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Steady the Distortion of the Transmitting Data due to the Spectral Shift Effect of Semiconductor Laser with increasing of Frequency in Optical Communication Systems

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Master Thesis

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STEADY THE DISTORTION OF THE TRANSMITTING DATA DUE TO THE SPECTRAL SHIFT EFFECT OF SEMICONDUCTOR LASER WITH INCREASING OF FREQUENCY IN OPTICAL COMMUNICATION SYSTEMS

by

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Mustafa Ghazi Fahad AL-AZZAWI

DEDICATION

To my family, My supervisor Prof. Dr. Osman Nuri Ucan, the jury's members of the thesis and to Altinbas University.

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ABSTRACT

STEADY THE DISTORTION OF THE TRANSMITTING DATA DUE TO THE SPECTRAL SHIFT EFFECT OF SEMICONDUCTOR LASER WITH INCREASING OF FREQUENCY IN OPTICAL COMMUNICATION SYSTEMS

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In this study, a semiconductor laser (also called laser diode (LD)), light emitting diode (LED) and Polymers Light-Emitting diode (PLED) have been studied in Steady the Distortion of the Transmitting Data due to the Spectral Shift Effect of Semiconductor Laser with increasing of Frequency in optical Communication Systems of the central wavelength and spectral width effected by increasing of frequency that casus the increase in temperature in light sources, where the increasing of frequency is very important in communication system that utilized to rise the data transmission bandwidth. We had designed an oscillation circuit to generate a narrow light pulse to simulate the transmission system. The different frequencies (10, 100, 10000, 100000 and 500000) Hz has been used for small pulse width (100, 500 and 1000) ns. The experimental test show that all optical sources suffer from a dispersion of spectrum in the beam and a visual red shift. This is more in LD and less in LED. The spectrum broadening is bad phenomena in optical communication systems that lead to losing of data due to saturation in spectrum of sources when light transfer through different medium. The results show that the LED is the best choice for data transmission which is very stable than LD and PLED that suffer from red shifting, in addition to subject spectrum broadening that cased by difference in transferring speed when passes in different medium cases interference and losses of data. Even so the LED has a disadvantage that it low in power which cannot be transmitting for long distance where the LD is best choice for free space optical communication system (FSO), while LED is best in optical fiber communication system.

Keywords: Optical Communication Systems, Data Distortion, Light Emitting Diode, Polymer Light-Emitting Diode, Laser Diode.

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LIST OF ABBREVIATIONS

2D : The Two Dimensions

β : The Propagation Constant

β_2 : The 2nd Derivative of The Propagation Constant of Fiber Mode

τ : Spontaneous Recombination Lifetime

A : The P-N Junction Area

B : The Pulse Broadening

D : Dispersion

E : The Electric Field Envelope

GVD : The Group Velocity Dispersion

L : Distance Between Reflected Mirrors of LD

$P(z)$: The Peak Power Changes, Because Of GVD

T : Temporal Pulse Duration

T_0 : Pulse Width That is Related to The Pulse Full Width τ_{FWHM} at half maximum

c : The Light Velocity in Vacuum

d : The P-N Junction Thickness

i : The Propagation Direction

n_a : Concentration of The Carrier in The Active Region

t : Time

t_g : The Group Delay Per Unit Length

v_g : The Group Velocity

w : The Frequency of The Signal

z : The Pulse Path

AC : Alternative Current

AlGaAs : Aluminum Gallium Arsenide

BER : Bit-Error Rate

CB : Conduction Band

DBR : Distributed Bragg Reflector

DC : Direct Current

DFB : Distributed Feedback

EA : Electron Affinity

EV : Electron Vacuum Level

FSO : Free Space Optical

GaAs : Gallium Arsenide

GHz : Giga Hertz

Hz : Hertz

InGaAs : Indium Gallium Arsenide

InP : Indium Phosphide

IP : Ionization Potential

IR	:	Infrared
ITO	:	Indium Tin Oxide
ITS	:	Intelligent Transport Systems
LD	:	Laser Diode
LED	:	Light Emitting Diode
LPF	:	Low Pass Filter
MHz	:	Megahertz
MOPA	:	Master Oscillator Power Amplifier
Nd:YAG	:	Neodymium-Doped Yttrium Aluminum Garnet
NIR	:	Near Infrared Region
OOK	:	On-Off Keying
PLED	:	Polymer Light-Emitting Diode
RF	:	Radio Frequency
QCW	:	Quasi Continuous Wave
RC	:	Resistor-Capacitor
SNR	:	Signal-To-Noise Ratio
TEC	:	Thermo-Electric Cooler
THz	:	Terahertz
UPW	:	Unplumbed Windows
V/A	:	Volt/Ampere

VB : Valence Band

VCSEL : Vertical Cavity Surface Emitting Lasers

VLC : Visible Light Communications

VME : Virtual Machine Environment

VXI : VMEbus Extensions for Instrumentation

1. INTRODUCTION

1.1 GENERAL OVERVIEW

During recent decades, the access to information through networked terminal equipment has grown enormously. The speed is one of the key factors that communication systems depend upon. The faster communication means it system is far more effective [1]. In the latest years, incredible growth and improvements have been discovered in communication and information technologies. As an increasing in usage for high speed internet in wide area of application such as live streaming, video-conferencing, etc., the requirements for capacity and bandwidth have been increases drastically [2]. The transmissions at higher-frequency have far more bandwidth compared to transmissions at lower-frequency, this means that the higher-frequency transmissions are able to send substantially far more data in less time .[3]

The growing of requirements to increase the size of transmitting data has leaded towards congestion in traditionally used of radio frequency spectrum and it rise up the need to move from RF carrier towards optical carrier. In contrast to radio frequency (RF) carrier in which spectrum usage is limited, the optical carrier doesn't need any spectrum licensing and for that reason it is an attractive possibility for capacity and high bandwidth applications [4].

Consequently, the network designers have advised that distribution and transmission systems utilize optical technologies to be able to satisfy high bandwidth goals and permit for furthermore development. Since these networks nowadays use electrical devices inside their switching and terminal devices, the optical transmission of data includes an opto-electronic receiver and transmitter at the ends of every distribution or transmission network segment. Standard systems utilize laser diodes (LD) for transmitters, photo diodes for receivers, and glass fibers for optical waveguides [5]

Since an optical communication system offers the potential to communicate various high bandwidth channels through its spatially limited and low loss core, the technologies of optical network have prompted the ongoing development of less expensive broadband data services. Even so, the effective development of the benefits provided by using optical waveguides should also need consideration of light sources, photo detectors and additional important sub-system elements. [6]

Transmitting signals at high frequencies is a daunting task. At high frequencies, parasitic elements, like capacitance and inductance, come to be much more considerable, and can influence on circuit behaviour in undesirable ways. In this case, these components should be traces as short as possible and made as small as possible to reduce the parasitic elements in the traces and components. Furthermore, a long extend of a copper wire or trace can behave as antenna, that could make the system subject to unwanted noise [7]. Optical communications assist minimizes these problems. Optical communications operate by utilizing an electrical signal to modulate a light source, and then making use of a light receiver to recreate the original electrical signal. Because the light is unchanged by electromagnetic waves, this is often useful for transmitting signals throughout long distances or inside the areas having significant radio interference [8].

Semiconductor lasers (LD) and light emitting diode (LED) are among the most important optoelectronics devices made use in optical communication systems. The overall commercial fiber optics and free-space optics (FSO) industry is focusing on making use of LD and LED due to their relatively high power, small size, and cost efficiency [9]. Almost all of these lasers are also used in both FSO and fiber optics; thus, availability is not a problem. Optical systems operate in the infrared (IR) or near infrared region (NIR) of light (430THz down to 300GHz). The optical communication is essentially a form of telecommunication that uses light as a medium by using an optical transceiver that utilized either LD or LED [10].

1.2 OPTICAL COMMUNICATION SYSTEM CONCEPT

The communication systems is utilized to transfers data from one place to another range from a few kilometers up to hindered or thousands of kilometers. The data is usually carried by used an electromagnetic carrier waves which it is frequency varies from a little megahertz (MHz) to many hundred Terahertz (THz). For communication systems that utilized optical signals in the visible or near-infrared (NIR) region to gain high carrier frequencies reach up to hundreds of Terahertz. The optical communication systems and microwave systems are different in each other in carrier wave frequency range that utilized to carry the data. The optical communication systems can be carrying data and transfer it near 1Tb/s bit rates. Recent optical communication systems can transfer data at speed reach up to 10Gb/s, suggesting that there is significant room for improvement [11]

The main structure of optical communication system is composed of [12]

- **Transmitter:** Transmits and Converts an electronic signal to the light signal. The most frequently used transmitters are semiconductor laser, including laser diodes (LD) and light-emitting diodes (LEDs).
- **Receivers:** In general, it is composed of a photo-detector, which is typically a semiconductor-based photodiode that used to converts light to electricity by using the photoelectric effect.
- **Communication channel** (Transfer Medium): it's based on optical communication type. For optical fiber communication system, the communication channel is fiber optic, where a core, a buffer and cladding where the cladding leads the light through the core by utilizing total internal reflection. For free space optical communication system (FSO) the transfer medium is air.

The three elements stander at all communication systems, figure 1.1 illustrated the block diagram for optical communication system structure [13].

Figure 1.1: Basic Structure of optical communication systems

Optical communication systems are classified to two wide categories: guided systems and unguided systems. In guided systems, the optical beam transmitted from the transmitter keeps spatially confined. As almost all guided systems presently work with optical fibers, they are usually called fiber optic communication systems. In unguided systems, the optical beam that transmitted from the transmitter will spreads in space, just like the microwave spreading [13].

Their operating needs, in general, appropriate pointing between the receiver and transmitter. In the terrestrial propagation case, the signal in unguided system can weaken significantly by scattering at atmosphere. However, this problem is gone in free-space optical (FSO) communications over the earth atmosphere (for example, in intersatellite communications). Even though, the FSO communication systems are essential for certain applications and had researched extensively, in other hand the terrestrial applications are utilize fiberoptic communication systems. [14].

The applications of optical communication system in telecommunication is usually classified into two categories; short haul and long haul, according to if the optical signal is transferred over relatively short or long distances in comparison with typical intercity distances (about 100km). The long-haul tele-communication systems needs high capacity trunk lines and take advantage by used of fiberoptic light wave systems. Certainly, the technology at the rear of fiberoptic communication is normally motivated by long haul applications. Every successive technology of light wave system has the ability to functioning at higher bit rates and through long distances. Regular regenerations of the optical signal by making use of repeaters continues to be needed for many long-haul systems [15].

1.3 ADVANTAGE AND DISADVATAGE OF OPTICAL COMMUNICATION SYSTEM

The main advantages of optical communication are [16]:

1. **Long Transmission Distance, Save Energy:** The optical communication has the ability to transmit more information and for a long distance. As a result, by using optical communication systems such as optical fiber communication, it can utilize the fiberoptic cables to communicate with overseas by placed on the seafloor.

2. **Transmit Massive Amount Information at One Time:** By using optical communication, a large number of users can get the required data at the same time. By compered, the electrical communication is able to transmit only 10 Gb of information (10 billion 0 and 1 signals). On the other hand, the optical communication can transmit up to 1Tb (1 trillion 0 and 1 signals) information.

3. **Fast Communication Speed:** The optical communication is not affected by noise, thus, it can transmit signals quickly, while the Electrical communication can have errors due to electrical noise, causing minimized in communication speed.

The main disadvantages of optical communication are:

1. High cost of transmitter/receiver, cables and other support equipment
2. Required expertise and skill during installation and interconnection.
3. At high data rates, the limitations of rising time can cause the distortion in data and thus to be lost.

1.4 PREVIOUS WORKS

1) Zulkepli, et al. (2008) [17], investigated the temperature effects on semiconductor laser output. In their work, a high-power LD was used as a light source. The Temperature Linear LM35 Analog Sensor was used in order detect the temperature and the spectrum analyzer has been used to measure the intensity. Heatsink combined with fan was used to dissipation of heat during the current pumping. The result shows that the temperature is higher with no fan in the system and it cause reduced in the intensity of the LD, as a result the LD power was also reduce. As a result, the study proven that it’s important to control the operating temperature of LD to get the most useful output.

2) Balasubramanian et al. (2010) [18], Investigated the operation of the 1.25Gb/s broadband digital optical link that utilized a Distributed Feedback Laser (DFB) as a transmitter. In their work they studied combined effects of the fiber-induced dispersion and temperature-dependent changes in LD output on the overall efficiency of digital optical link. While the functioning temperature of LD is changed, the optical pulse properties have been discovered for 1.25Gb/s input data. The suggested simulations performed at several operating temperature and the link distances to compute the increase in eye opening to various range of distance and temperature, while showing a consistent drop in other ranges.

3) Farsad, et al. (2011) [19], was investigated the temperature effects on different functionality of a 60W Quasi-continuous-wave (QCW) laser diode. The results show that the operation voltage and the conversion efficiency of LD has been minimized as the rises of the working temperature affiliated with a red shift on the laser peak wavelength. In addition, the results show that the emission peak wavelength for laser shifts is about 0.26nm and the transformation efficiency reduces 1.76 % as the temperature has been increased from 40 to 50℃.

4) Michaud, et al. (2015) [20], provided a thermo reflectance approach to measure the variations in temperature at the output aspect of high-power GaAs-based LD that generate a 980nm Laser. Two types of diodes with several unplumbed windows was studied to identify the effect of unplumbed windows length on the temperature change. Their work proves that in the active region vicinity in which the catastrophic optical damages may be susceptible to happen, and the short unplumbed windows diode heats far more than the long unplumbed windows one.

