices are between 700 and 1000 dollars.

In conclusion, the portable light source we created can be used conveniently for surgical purposes. However, it cannot be advised during surgeries due to the its limited exposure time, since changing the battery in the course of the surgery takes additional time. Still, there is no inconvenience in using it as an supportive equipment during the surgery.

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APPENDICES

APPENDIX A SOFTWARE CODE

A-1 MAIN.C

```
/*********************************************************************
* FileName: MAIN. C
* Dependencies: Main Function
* Processor: PIC12HV752
* Compiler: CCS C V5.021
*********************************************************************
* Author                  Date          Version         Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer Öztürk          04.03.15       V 1.06
*********************************************************************/
// Include Section
#include <main.h>
/********************************************************************/
// @ Function: GetKey
// @ Overview: It is a function designed for push-button control.
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: K_KEY, K_NULL= 0, K_UP, K_DOWN, K_ON, K_UP_L,
//  K_DOWN_L, K_ON_L
// @ Note: None
/********************************************************************/
K_KEY GetKey(void) {
  K_KEY key_temp;
  key_temp = K_NULL;
  key_temp = BUTTON_GetPush();
  if(key_temp != K_NULL){
     if(++count >= (COUNT_MAX+1))
        count = COUNT_MAX+2;
```

```
  }else{
       count = 0;
  }
  if(count == 3)
      return (K_KEY) key_temp;
  else if(count >= COUNT_MAX){
       count = COUNT_LONG_CONT_MIN;
       return (K_KEY)(key_temp + 3);
  }
   return K_NULL;
} /*End GetKey() Function */
/**********************************************************************/
/* @ Function: main
// @ Overview: Main Function
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: None
// @ Note: None
/**********************************************************************/
void main() {
  K_KEY key = K_NULL;
  ST_STATE state  = ST_STANDBY;
  initilization();  /* Initial setting of the hardware*/
  ///****************** INFINITE LOOPS ********************************///
  while(TRUE){
  ///--------------------------------------------------------------------------------------------///
  ///***************** SYSTEM TASK ********************************** ///
  ///--------------------------------------------------------------------------------------------///
  delay_ms(10);
  key = GetKey();
  ///---------------------------------------------------------------------------------------------///
  ///*****************   STATE  *****************************************///
  ///---------------------------------------------------------------------------------------------///
```

```
switch(state){
  /************* ST_MAIN *************/
  case ST_MAIN:{
    switch(key) {
      case K_ON       :{
                    preduty = 0;
                    state = ST_STANDBY;
                   }
                   break;
      case K_UP       :{
                    state = ST_UP;
                   }break;
      case K_DOWN     :{
                    state = ST_DOWN;
                   }break;
      case K_ON_L     : break;
      case K_UP_L     :{
                   state = ST_LONGUP;
                   }break;
      case K_DOWN_L   :{
                   state = ST_LONGDOWN;
                   }break;
      default:         break;
    }//END SWITCH(key)
  }break;
  /************* ST_STANDBY *************/
  case ST_STANDBY :
  {
    if(key == K_ON){
      preduty = DUTY_MAX;
      state = ST_MAIN;
    }
  }break;
```

```
/************* ST_UP *************/
case ST_UP :
{
  if(preduty <= (DUTY_MAX-DUTY_AMOUNT))
    preduty += DUTY_AMOUNT;
  else
    preduty = DUTY_MAX;
  state = ST_MAIN;
}break;
/************* ST_DOWN *************/
case ST_DOWN :
{
  if(preduty >= DUTY_AMOUNT)
    preduty -= DUTY_AMOUNT;
  else
    preduty = DUTY_MIN;
  state = ST_MAIN;
}break;
/************* ST_LONGUP *************/
case ST_LONGUP :
{
  if(preduty <= (DUTY_MAX - DUTY_LONG_AMOUNT))
    preduty += DUTY_LONG_AMOUNT;
  else
    preduty = DUTY_MAX;
  state = ST_MAIN;
}break;
/************* ST_LONGDOWN *************/
case ST_LONGDOWN :   {
  if(preduty >= DUTY_LONG_AMOUNT)
    preduty -= DUTY_LONG_AMOUNT;
  else
    preduty  = DUTY_MIN;
```

```
        state = ST_MAIN;
      }break;
      /************** DEFAULT STATE **************/
      default: state = ST_MAIN; break;
    } //END SWITCH(STATE)
  }//END INFINITE LOOPS
}//THE END MAIN
```