1.5 AIM OF THE WORK

This work is aiming to study the effect of the increases of the frequency in optical communication systems for data transmitted. We have investigated the change in characterization of an optical signal which accompanied to increases of frequency that considered as a daunting task when operate at high frequency. The study investigate distortion in data causes by dispersion of spectrum in the beam and a visual red shift of LD, LED and PLED with increasing of frequency optical communication systems in order to keep the data distortion less as can.

1.6 THESIS LAYOUT

- **Chapter One:** gives a concept about optical communication system concept, with an illustration of techniques, previous work and application in that field.
- **Chapter Two**: Described the theoretical concept of optical communication system basics. It also details the most optical source that used in optical communication and explained it’s structure, physics and application and the issue of data distortion.
- **Chapter Three**: describe the experimental set up, with details the instrument used in operation and measurement.
- **Chapter Four**: describes the results and discussion of the result.

- **Chapter Five**: is summarizes the main conclusions of the work and recommendations for future work.

2. PRINCIPLES OF OPTICAL COMMUNICATION SYSTEMS AND PULSE BROADENING ISSUE

2.1 OPTICAL COMMUNICATION SYSTEM

Optical systems can carry out data in one of the two basic methods: digital or analogue. Any optical communication system is composed of three basic elements which is: optical transmitter, transmitting medium and optical receiver. In this research we focused on transmitter side and optical transmission were the data can be subject to distortion [21].

The optical transmitter transforms the electrical signal into an optical signal. The optical signal sources can be either a Light Emitting Diode (LED), Polymer Light-Emitting Diode (PLED) or a Laser Diode (LD). LD have some benefit than LED, which it can be focused to a very narrow range, making it possible for control over the incidence angle. LD is also keeping the character of the signal through a long distance that makes the LD is ideal for long transmission distances. On the other hand, the one of the disadvantages of LD, is the distortion of signal can be occurred, generally the clipping distortion. In this chapter we have details the fundamental and specification of these types [22].

2.2 LIGHT-EMITTING DIODE (LED)

LED's are generally the unique optoelectronic equipment for optical communication, and they're broadly utilized as incoherent light sources in some applications like short-distance optical fiber communications and lighting. In addition, LED's can be utilized as a wireless transmitter, which is not possible for some other kind of lights in broadband transmissions [23].

LEDs that designed for usage in optical fiber communication system are defers from the LEDs that used in display in it is structure, since in LEDs that used in optical fiber communication is needing to receive a sharp diagram of routing and little size of shone spot, once needs a high power of emitting. Consequently, the LEDs used in optical communication generally includes one or several layers that usually are alloyed in nonuniform on the plane of PN transition. In addition, the

LEDs used in communication is operates at higher current density than LEDs use in display. All of these factors serve as further sources for destruction phenomena in optical fiber LEDs [23].

For LEDs that operate with fiberoptic communication lines, there's a requirement to keep the linear interval width of the output capacity reliance on the current, and the availability of radiation capacity in the fixed working current is required too. The default of this condition influence to minimize the dynamic range of fiberoptic lines. Beyond, for LED of optical communication and at the point of view of efficiency, there's a need to keep the parameters of V/A characteristics in the working range of currents, since any changes in these parameters lead to instability in the transfer coefficients for the optical fiber lines [23].

2.2.1 Principles of Operation and Properties of LED

In theory, the basic operation of a common LED takes place when it is positioned in a forward-bias state by applying a positive voltage throughout the device, that cause enough current to flow. With this condition, the holes of the p-type and electrons in the n-type move into the p-n junction n and recombine with the carriers of reverse polarity. Once these carriers are recombined, the photons are released from the device. When the voltage across the device is raised, the current flowing within the device is also raised. Consequently, further carriers recombine a more generation of higher photons emission. Figure 2.1 illustrated the LED operation under forward bias condition and recombination process [24].

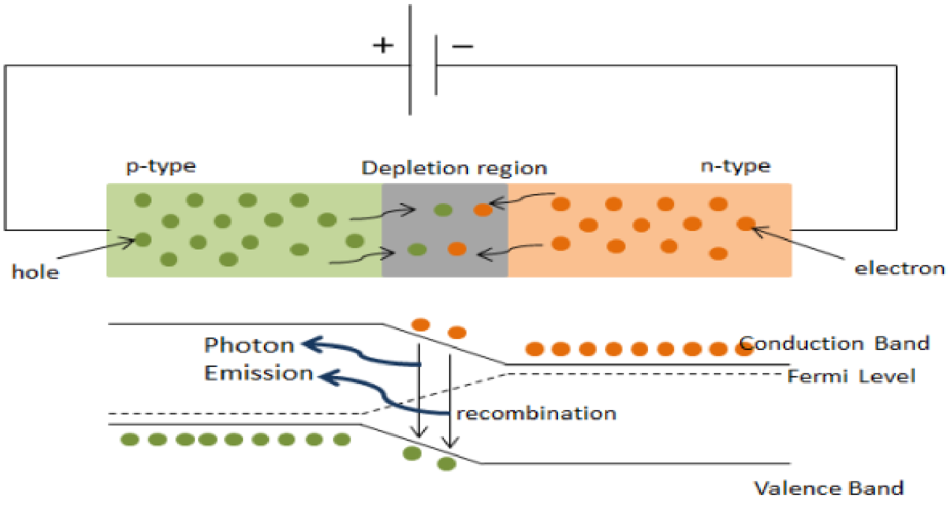


Figure 2.1: LED operation under forward bias condition and recombination process.

Through the recombination process, the holes and electrons can recombine often nonradiatively or radiatively. Radiative recombination leads to the emission of photons. On the other hand, the nonradiative recombination causes the holes and electrons to convert to a vibrational energy without photons released. One of the most important reasons for nonradiative recombination is the defects and impurities of the crystal structure [24].

2.2.2 LED Bandwidth

The LED dB bandwidth is defined from zero hertz to the frequency where the optical power at higher bandwidth which is transmitted by the LED and received in photodetector is minimized to half of its value at low frequency. For LEDs that has been used for lighting applications, the PN junction area of diode is large. Some of these LEDs have large capacitance and as a result large Time Constant of Resistor-Capacitor (RC) that determines the bandwidth. However, a standalone communication LEDs has a smaller sized active region, consequently a smaller RC time constant. Therefore, a communication LED is manufactured for higher bandwidth and, as a result, can be modulated faster. The relationship between the injected minority carrier concentration and the optical power can be described using the monomolecular model. It is rate equation is provided as [24]:

$$n_a = \frac{I_\tau}{qAd}\left(1 - e^{\frac{-t}{\tau}}\right) \tag{2.1}$$

Where: n_a is the concentration of the carrier in the active region, A the p-n junction area and d is the p-n junction thickness, and τ: spontaneous recombination lifetime.

2.2.3 Application of LED

Modern day LEDs can be categorized to three types, visible light emitting diode LEDs, ultraviolet light emitting diode LEDs (UV LEDs), and infrared light emitting diode LEDs (IR LEDs), the visible and IR LEDs can be used in communication purpose. Table 2.1 illustrated the LEDs types and application [25].

Table 2.1: Some types of LEDs and it is application [25]

Optical Region	Type	Application
Red LED	Narrow directivity	Optical switches
	High output	Barcode readers, Optical switches
	Resonant Cavity	Optical fiber communications
Infrared LED	Current confinement type (small light-spot type)	Optical fiber communications, Optical switches
	High-speed response	Optical fiber communications, Optical rangefinders
	High output	Lighting for infrared cameras, Optical switches, Triangulation measurement
	Long wavelength	Optical switches, Moisture and gas detection

2.3 POLYMER LIGHT-EMITTING DIODES (PLEDS)

PLEDs (also known as Light-Emitting Polymer (LEP)), are among the most promising technologies for applications in optoelectronic devices. In 1989, the high efficiency PLEDs has been demonstrated for the first time at the Cavendish Laboratories in Cambridge (UK), such devices have been intensively researched and gradually optimized. A large range of new electroluminescent polymers have been acquired by the development the approaches of tailored organic synthesis. Alternatively, the structure of the device has been improved with regards to the energy level matching in between the several layers with the intro of polymeric interlayers. The main key strengths of PLEDs is that the lower costs in production, flexible devices, large areas, increased color contrast, lightweight robust devices. The applications of PLED is the use in display technology and it can be uses in communication [26].

Nowadays, the PLEDs are used as a device for signal transmission in field of visible light communications (VLC). The most significant characteristics of PLED is their response speed which is very important in communications. VLC is a new access network developed at the last ten years and is depending on the intensity modulation of VL through a high speed which have been invisible to the human eye. The typical regular modulation format employed in VLC is the on-off keying modulation (OOK) that used with signal transmission when the device is being concurrently driven as a usual light source with a DC bias. The visible light communications had been developed as an alternate wireless communications method to classic radio frequency methods like Wi-Fi. It is also motivated by the problems because of the highly congested radio frequency spectrum and premium license fees. The make use of the visible region of the electromagnetic spectrum gives a good integration with popular infrastructures for a new range of options involving the vehicle to vehicle communications for ITS systems (intelligent transport systems), underwater communix Ccations and indoor localization systems, VLC can be utilized for wireless communications in cases where RF interferences are a significant problem such as in hospitals or on commercial flights in which the radio wave links may affect life support equipment [27].

2.3.1 PLEDS Physics and Design Considerations

A PLED is consists of a very thin layers of polymer films (standard thickness between 50nm to 500nm) and witch between two electrodes. In a standard PLED structure, there’re two polymer layers, one is works as the hole transporting layer and the second work as the light-emission layer. A layer of indium tin oxide (ITO) is commonly used as the transparent anode that enables the light generated within the diode to get out of the device. The metal cathode is easily deposited on the top of the polymer via thermal evaporation. Figure 2.2 illustrated the PLED configurations for both single-layer and two-layer PLED [28].

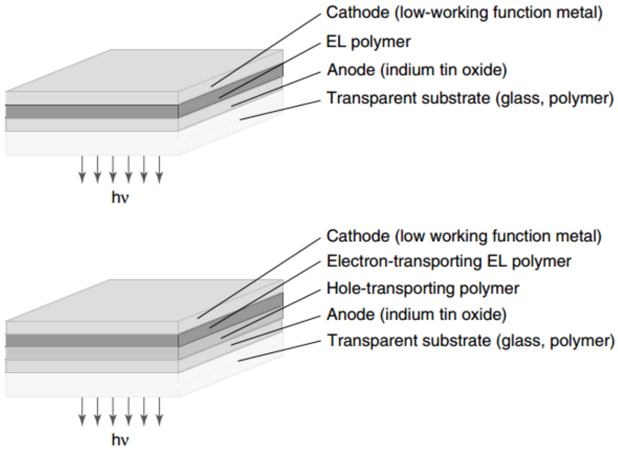


Figure 2.2: PLED layouts of: single-layer PLED (upper) and a 2-layer PLED (lower)

2.3.2 The Advantage and Disadvantage of PLEDS

Organic and PLEDs have many advantages involve: low-cost and solvent-based processing. Interestingly, the usage of PLED for VLC poses a number of serious challenges that should be dealt with to competes with the more started inorganic semiconductor technologies. The key challenge is [29]:

- The raised number of charge carrier traps when compared with more crystalline inorganic semiconductors.
- The relatively low charge carrier mobility.

The grouping of these two effects are causes a significant minimization in the response speed of PLEDs which turn decreases the obtainable transmission speed. An additional important limit presented in the on-off switch speed of PLEDs is due to the general geometry of the devices in which a thin film (generally about 100nm) of the polymeric active layer is enclosed in between two metallic electrodes along with lateral dimensions in the order about millimeters squared or larger. This geometry lead to a significant capacitance, that, together with the intrinsic series resistance, provides rise to characteristic of a low pass filter transfer function (LPF). The cut off frequency for these types of LPF is lower for large area device because of a higher capacitance, therefore, limiting the speed rate of light intensity modulation [29].

2.4 LASERS DIODE (LD)

LDs are the most common of all lasers. The first LD was developed in the 1960, and it have evolved a long way as then to get development that makes LD small in size, low in power consumption and be accurate. LD has been used in a large range of applications, from CD/DVD players, to the laser printers and to telecommunications systems. The simple LD are lighter and much smaller, in addition it much more rugged, when compared to other lasers [30].

The general materials for LD are compound semiconductors with a direct bandgap, like indium gallium arsenide (In Ga As), indium phosphide (In P), gallium arsenide (Ga As) and aluminum gallium arsenide (Al Ga As). The multiple semiconductor materials have alloys form four-element (quaternary) and three element (ternary) compounds, for example, permits them to be tuned with respect to their bandgap or lattice constant. The optical gain is obtained by stimulated the emission inside the active layer, i.e. GaAs layer. The travel wave is limited in its propagation on the two sides of the active medium and it as a result travels back and forth, generating a standing wave that possesses an individual spectrum of permitted cavity modes, known as longitudinal modes. The output spectrum is figure out by the overlap in the line shape and allowed oscillations of the optical gain as a function of the injected carrier concentration. The three essential elements of a LD, as detailed in Figure 2.3 [31, 32].

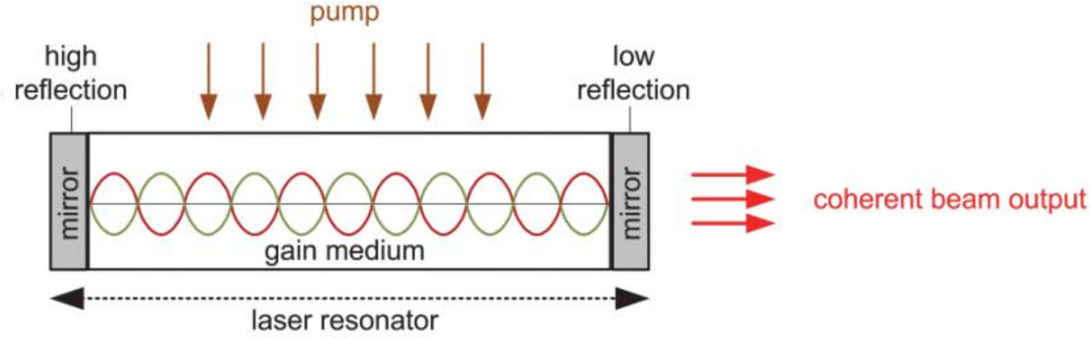


Figure 2.3: Essential components of a laser diode: gain medium, resonant cavity, and pump

2.4.1 Laser Diode Structure and It’s Operation Principle

The Laser diode is consisting of two layers of Semiconductors that are N-type and P-type. The semiconductors layers are constructed from GaAs doped with some materials such as aluminum, selenium or silicon. The structure is same as that of LED with the exception of the channels utilized in Laser are thin to generate a single beam of light. The main structure of a LD is shown in Figure 1. The light emission layer (active layer) sandwiched in between the n and p type clad layers (dual heterostructure) is made on n-type base, and voltage is placed across the PN junction via the electrodes. The two edges of the active layer include mirror-like surface. Once forward voltage is put on, electrons combine with holes at the PN junction, and transmit the light, which is is not a laser yet; it's confined on the inside the active layer since the clad layers refractive index are smaller than the active layer. Additionally, the two ends of the active layer work as a reflecting mirror in which the light reciprocates inside the active layer. After that, the light is increased by the activated emission process and then the laser oscillation is produced [33].

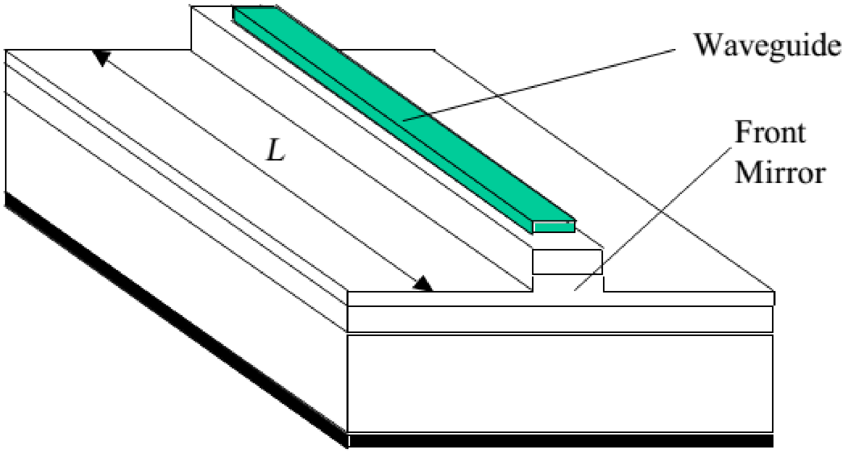


Figure 2.4: The structure of an edge-emitting LD

2.4.2 Laser Diodes Types

The LD can be classified to two main types based on its power, which are: low power LD and high-power LD.

2.4.2.1 Low-Power LD

These low power LD are depending on single emitters. Wavelengths in range from 375 nm to 1550 nm are obtainable in a range of power which usually starts below 1 milli watt up to some watts. These types are available in a range of packages, and the most regular package utilized is the TO-Can structure. This To-Can has been used to dispersed heat from LD to maximize its performance. Figure 2.5 shows the shape of TO-Can LD [35, 36].

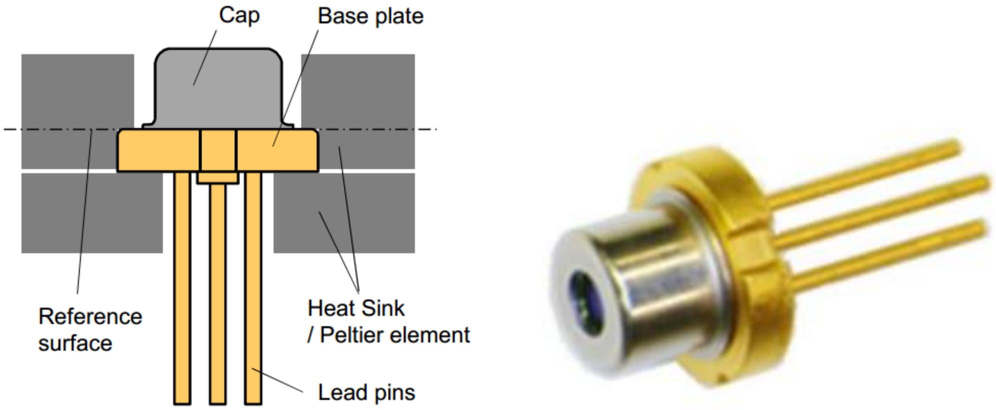
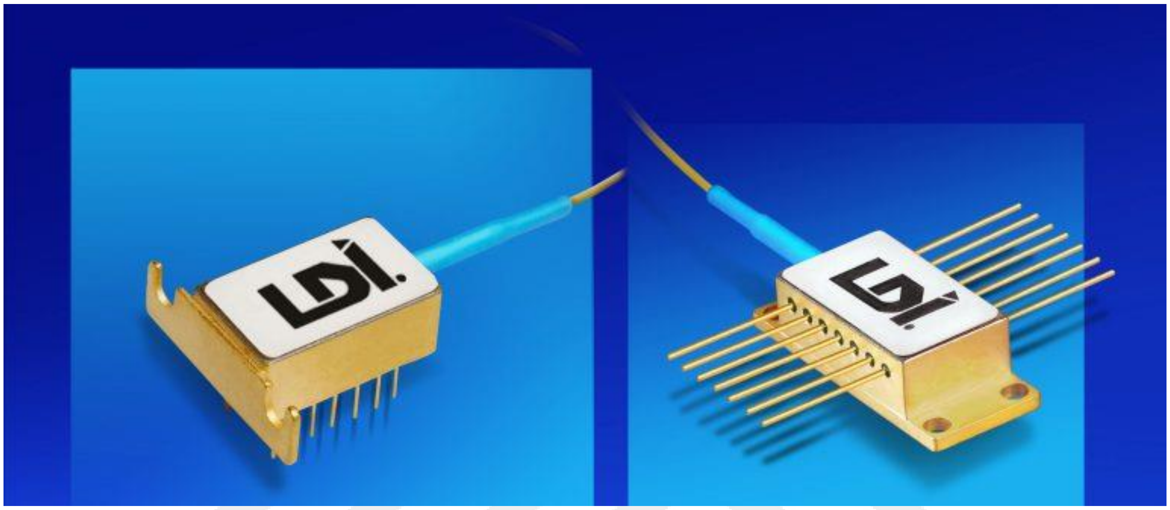


Figure 2.5: TO-Can LD

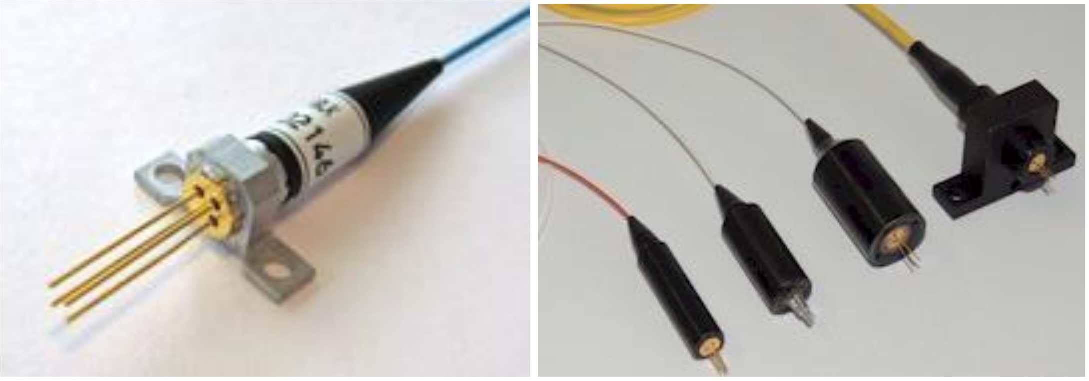
The other types of low power LDs that used in telecommunication application has another package that used for heat dispersion which are: DIL (Dual-In-Line) and butterfly. The both have 14pin packages and they have plates for heat dispersion. Figure 2.6 shows the two types of telecommunication LD [37].



(a) (b)

Figure 2.6: Two types of telecommunication LD: (a) DIL (b) butterfly

Most other packages are utilized involves coaxial packaging which is used for pulsed LD, a standard TO56 cans and a range of fiber pigtailed LD with CD/DVD style LD bundled into a special designed housing which usually includes the fiber output and focusing optics. Figure 2.7 shows these two types,



(a) (b)

Figure 2.7: (a) coaxial LD (b) fiber pigtailed LD

The additional structures of low power LDs involve, The Master Oscillator Power Amplifier (MOPA) and Vertical Cavity Surface Emitting Lasers (VCSEL). The master oscillater power amplifier lasers had been designed in order to rise the output power of single-mode LD while keeping a narrow line width. It has an oscillator section that used to generates a fairly narrow spectral output, and a it also has a built-in power amplifier section that raises the output power with no effect on the spectral output. The VCSEL can be manufactured in 2D arrays for employ in optical computing, communications and printing. The structure of these laser has a circular aperture enabling the output beam to be quickly collimated by using a simple spherical lens [37, 38].

Single frequency LD is one other interesting member of the LD family. These units are now presented to meet the requisites for high bandwidth communications and for spectroscopy. Additional advantages of these systems are lower power requirements and lower threshold currents. One kind of these structure type is the distributed feedback (DFB) LD (shown in Figure 2.8). It has been made to emit light at the wavelengths range of fiber optic communication between 1300nm and 1550nm [38].

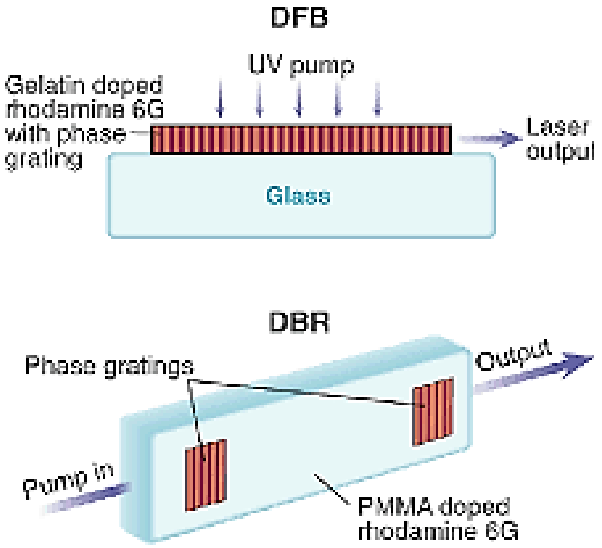


Figure 2.8: Single frequency laser diode: DFB (upper), DBR (lower)

2.4.2.2 High-Power LD's

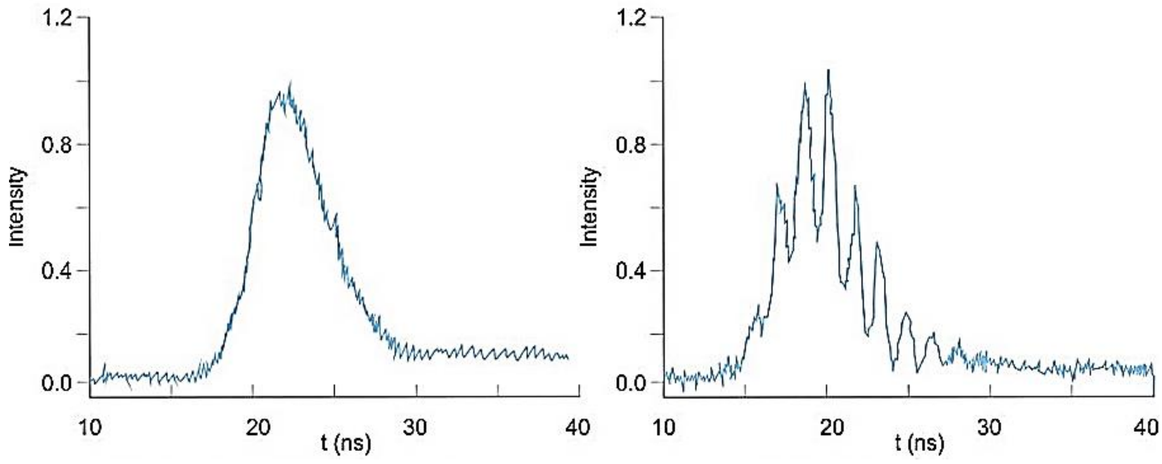
A high-power LDs is made in cases when the electrical properties of intrinsic semiconductor are improved by adding impurities to the crystal wafer surface. These types of LDs are light and small, and it required minimal power. The power output of these lasers is what refers to it as "high power" which is (>10 Watts). These LDs are available at wavelengths ranging from the near infrared (NIR) up to 2000nm region, and it commonly available in the range between 808 nm to 980 nm. They provide a very good electrical to optical performance of around 50%. These LDs has very widely packaging styles such as copper bar mounts, fiber coupled, etc. The application of these devices are widely and it utilized in communication, illumination, materials processing, sensing and medical and cosmetic applications. For communication application it commonly used with FSO communication. The appropriate wavelengths range of these LDs are in-between 1300 nm and 1600 nm because it invisible and have a lower divergence (the light will not "spread" when it travels). Figure 2.9 shows one regular types of high-power LD packages called [40].