A-2 MAIN.H

```
/******************************************************************
* FileName: MAIN.H
* Dependencies:
* Processor: PIC12HV752
* Compiler: CCS C  V5.021
******************************************************************
* Author                 Date          Version      Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer Öztürk        04.03.15       V 1.06
******************************************************************/
/*****************************************************************/
//PIC Section
#include <12HV752.h>
#device ADC=16
/*****************************************************************/
//Fuses Section
#FUSES NOWDT                   // No Watch Dog Timer
#FUSES NOBROWNOUT              // No brownout reset
#FUSES NOMCLR                  // Master Clear pin used for I/O
/*****************************************************************/
//Use Section
#use delay(internal=8000000)    //Internal 8Mhz RC Osc, no CLKOUT
/*****************************************************************/
// Define Section
```

```
#define COUNT_MAX                          100
#define COUNT_SHORT_PRESS_KEY          3
#define COUNT_LONG_PRESS_KEY_TIME    50
#if ((COUNT_MAX - COUNT_LONG_PRESS_KEY_TIME ) > COUNT_SHORT_PRESS_KEY)
#define COUNT_LONG_CONT_MIN (COUNT_MAX-COUNT_LONG_PRESS_KEY_TIME)
#else
   #define COUNT_LONG_CONT_MIN   (COUNT_SHORT_PRESS_KEY+1)
#endif
#define DUTY_MAX                  500  /* Maximum duty rate */
#define DUTY_AMOUNT             25    /* The rate of duty change in the short press */
#define DUTY_LONG_AMOUNT 50   /* The rate of duty change in the short press */
#define DUTY_MIN                  23   /* Minimum duty rate */
//*****************************************************************//
// Include Section
#include "REG12HV752.H"
#include "NPWM.C"
#include "BUTTON.C"
#include "TMR0.C"
/******************************************************************/
// Typedef section
enum tag_KEY {K_NULL= 0, K_UP, K_DOWN, K_ON, K_UP_L, K_DOWN_L, K_ON_L};
typedef enum tag_KEY K_KEY;
enum tag_ST_STATE {ST_STANDBY = 0, ST_MAIN,  ST_UP, ST_DOWN, ST_LONGUP, ST_LONGDOWN};
typedef enum tag_ST_STATE ST_STATE;
/******************************************************************/
// Global Variable Section
unsigned long preduty = 0;
unsigned long duty = 0;
unsigned long count = 0;  /* Used in GetKey() Function*/
/******************************************************************/
//Initilization Function Section
```

```
/*****************************************************************/
/* @ Function: initilization
// @ Overview: Hardware Initial Settings
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: None
// @ Note: None   */
/*****************************************************************/
void initilization(void){
  disable_interrupts(GLOBAL);
  setup_timer_4(T4_DISABLED,0,1);
  setup_comparator(NC_NC_NC_NC);
  PORTA = 0x00;
             //76543210
  TRISA = 0b11111010;
  RAPU = 0;   //0 = PORTA pull-ups are enabled by individual PORT latch values
             //76543210
  WPUA =0b11111010;
  NPWM_init();
  BUTTON_init();
  TMR0_init();
  enable_interrupts(INT_TIMER0);
  enable_interrupts(GLOBAL);
delay_ms(1000);
}/* END INITILIZATION FUNCTION */
/*****************************************************************/
// INTERRUPT SERVICE RUTINE SECTION
/******************************************************************
// @ Function: TIMER0_ISR
// @ Overview: TIMER0 Interrupt service rutine
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: None
```

```
// @ Note          :-
*********************************************************************/
#INT_TIMER0
void TIMER0_ISR(void){
  T0IF = 0;                        /* Clear timer0 overflow interrupt flag bit */
  set_timer0(100);            /* Sets the count value of a real time clock/counter. */
  if(preduty == 0){
     duty = 0;
     NPWM_Set_PWM_Duty(duty);
  } else {
     if( preduty > duty) {
        ++duty;
        NPWM_Set_PWM_Duty(duty);
       }
     if (preduty < duty){
        --duty;
        NPWM_Set_PWM_Duty(duty);
     }
  }
}/* END TIMER0_ISR() FUNCTION*/
```

A-3 BUTTON.H

```
/*******************************************************************
* FileName:         BUTTON.H
* Dependencies:  Control of membrane switches
* Processor:         PIC12HV752
* Compiler:          CCS C  V5.021
*******************************************************************
*   <VBAT>---<PULL UP RESISTOR>-----<MEBRANE SWITCH>---<GND>
*                              |
*                           <PIN>
* Author                              Date        Version       Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