Figure 2.9: Traditional high-power Coherent Laser Diode Bar packages

2.4.3 SOME SIGNIFICANT CHARACTERISTICS OF LDs

2.4.3.1 Optical Spectrum

For LD, the optical spectrum is dependent upon the specified properties of the laser’s optical cavity. Many index-guided and conventional gain systems have a spectrum that have multiple peaks, while the LD types distributed Bragg reflector (DBR) and distributed feedback (DFB) shows a single well-defined spectral peak. Figure 2.10 illustrated the comperes between the two spectral behaviors [41].



(a) (b)

Figure 2.10: Multimode vs single-mode spectra: (a) single mode, (b) Multimode

2.4.3.2 Changes in Center Wavelength by Temperature

Temperature is a factor that effect on LD center wave, in which the center wavelength is proportional directly to its operating temperature. There's always a linear relationship between the center wavelength and temperature (as shown in Figure 2.11) [42].

When the LD temperature increases, the center wavelength of the LD will increasing too. This characteristic is beneficial in LD pumping of solid state lasers, spectroscopy applications etc. [42].

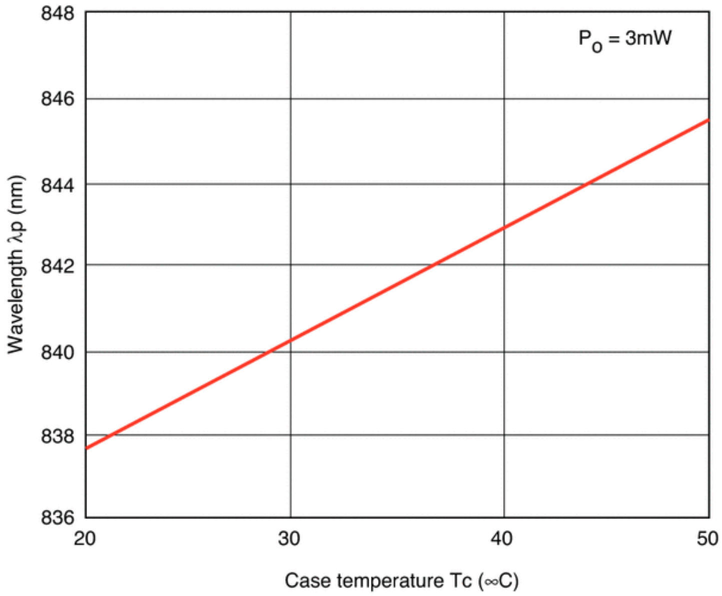


Figure 2.11: The temperature effects on center wavelength

2.4.3.3 Mode Hopping

It is the phenomenon in which the laser shows sudden jumps of optical frequency, that are often associated with changes between several modes of its resonator and it is mainly reviewed in the situation of single-frequency lasers. By some external effect, such a laser can work on a single resonator mode for a time, however, when it suddenly switches to another mode. This results in these other modes are suddenly takes over most of the optical power. Figure 2.12), These LD hops through discrete wavelength bands and doesn't show constant tuning through a broad range. This phenomena is should be take into consideration when temperature tuning the device. Figure 2.12 illustrated the mode hope [43].

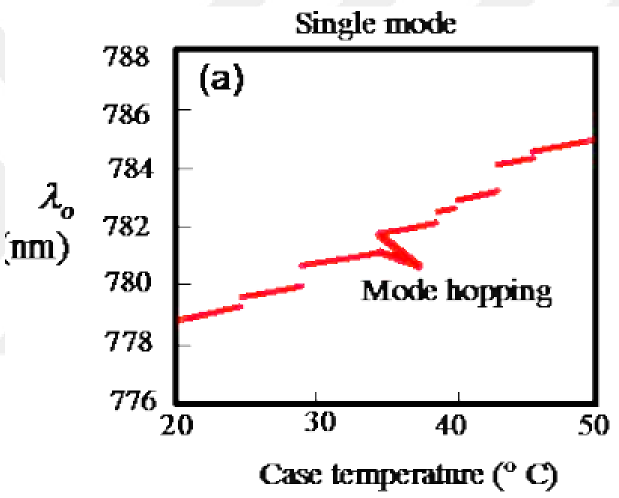


Figure 2.12: Mode hopping discovered when the temperature tuning a single-mode LD

2.4.4 Advantage and Disadvantage of Laser Diode

The main laser diodes advantage is described in follows [44]:

- LD is operating in lower power rather than other laser types.
- LD can generate a high-power output when compared to other types of lasers.
- LD is smaller in size.
- It can easily have manufactured in arrays.
- It is the relatively low-cost device that can used to produce laser output.
- LD has high efficiency.

Some disadvantage of LD is given below [44]:

- It produces more divergent laser beam.

- LD needs big and expensive optics for large source size.
- It has suffered from heating problem.
- LDs are needs high drive current in order to drive the large laser pellets.

The most important LD issue, that LD is very sensitive to changes in current and temperature, in which the wavelength of LD can change by approximately 0.1 nm/◦ and the threshold current and efficiency may change significantly because of temperature and aging. Thermal, electrical and optical feedback is required to maintain operation and protect the LD from failing. This adds cost and complexity to the system. The LD sensitivity leads to lower reliability and reduce the life times.

From prior discussions it's clear that the both LDs and LEDs have weaknesses and strengths when considering using in optical communications. The LDs have higher optical power output and can switch faster, in other hand the LED systems are simpler, cheaper and more dependable. While the minimal divergence and the coherence of LD are ideal for fiber optic communication systems, it don't play as big a role in free space optical communication. Furthermore, whilst the LDs can switch faster, the LEDs can switch fast enough for various applications. Table 2.2 shows a comparison of the main features of LED and LD for wireless optical communication systems.

Table 2.2: LED vs. LD for wireless optical communication System

Characteristics	**LED**	**LD**
Modulation bandwidth	From tens of kilohertz up to hundreds of mega hertz	From tens of kilohertz up to tens of gigahertz
Optical spectral width	25nm-100nm	0.1nm to 5nm
Special circuit required	None	Temperature and threshold compensation circuitry
Eye's safety	It can be considered eye-safe	Should be rendered for eye-safe
costly	Low cost	Moderate to high cost
Reliability	High	Moderate

2.5 DISPERSION PHENOMENA IN OPTICAL COMMUNICATION SYSTEMS

Dispersion refers to a broad class phenomenon relate the fact that the electromagnetic wave velocity is depends upon the wavelength. In telecommunication point of view, the dispersion term is commonly used to describe the processes which can cause degraded in optical signal that propagating in an optical fiber and carried by the electromagnetic waves. This deterioration occurs due to the different components of radiation have numerous frequencies propagate with varied velocities. The dispersion phenomena are especially important in optical telecommunication. They present a specific challenge once an optical link utilizes a cheap LD at relatively high frequencies. This problem stems from the absence of good linearity through the conversions of the electrical signal inside the light source. The frequency dependent distortion usually limits the bandwidth of transmission system. They're several methods for minimization and control, however, they may need the use of a prohibitively and alternate expensive laser, or a more complicated system design. Digital devices use multi-level symbol sequences or binary to display information [45, 46].

The digital channel performance is depending upon it conveying a timely rendering of the original data, without exceeding a certain probability of error. Unfortunately, the inherent non-linearity of a LD working at the frequencies needed to achieve high bit-rates may causes distortion to the optical signal. A distorted signal can change the shape and/or phase of the data symbol, forming errors and inter-symbol interference (ISI) at the decision gate of the receiver. This leads to rise in bit-error rate (BER) of the channel and may be a limiting the factor for the info services that system can support. The most networked data exists or originates is in analogue form, and the most terminal devices is analogue in nature. Therefore, the optical transmission systems that utilize analogue modulation techniques have got the potential to allow end-users to prevent the replacement of their present devices. However, due to the benefits and the affordability of digital technologies, the exchange of predominantly analogue data is rapidly changing through the world. So, the transmission systems that economically make it possible for some flexibility in controlling a migration from analogue to digital forms have become favored assets to network operators [47].

Changes to a transmitted optical frequency, intensity/power, phase or electric field should be analogous or proportional to corresponding input signal variants. The performance of analogue transmission system is measured by evaluating the quantity of interference and noise that is applied to the signal waveform. As a result, the transmitter, the receiver, the waveguide and collectively need to deliver a linear response. Within the bounds of their systems, microwave and electrical systems have been successful in handling analogue data. Even so, much of the potential in optical systems is still untapped. Especially, the inexpensive LDs modulation have used analogue signals is currently restricted to low-frequency bands since the device non-linearities considerably degrade their optical efficiency at high frequencies. Many analogue systems face this kind of problem when a bandwidth is higher than 600 MHz is needed [47].

The LD non-linearity, that has a frequency dependent element, however contributes significant signal distortion once the complex waveform has 'high-frequency' contents. Additionally, to the frequency factor which usually causes optical signal distortion, an increase in the channels number carried by the system raises the peak-to-rms ratio on the modulating signal. This implies that the channels number may also affect the distortion from the LD. Considering that the distortion effects from one channel could fall inside the bandwidth of many other channels, the greater the channels number carried by the optical system, the greater the challenge with inter-channel interference. The larger the nonlinearity of the characteristic of LD modulation, the further prominent the interference, and the reduce the signal-to-noise ratio (SNR) for every multiplexed channel. This problem could be prevented by either using modulation systems which usually are nearly linear through a broader bandwidth or by limits the channel count. The degree of linearity needed depends on the number of channels (or sub-carrier frequencies) given by the system, and also the threshold of each channel to interference and noise [48].

Apart from modulation plans and data formats, an optimally designed and constructed optical transmission system may also need the detailed consideration of dispersion. The dispersion is a bandwidth limiting distortion effect which occurs within the optical waveguide. It could be minimized by decreasing the travel length within the fiber, by utilizing high-cost narrow line-width lasers, or by utilizing spectral wavelengths at or near the zero-dispersion transmission wavelength. Because of the nature of many distribution networks, the main trunk segments which are long enough to handle dispersion limitations may afford the expense of handpicked, 'high-end' light sources. Since the transmission service given by such a trunk segment is distributed among very most downstream clients, its expensive may also be justifiable and distributed. Amongst network segments in which the distances are generally short, dispersion effects are much less significant.

This realm of application allows LD line-width requirement to be less expensive and restrictive [49].

In summary, the radiation of shortest wavelengths has greater refraction indices when compared to that for the longest wavelengths, thus, the light at varied wavelengths is transferring with different speeds. The further monochromatic light via the transmitter the greater velocity difference between shortest and longest component propagating throughout the medium. Certainly, the small band width of the optical source, the lesser dispersion effects. However, there are some other factor can be effect on pulse width such as thermal effect that what we would discovering in our experiment.

2.5.1 Signal Distortion Concepts

Due to dispersion as the optical pulses transfer over the transmitting medium (such as fiber) they broaden. The spectrum broadening is bad phenomena in optical communication systems that lead to losing of data due to saturation in spectrum of sources when light transfer through different medium. as shown in Fig 2.13. When the pulses transfer on the medium due to broadening, the pulses start overlapping slowly with each other. After some distance the pulses barely stay distinguishable. once the signal propagates even more, the pulses lose their identity and the information is lost [50].

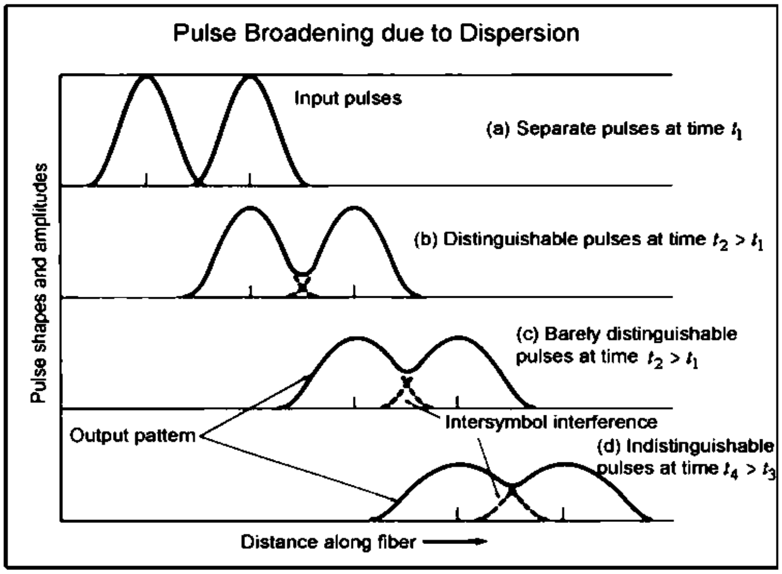


Figure 2.13: Pulse broadening due to dispersion

The dispersion represents the pulse broadening per unit distance per unit spectral width of the optical source. To calculate dispersion, first we get the group velocity of the pulse, which can be calculated from following formula [50]:

$$v_g = \frac{\partial w}{\partial \beta} = 2\pi c \frac{\partial}{\partial \beta}\left(\frac{1}{\lambda}\right) \qquad (2.2)$$

Where: β is the propagation constant, w is the frequency of the signal, c is the light velocity in vacuum, λ is the corresponding free-space wavelength.

The pulse broadening can be calculated from [50]

$$\mathrm{B} = \frac{\partial t_g}{\partial \lambda}\,\sigma_\lambda \qquad (2.3)$$

Where: B is the pulse broadening, t_g is the group delay per unit length which can be calculated from [50]:

$$t_g = \frac{1}{v_g} = 2\pi c \frac{\partial}{\partial \beta}\,(\frac{1}{\lambda}) \qquad (2.4)$$

Then, by subtracted the equation 2 in 4 and 4 in 3 we can get the pulse broadening equation [50]:

$$\mathrm{B} = -\,\frac{\sigma_\lambda}{2\pi c}\left\{2\lambda\frac{\partial \beta}{\partial \lambda} + \lambda^2\frac{\partial^2 \beta}{\partial \lambda^2}\right\} \qquad (2.5)$$

And the dispersion can be calculated from:

$$\mathrm{D} = \frac{\partial t_g}{\partial \lambda} = -\,\frac{1}{2\pi c}\left\{2\lambda\frac{\partial \beta}{\partial \lambda} + \lambda^2\frac{\partial^2 \beta}{\partial \lambda^2}\right\} \qquad (2.6)$$

Where: D is the Dispersion, which is the pulse broadening per unit distance per unit spectral width, unit (ps/Km/nm)

2.5.2 Effect of The Group Velocity Dispersion on Optical Pulse

To illustrate the group velocity dispersion (GVD) influence on the pulse propagation for fiberoptic in “linear” regime. The main effects associated with GVD are [51]:

- The group velocity dispersion caused the pulse broadening
- The group velocity dispersion caused the pulse chirping
- The group velocity dispersion caused the pulse compression

The equation that presents the effect of GVD on propagation of optical pulse ignoring the loss and nonlinearities is [51]:

$$i\frac{\partial E}{\partial z} = \frac{\beta_2}{2}\frac{\partial^2 E}{\partial t^2} \tag{2.7}$$

Where i, is the direction of the propagation, E, is the envelope of electric field, t is the time, z, the pulse path, β_2 is the GVD parameter. β_2 is the 2nd derivative of the propagation constant in fiber mode with frequency consideration, which can be calculating from following equation [51]:

$$\beta_2 = \frac{\partial^2 \beta}{\partial \omega^2} \tag{2.8}$$

Where β, is the fiber mode propagation constant, ω is the laser frequency.

For the Gaussian shape input pulse, the pulse width (temporal pulse duration) on z can be calculated by [51]:

$$T = T_0\sqrt{1 + \left(\frac{T_c}{T_0}\right)^4} \tag{2.9}$$

Where: τ_0 is the pulse width of time that is related to the pulse full width τ_{FWHM} at half maximum $\approx 1.665\tau_0$) is increases with z, and τ_c is computed by [51]:

$$T_c = \sqrt{\beta_2 z} \tag{2.10}$$

the L is the fiber length, which can be calculated by [51]:

$$L_D = \frac{T_0}{|\beta_2|} \tag{2.11}$$

By subtract 2.10 and 2.11 in 2.9 we get:

$$T = T_0\sqrt{1 + \left(\frac{z}{L_D}\right)^2} \tag{2.12}$$

Then,

$$\frac{T}{T_0} = \sqrt{1 + \left(\frac{z}{L_D}\right)^2} \tag{2.13}$$

Or,

$$\left(\frac{T}{T_0}\right)^2 = 1 + \left(\frac{z}{L_D}\right)^2 \tag{2.14}$$

Then

$$\left(\frac{T}{T_0}\right)^2 - 1 = \left(\frac{z}{L_D}\right)^2 \tag{2.15}$$

OR

$$\frac{z}{L_D} = \sqrt{\left(\frac{T}{T_0}\right)^2 - 1} \tag{2.16}$$

Thus

$$L_D = \frac{z}{\sqrt{\left(\frac{T}{T_0}\right)^2 - 1}} \tag{2.17}$$

Also, the peak power changes, because of GVD, are given by [51]:

$$P(z) = \frac{P_0}{\left[1 + \left(\frac{z}{L_D}\right)^2\right]^{1/2}} \tag{2.18}$$

And, the group velocity C can be calculated from:

$$C = \frac{2\pi\,\Delta\lambda}{T} \tag{2.19}$$

$$PT = \frac{2\pi\,\Delta\lambda}{C} \tag{2.20}$$

Where: C, is the pulse width of laser wavelength that is related to the pulse full width τ_{FWHM} at half maximum

For: $T = T_0 \longrightarrow \Delta\lambda = \Delta\lambda_0$

Then:

$$T_0 = \frac{2\pi \, \Delta\lambda_0}{C} \tag{2.21}$$

By subtract 2.20 and 2.21 in 2.16 we can get:

$$\frac{z}{L_D} = \sqrt{\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2 - 1} \tag{2.22}$$

As an example, the group velocities that may affect on optical signal that transfer throughout medium can be influenced by material dispersion. This mainly because of the group velocities of several materials become varied. As a result, the different materials that cover the optical path L in many times may causes the material pulse broadening. Figure 2.14 illustrated the broadening effect for the temporary pulse of the Gaussian shape through the propagation in an optical fiber [51].

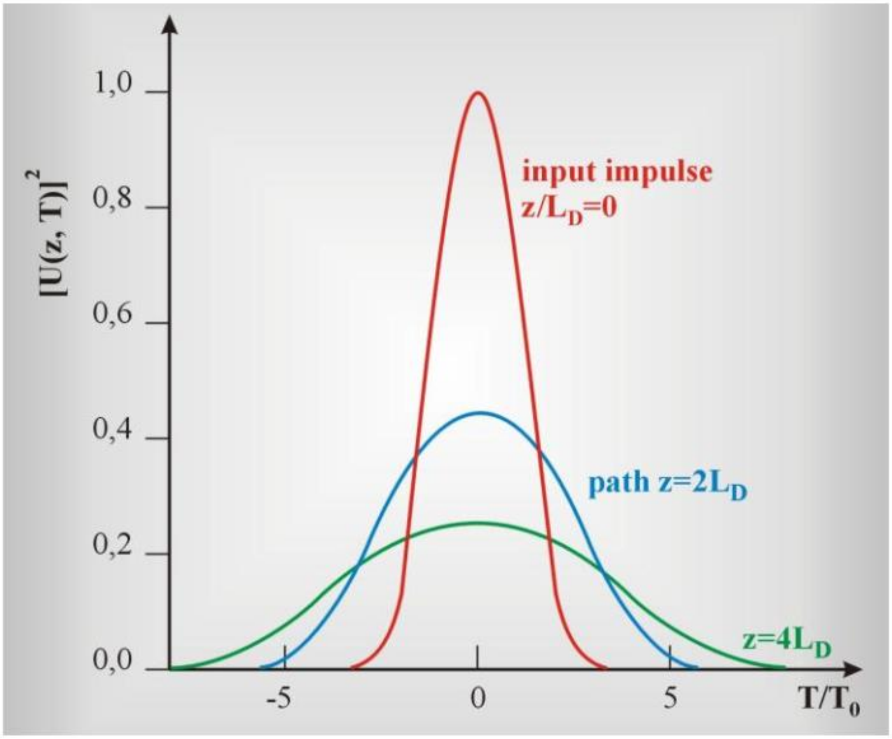


Figure 2.14: Pulse Broadening of the Gaussian shape through the propagation in an optical fiber

3. EXPERIMENTAL SETUP

3.1 INTRODUCTION

This chapter explained the experimental setup and the instruments used to study the spectral width effected by increasing of frequency that casus the increase in temperature in light sources which can cause dispersion of spectrum in the beam and a visual red shift. Three types of light sources (LED, PLED and LD) and three wavelengths (650, 780, and 810nm) for each one has been used and tested. The circuited has been designed to provide different frequencies (10, 100, 10000, 100000 and 500000) Hz for small pulse width (100, 500 and 1000) ns. A digital oscilloscope is used to monitor the modification of frequencies due to changed capacitor and resistors values. A two type of spectrometer has been used to monitor the laser pulse and detect the shifting in wave length and the spectrum width as raised the frequency of light source. All specification of equipment as well as the circuit design have described in detail.

3.2 EXPERIMENTAL SETUP

The experiment involves devices and component that been used to monitor the changes in optical wave as the change of frequency. The light sources have been tested are: three types of laser diode (LD) of wavelengths (650, 780, 810) nm, three light emitted diode (LED) of wavelengths (650, 780, 810) nm and three polymer Light-Emitting diode (PLED) of wavelengths (650, 780, 810) nm. Figure 3.1 shows the experimental setup in laboratory.

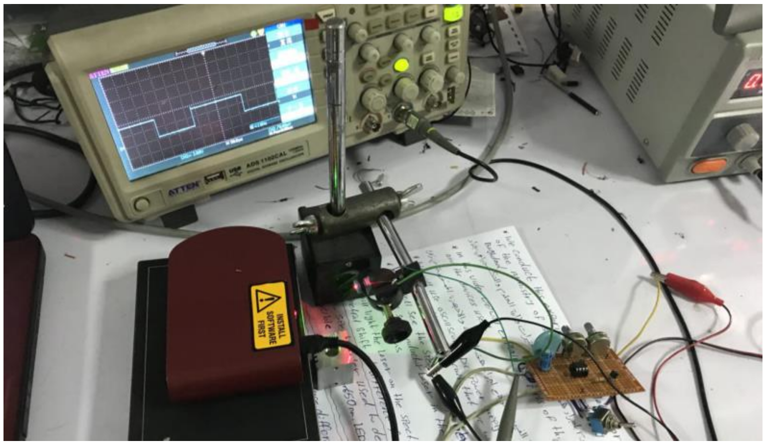


Figure 3.1: Experimental Setup

3.2.1 Optical and Electronic Parts

3.2.1.1 Oscillation Circuit

The first part is the oscillation circuit which is used to change the frequency of optical transmitter. The circuit consisted from IC timer, which is capable of producing accurate time delays or oscillation. We used a monolithic timing circuit type NE555. The circuit includes two 50KΩ potentiometer, three capacitors of value: (C1= 5nf), C2= (10nf), and C3= (47nF). and one bipolar transistor. The light source used in test are: three laser diodes, LED and PLED of wave length (650nm, 780nm and 808nm). The circuit has been supplied by 5-volt DC power supply. Figure 3.2 show the circuit diagram.

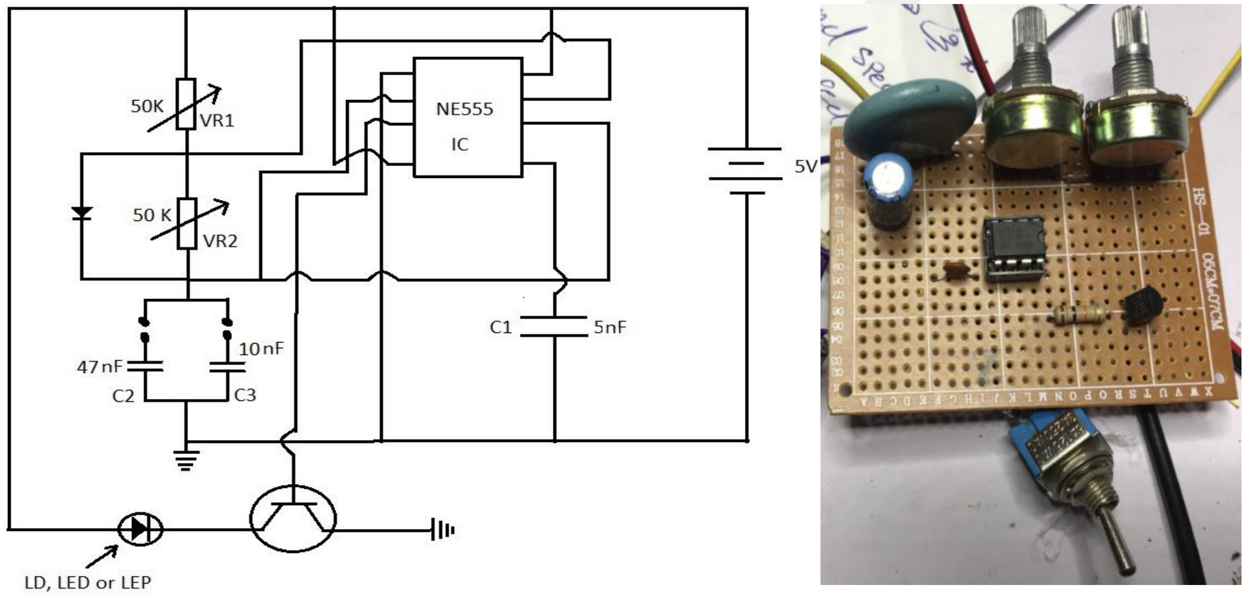


Figure 3.2. oscillation circuit diagram

3.2.1.2 Light Sources

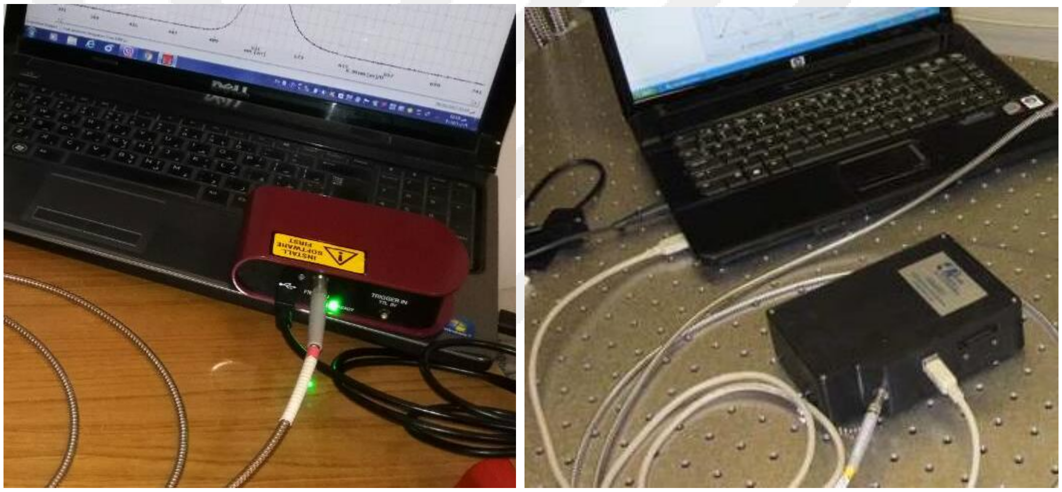
The light sources used in experiment are

1. Three laser diode (LD) of wavelengths (650, 780, 810) nm
2. Three light emitted diode (LED) of wavelengths (650, 780, 810) nm
3. Three polymer Light-Emitting diode (PLED) of wavelengths (650, 780, 810) nm

3.2.2 Experimental Devices

3.2.2.1 Spectrometer

In order to investigate the effect of increase of frequency on optical sources, we have used spectrophotometer. We have been used two types of spectrometer, first is high-sensitivity optical spectrum analyzer type "Thorlabs" (figure 3.3-a) of range between (320 nm) and (740 nm) and 50pm sensitivity this used to detect shifting for visible range 650nm (LD, LED and PLED) and the high-resolution spectrometer type "Ocean Optics HR4000" (figure 3.3-b), which give a spectral output for wave range from 700nm to 900nm and 50pm sensitivity. Figure 3.3 shows the two spectrometers used in experiments.