```
* Muzaffer OZTURK        07.03.15      V 1.00        First release
*******************************************************************/
#ifndef BUTTON_H_
#define BUTTON_H_
//
*****************************************************************//
// Defines Section
#define P_DW  PORTAbit.p3  /*Defined "DOWN" button I/O pin */
#define P_UP    PORTAbit.p4  /*Defined "UP" button I/O  pin */
#define P_ON   PORTAbit.p5  /*Defined "ON/OFF" button I/O pin */
#define T_DW TRISAbit.p3    /*Defined  "DOWN" button tri-state control bit*/
#define T_UP   TRISAbit.p4    /*Defined  "UP" button tri-state control bit*/
#define T_ON   TRISAbit.p5      /*Defined  "ON/OFF" button tri-state control bit*
//*****************************************************************//
// Prototypes Section
void BUTTON_init(void);                    /* Initial setting of the membrane switches */
unsigned int BUTTON_GetPush(void);  /* Returns with the pressed button */
#endif    /* END BUTTON_H_ */
```

A-4 BUTTON.C

```
/*******************************************************************
* FileName: BUTTON.C
* Dependencies: Control of membrane switches
* Processor: PIC12HV752
* Compiler: CCS C  V5.021
*******************************************************************
*   <VBAT>---<PULL UP RESISTOR>-----<MEBRANE SWITCH>---<GND>
*                           |
*                        <PIN>
* Author                        Date            Version       Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer OZTURK        07.03.15      V 1.00         First release
*******************************************************************/
```

```
#ifndef BUTTON_C_
#define BUTTON_C_
//*********************************************************************//
// Include Section
#include "BUTTON.H"
/*********************************************************************
// @ Function: BUTTON_init
// @ Overview: Initial setting of the membrane switch
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: None
// @ Note          :-
*********************************************************************/
void BUTTON_init(void){
   P_UP  = 0;
   P_DW  = 0;
   P_ON  = 0;
   T_UP  = 1; /* Pin configured as an input (tri-stated) */
   T_DW  = 1; /* Pin configured as an input (tri-stated) */
   T_ON  = 1; /* Pin configured as an input (tri-stated) */
}
/*********************************************************************
// @ Function: BUTTON_GetPush
// @ Overview: Returns with the pressed button
// @ PreCondition: None
// @ Paremeters: None
// @ Return Type: unsigned int (0-255)
// @ Note: UP = 1, DOWN =2, ON/OFF = 3, NULL = 0
*********************************************************************/
unsigned int BUTTON_GetPush(void) {
     if(!P_UP)
         return 1;
     else if(!P_DW)
```

```
        return 2;
    else if(!P_ON)
        return 3;
    else
        return 0;
}
#endif /*BUTTON_C_ */
```

A-5 NPWM.H

```
/*********************************************************************
* FileName: NPWM. H
* Dependencies: Generates Pulse Width Modulation (PWM) Signal on the CCP1 pin
* Processor: PIC12HV752
* Compiler: CCS C  V5.021
*********************************************************************
* Author                    Date         Version      Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer OZTURK       07.03.15      V 1.00        First release
*********************************************************************/
#ifndef NPWM_H_
#define NPWM_H_
//
******************************************************************//
// Defines Section
#define NPWM                PORTAbit.p2   /* Define CCP1  pin*/
#define TRIS_NPWM           TRISAbit.p2
#define NPWM_PERIOD    124           /* 99 = 20KHz, 124 = 1KHz*/
#define NPWM_DIV          T2_DIV_BY_16    /* Initializes timer 2*/
//
******************************************************************//
// Macro Section
/* The corresponding TRIS bit must be cleared to enable the PWM output on the CCP1
pin. */
```

```
#define NPWM_ON()      { TRIS_NPWM = 0; }
#define NPWM_OFF()     { TRIS_NPWM = 1; }
//
*****************************************************************//
// Prototypes Section
void NPWM_init(void); /* Sets up the PWM module. */
#inline void NPWM_Set_PWM_Duty(unsigned long duty);  /*Writes the 10-bit value to the PWM to set the duty.*/
#endif /* END NPWM_H_ */
```

A-6 NPWM.C

```
/**********************************************************************
* FileName: NPWM.C
* Dependencies: Generates Pulse Width Modulation (PWM) Signal on the CCP1 pin
* Processor: PIC12HV752
* Compiler: CCS C  V5.021
**********************************************************************
*
* Author                  Date          Version       Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer OZTURK     07.03.15      V 1.00          First release
*********************************************************************/
#ifndef NPWM_C_
#define NPWM_C_
//********************************************************************//
// Include Section
#include "NPWM.H"
/**********************************************************************
// @ Function      :NPWM_init
// @ Overview      :Pulse Width Modulation (PWM) Signal Initialization
// @ PreCondition  :None
// @ Paremeters    :None
// @ Return Type   :None
// @ Note          :-
```