(a) (b)

Figure 3.3: Spectrophotometer, (a) Thorlabs, (b) Ocean Optics HR4000

3.2.2.2 Oscilloscope

For check the value of frequency modified by oscillation circuit, we have used 200 MHz digital oscilloscope type "Tektronix TDS2022C" that provides affordable performance in a compact design. It has up to 200MHz bandwidth and 2GS/s maximum sample rate, The Tektronix offers real-time sampling with a minimal of 10X oversampling on each channel, at all times to effectively capture signals. And it useful in this work. Figure 3.4 shows the Tektronix TDS2022C oscilloscope used in experiments.

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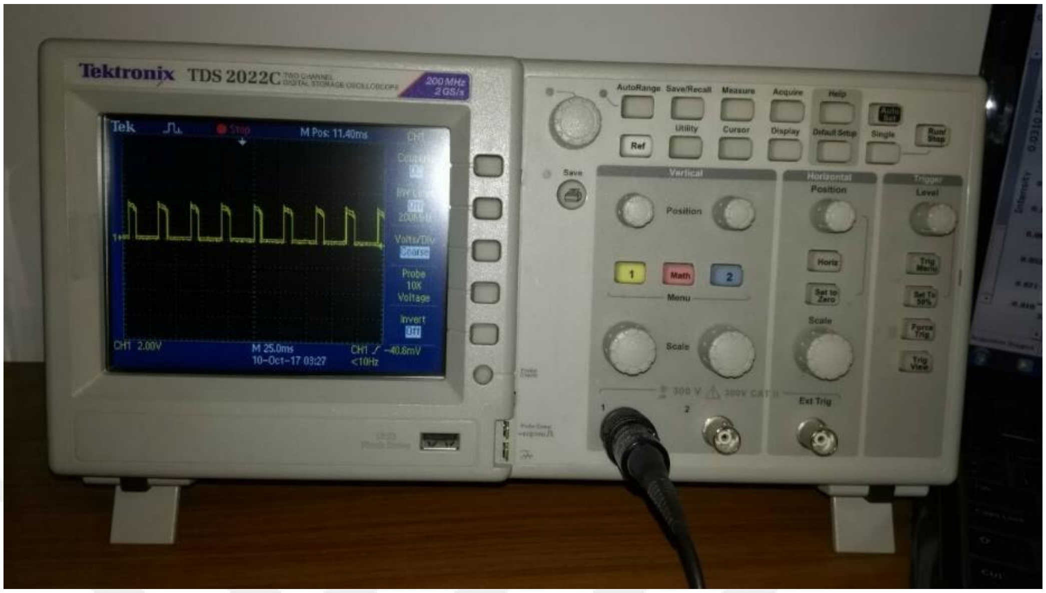


Figure 3.4: Tektronix TDS2022C Digital Storage Oscilloscope

3.2.2.3 DC Power Supply

A variable switching dc power supply type HYelec model “HY5005E-2” have been used in order to supply circuit by DC voltage to. Figure 3.5 shows the power supply used in experiments.

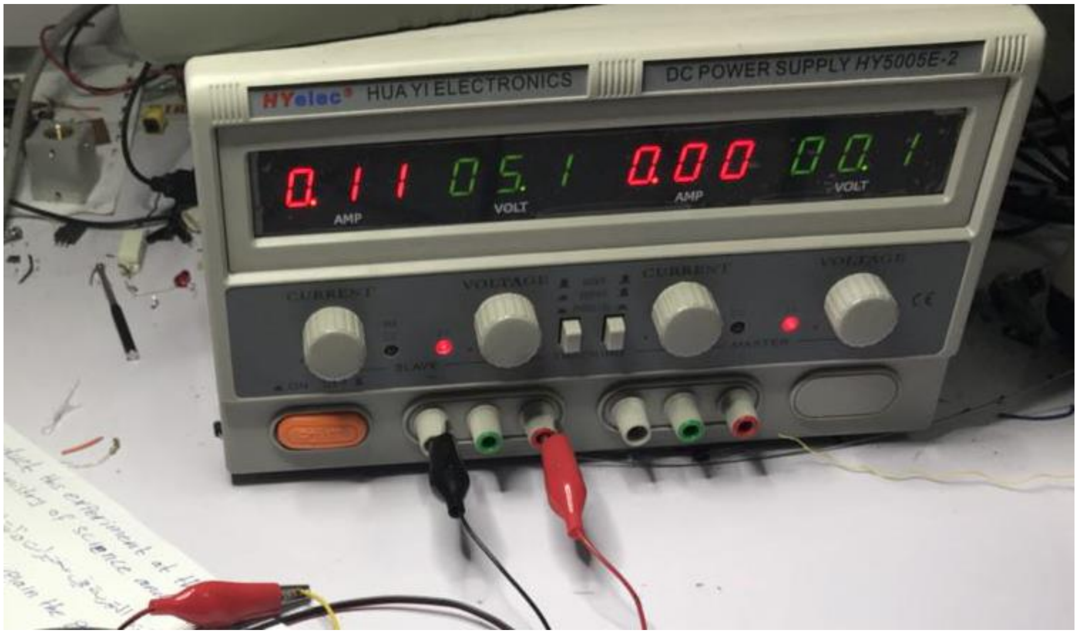


Figure 3.5: HY5005E- HYelec DC power supply

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter shows the measurements results that have been obtained from laboratory experiment. The test is focused on measured the wavelength shifting for LD, LED and PLED when increases the frequencies and determine the wave shift and spectrum shift as an increase of frequencies. Finally discuss the result in detail.

4.2 WAVELENGTH SHIFT MEASUREMENT

To measure the red shift in wavelength for light source of LD, LED and PLED, we have test these light sources for three wavelengths (650, 780, 810) nm for a range of frequcies and three pulse duration. In order to calculate the wavelength shifting value and the spectrum shift (dispersion in signal), we first measured the laser wavelength (λo) and the spectrum width (Δλ) at steady state (at low frequency), after that we have changed the value of potentiometer in oscillation circuit in order to get a range of frequencies on optical sources then measure the quantity of shifting in wave length and increases in spectrum width (Δλ) as increasing of that frequency. Figure 4.1 illustrated the calculation method.

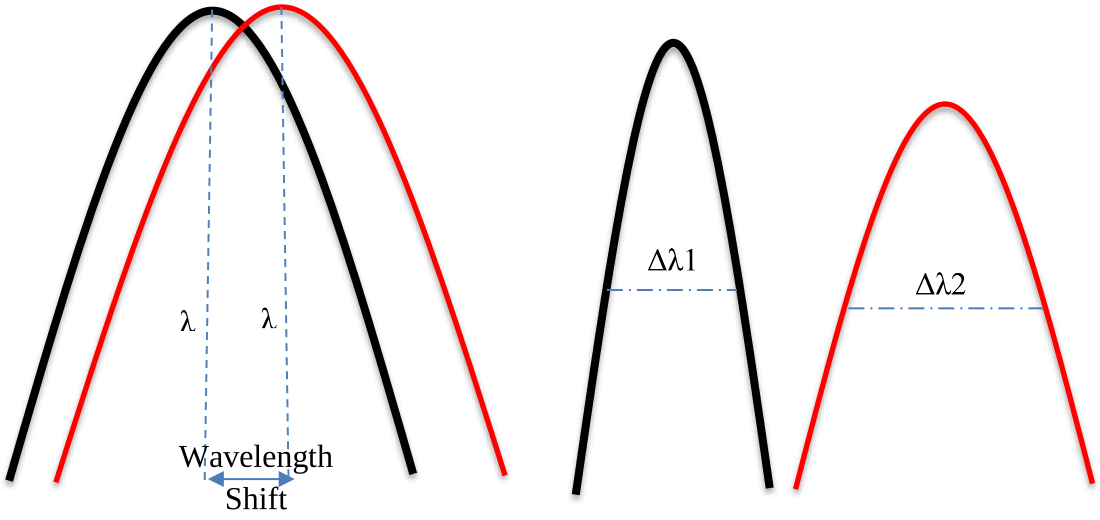


Figure 4.1: wavelength shift (Left), the spectrum shift (right)

As shown from figure 4.1 (left), the wavelength can subject to shift in its wave length by:

$$W_{sh} = \lambda_0 2 - \lambda_0 1 \tag{4.1}$$

Where: W_{sh}, is the wavelength shift. $\lambda_0 1$, is the laser wavelength at lower frequancy. $\lambda_0 2$, is the laser wavelength after increasing the frequancy.

The laser pulse is also subject to change in its spectrum width, as shown from figure 4.1 (right), the change in spectrum width can effect on signal which cause pulse brodinning and as a result dispertion in data. The spectrum shift can be calculated exprementaly by compute the pulse width at low frequancy then compute the changes in pulse width as a result of increasing the frequancy:

$$S_{sh} = \Delta\lambda 2 - \Delta\lambda 1 \tag{4.2}$$

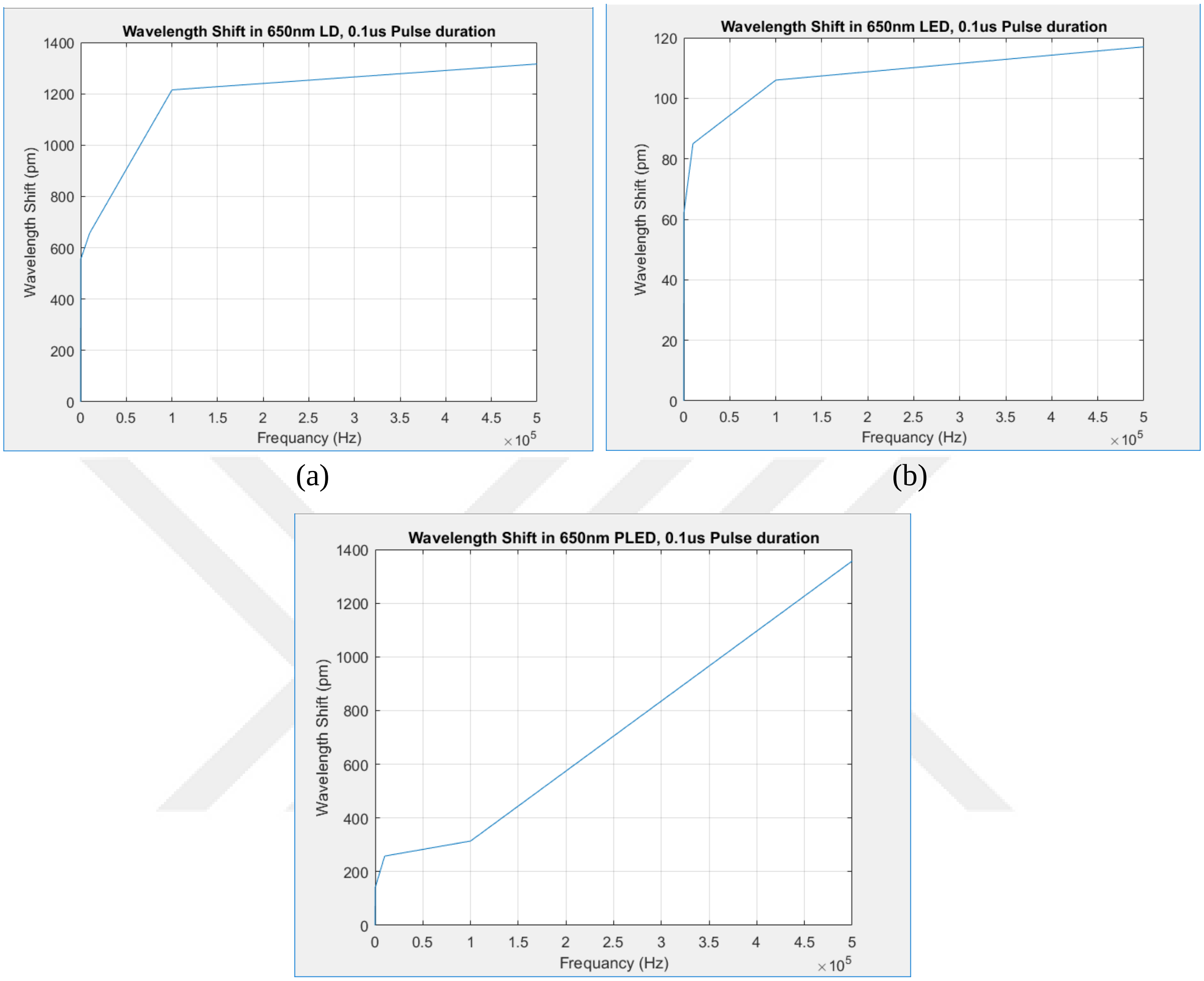
Where: S_{sh}, is the spectrum width shift. $\Delta\lambda 1$, is the spectrum width of the laser pulse at lower frequancy. $\Delta\lambda 2$ is the spectrum width of the laser pulse after increasing the frequancy.