```
************************************************************************/
void NPWM_init(void){
    /* (1)  Disable  the  CCP1  pin  output  driver  by  setting the associated TRIS bit. */
    NPWM  = 0;
    TRIS_NPWM = 1;
    /* (2) Load  the  PR2  register  with  the  PWM  period value. */
    PR2 = NPWM_PERIOD;
    /* (3)  Configure the CCP1 module for the PWM mode by  loading
    the CCP1CON register with the appropriate values.*/
                    // 76543210        //  7    6    5    4            3   2   1    0
    CCP1CON = 0b00001111;        // — —   DC1B<1:0>   CCP1M<3:0>
// DC1B<1:0>: PWM Duty Cycle Least Significant bits
// CCP1M<3:0>: CCP1 Mode Select bits.. 11xx = PWM mode
    /* (4) Load the CCPR1L register and the DC1B<1:0> bits of the CCP1CON
    register,  with the PWM duty cycle value.  */
    CCPR1L =0;
     /*(5) Configure and start Timer2: */
    TMR2IF = 0;
    TMR2ON =1;
    T2CON = NPWM_DIV;
    /*(6) Enable PWM output pin */
    TRIS_NPWM =0;
    //NPWM_OFF();
}
/************************************************************************
// @ Function…….: NPWM_Set_PWM_Duty
// @ Overview……: Pulse Width Modulation (PWM) Signal Initialization
// @ PreCondition .:None
// @ Paremeters…..:Duty value may be an 16 bit constant or variable
// @ Return Type...:None
// @ Note…………:Writes the 10-bit value to the PWM to set the duty.
************************************************************************/
#inline void NPWM_Set_PWM_Duty(unsigned long duty){
```

```
    set_pwm1_duty(duty);
}
#endif /* END FILE NPWM_C_ */
```

A-7 TIMER0.H

```
/*********************************************************************
* FileName………..: TMR0.H
* Dependencies…...: Generate TIMER0 interrupt
* Processor………..: PIC12HV752
* Compiler………...: CCS C  V5.021
*********************************************************************
* Timer0 will generate an interrupt when the TMR0
* register overflows from FFh to 00h.
* Author                    Date          Version       Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer OZTURK        07.03.15      V 1.00         First release
*********************************************************************/
#ifndef TMR0_H_
#define TMR0_H_
// *****************************************************************//
// Prototypes Section
void TMR0_init(void); /*Sets up the timer 0*/
#endif /*END FILE TMR0_H_ */
```

A-8 TIMER0.C

```
/*********************************************************************
* FileName…………: TMR0.C
* Dependencies…….: Generate TIMER0 interrupt
* Processor…………: PIC12HV752
* Compiler………….: CCS C  V5.021
*********************************************************************
* Timer0  will  generate  an  interrupt  when  the  TMR0
* register overflows from FFh to 00h.
* Author                    Date          Version       Comment
```

```
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Muzaffer OZTURK        07.03.15     V 1.00        First release
*******************************************************************/
#ifndef TMR0_C_
#define TMR0_C_
//*****************************************************************//
// Include Section
#include "TMR0.H"
/******************************************************************
// @ Function……: TMR0_init
// @ Overview…...: Sets up the timer 0
// @ PreCondition.: None
// @ Paremeters….: None
// @ Return Type...: None
// @ Note…………: None
*******************************************************************/
void TMR0_init(void){
                        //76543210
  OPTION_REG = 0b11000110;
}
#endif /*END TMR0_C_ */
```

APPENDIX B PERMITS AND APPROVALS

25.05.2015

İngilizce adı "DEVELOPMENT OF THE WHITE LIGHT EMMITING DIODE ILLUMINATED ENDOSCOPIC LIGHT SOURCE" olan ve türkçe adı ile "ENDOSKOPİ CİHAZLARI İÇİN BEYAZ LED IŞIK KAYNAĞI GELİŞTİRME" isimli tezin sahibi ve yazarı olan Muzaffer ÖZTÜRK, bu tezi "Endoser Tıbbi Cihazlar San. ve Tic. Ltd. Şti." şirketi Araştırma ve Geliştirme (Ar-Ge) biriminde 1507 – TÜBİTAK KOBİ Ar-Ge Başlangıç Destek programı kapsamında bulunan "ENDOSKOPİ CİHAZLARI İÇİN LEDLİ IŞIK KAYNAĞI " başlıklı ve " 7120540" numaralı proje kapsamında gerçekleştirmiştir.

Söz konusu tez, tarafımca malumat ve bilgim dâhilindedir.

Müdür

Abdülferit ALHAN

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