4.2.1 LD, LED and PLED at (650nm) and (0.1μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.1 shows the value of shifting with various frequencies, figures 4.2 is illustrated the wavelength shift.

Table 4.1: Wavelength shift for 650nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.1	638. 131	0	689.851	0	685.373	0
100	0.1	638. 687	556	689.913	62	685.514	141
10000	0.1	638. 789	658	689.936	85	685.631	258
100000	0.1	640.004	1215	689.957	106	685.687	314
500000	0.1	640.105	1316	689.968	117	686.730	1357



(a) (b)

(c)

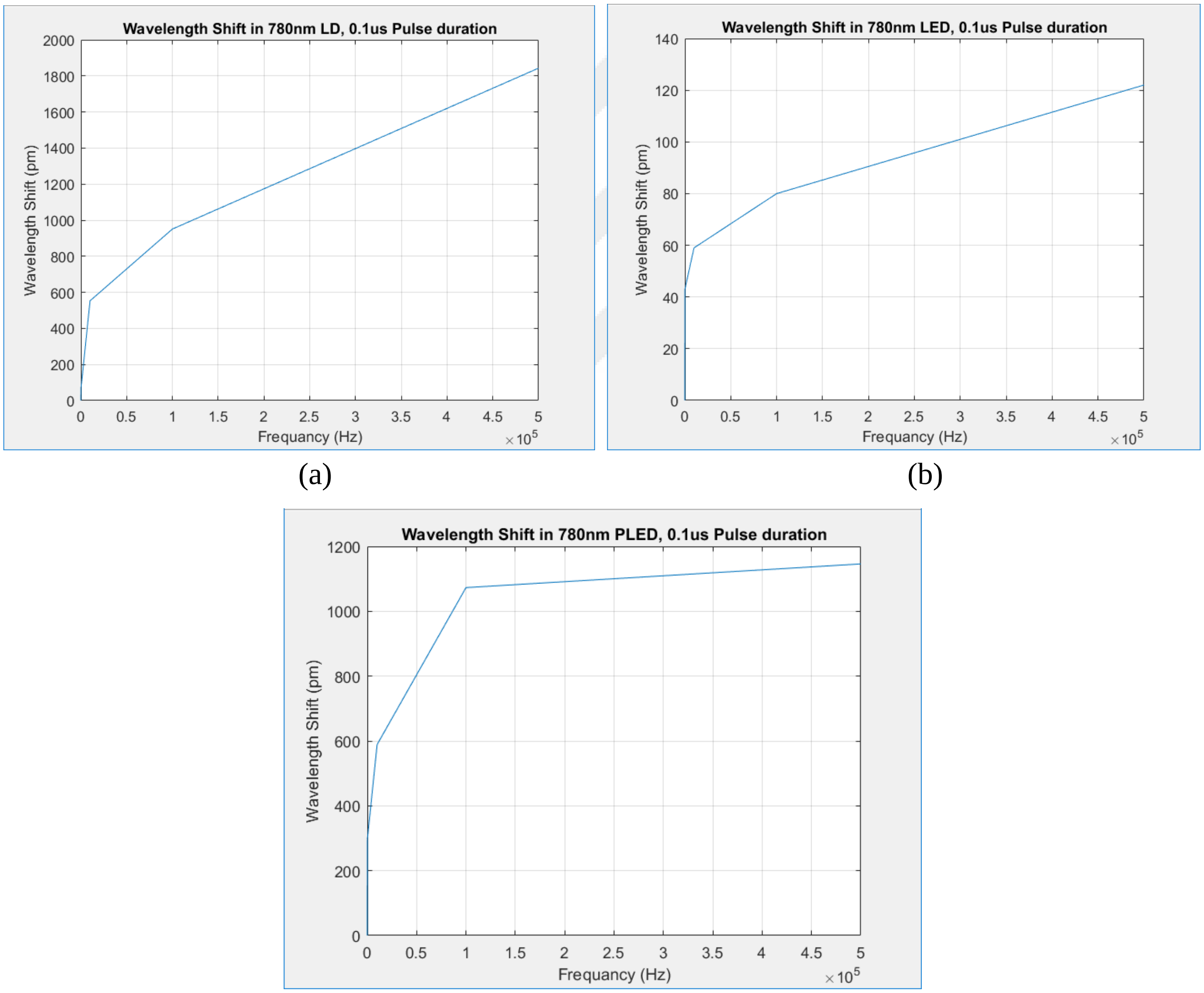
Figure 4.2: The wavelength shift at 0.1μs pulse duration for 650nm: (a) LD, (b) LED, (c) PLED

4.2.2 LD, LED and PLED at (780nm) and (0.1μs) Pulse Duration

The 780nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.2 shows the value of shifting with various frequencies, figures 4.3 is illustrated the wavelength shift.

Table 4.2: Wavelength shift for 780nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.1	784.030	0	788.642	0	772.872	0
100	0.1	784.097	67	788.685	43	773.169	297
10000	0.1	784.583	553	788.701	59	773.461	589
100000	0.1	784.981	951	788.722	80	773.945	1073
500000	0.1	785.873	1843	788.764	122	774.018	1146



(a) (b)

(c)

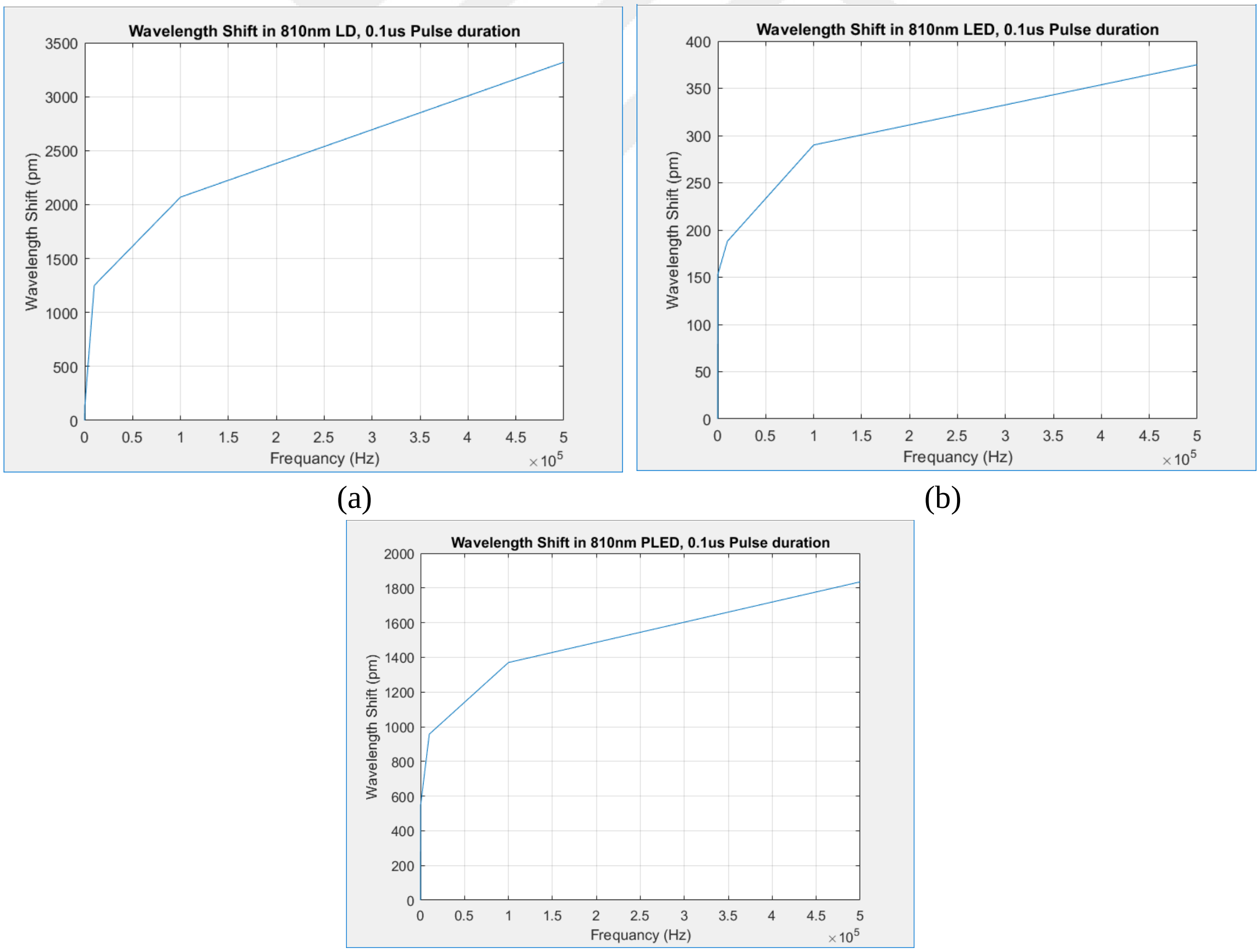
Figure 4.3: The wavelength shift at 0.1μs pulse duration for 780nm: (a) LD, (b) LED, (c) PLED

4.2.3 LD, LED and PLED at (810nm) and (0.1μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.3 shows the value of shifting with various frequencies, figures 4.4 is illustrated the wavelength shift.

Table 4.3: Wavelength shift for 810nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.1	807.766	0	809.730	0	811.018	0
100	0.1	807.894	128	809.883	153	811.563	545
10000	0.1	809.017	1251	809.918	188	811.975	957
100000	0.1	809.835	2069	810.020	290	812.388	1370
500000	0.1	811.086	3320	810.105	375	812.853	1835



(a) (b)

(c)

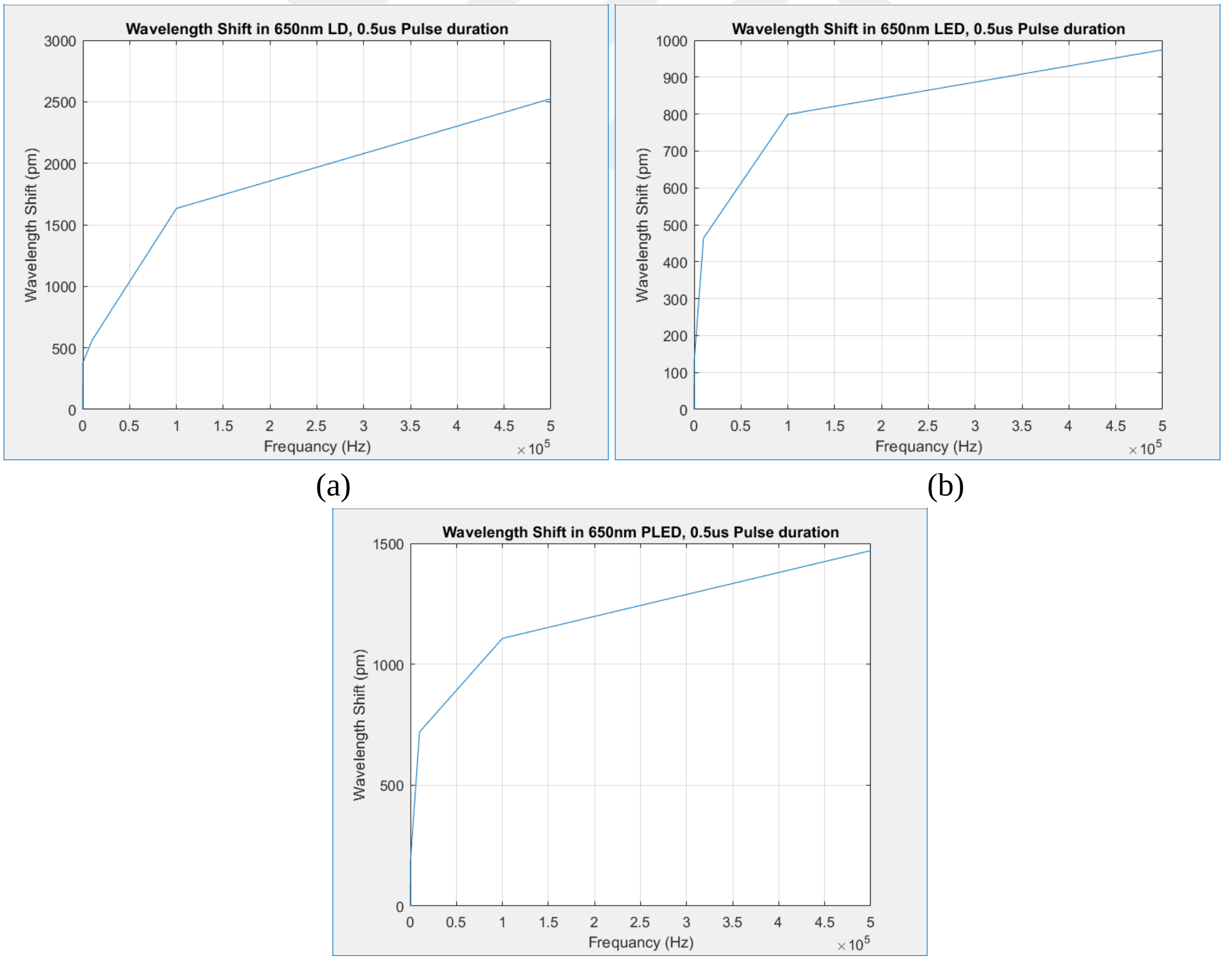
Figure 4.4: The wavelength shift at 0.1μs pulse duration for 810nm: (a) LD, (b) LED, (c) PLED

4.2.4 LD, LED and PLED at (650nm) and (0.5μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.4 shows the value of shifting with various frequencies, figures 4.5 is illustrated the wavelength shift.

Table 4.4: Wavelength shift for 650nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.5	638.353	0	689.768	0	687.550	0
100	0.5	638.733	380	689.898	130	687.735	185
10000	0.5	638.916	563	690.232	464	688.270	720
100000	0.5	639.986	1633	690.567	799	688.657	1107
500000	0.5	640.878	2525	690.742	974	689.020	1470



(a)

(b)

(c)

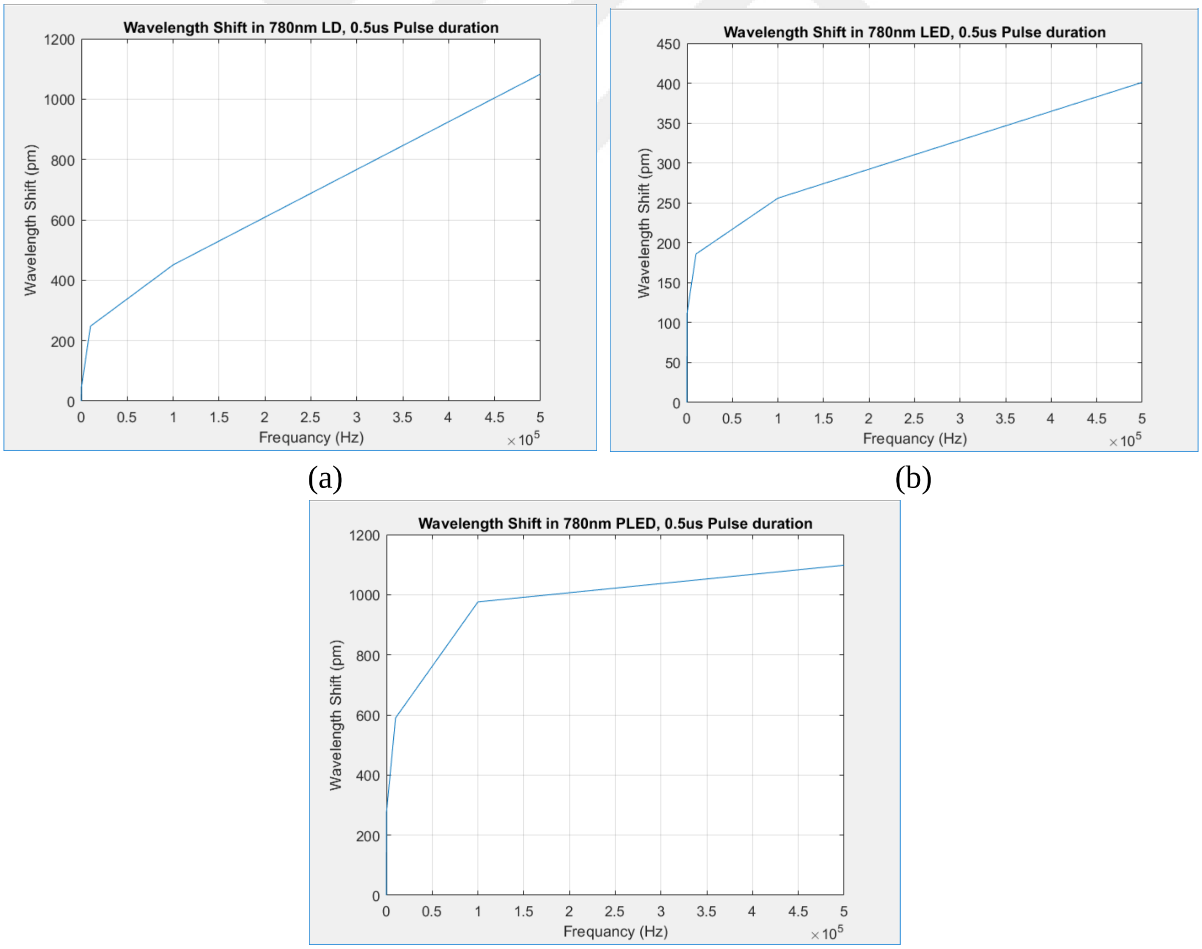
Figure 4.5: The wavelength shift at 0.5μs pulse duration for 650nm: (a) LD, (b) LED, (c) PLED

4.2.5 LD, LED and PLED at (780nm) and (0.5μs) Pulse Duration

The 780nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.5 shows the value of shifting with various frequencies, figures 4.6 is illustrated the wavelength shift.

Table 4.5: Wavelength shift for 780nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.5	784.090	0	788.564	0	772.875	0
100	0.5	784.134	44	788.675	111	773.150	275
10000	0.5	784.338	248	788.750	186	773.465	590
100000	0.5	784.541	451	788.820	256	773.851	976
500000	0.5	785.173	1083	788.965	401	773.973	1098



(a) (b)

(c)

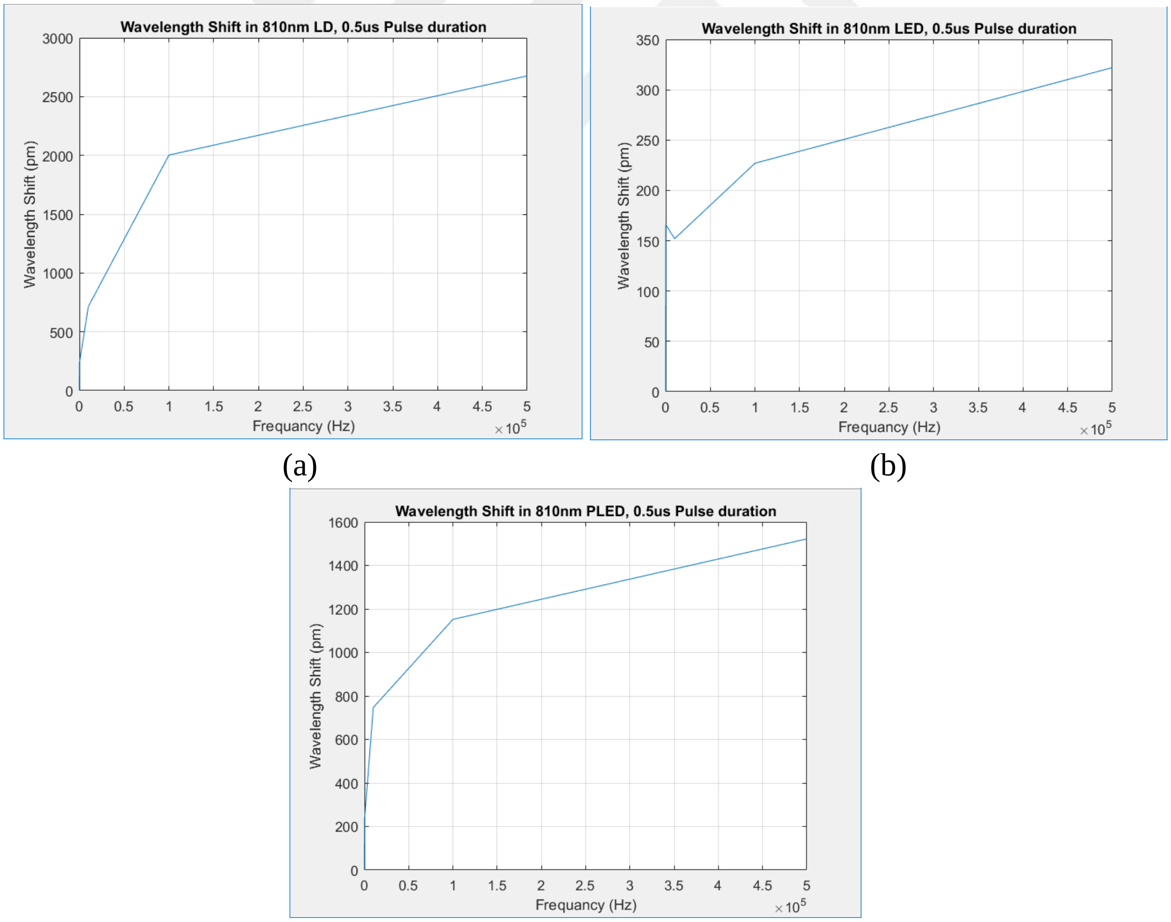
Figure 4.6: The wavelength shift at 0.5μs pulse duration for 780nm: (a) LD, (b) LED, (c) PLED

4.2.6 LD, LED and PLED at (810nm) and (0.5μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.6 shows the value of shifting with various frequencies, figures 4.7 is illustrated the wavelength shift.

Table 4.6: Wavelength shift for 810nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	0.5	807.750	0	809.558	0	811.128	0
100	0.5	807.986	236	809.724	166	811.360	232
10000	0.5	808.465	715	809.710	152	811.875	747
100000	0.5	809.753	2003	809.785	227	812.280	1152
500000	0.5	810.426	2676	809.880	322	812.650	1522



(a) (b)

(c)

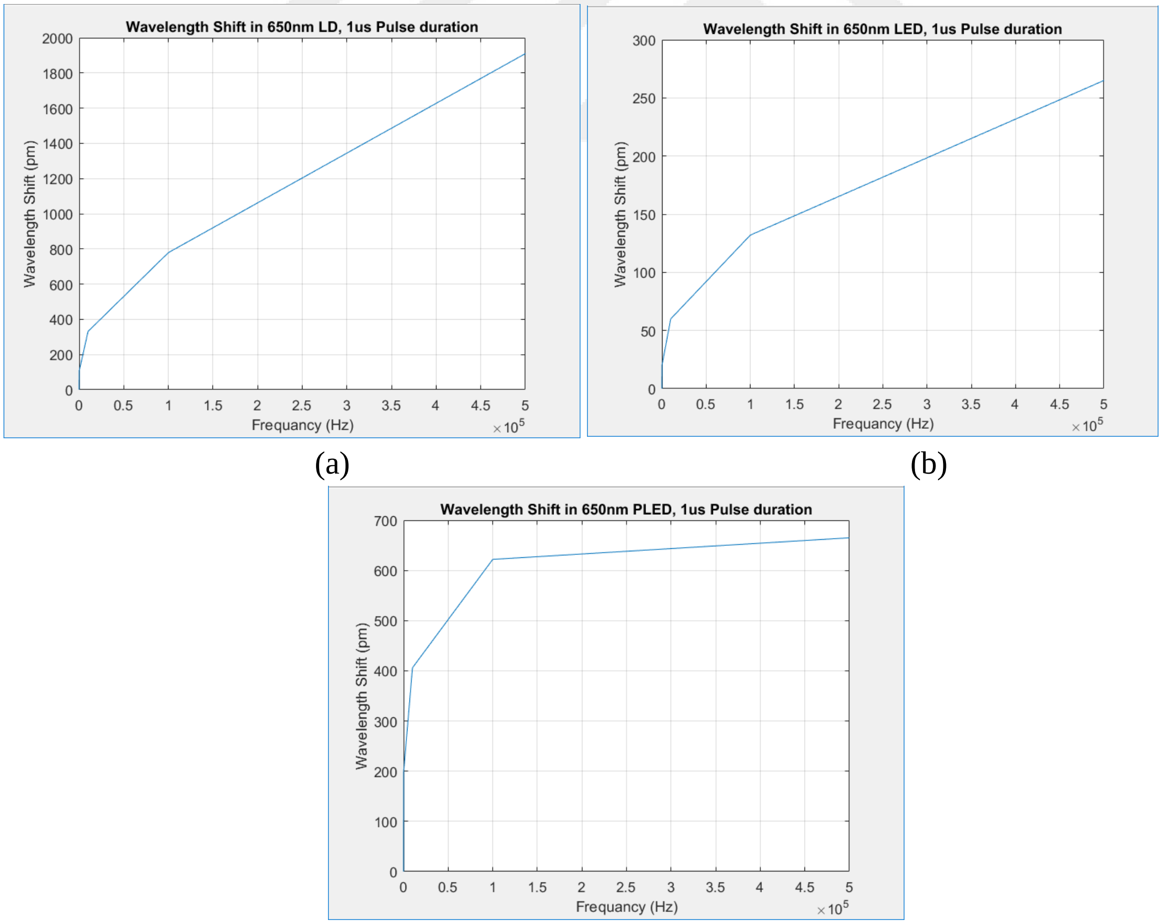
Figure 4.7: The wavelength shift at 0.5μs pulse duration for 810nm: (a) LD, (b) LED, (c) PLED

4.2.7 LD, LED and PLED at (650m) and (1μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.7 shows the value of shifting with various frequencies, figures 4.8 is illustrated the wavelength shift.

Table 4.7: Wavelength shift for 650nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	1	638.545	0	689.860	0	685.365	0
100	1	638.651	106	689.880	20	685.563	198
10000	1	638.876	331	689.920	60	685.771	406
100000	1	639.324	779	689.992	132	685.987	622
500000	1	640.455	1910	690.125	265	686.030	665



(a) (b)

(c)

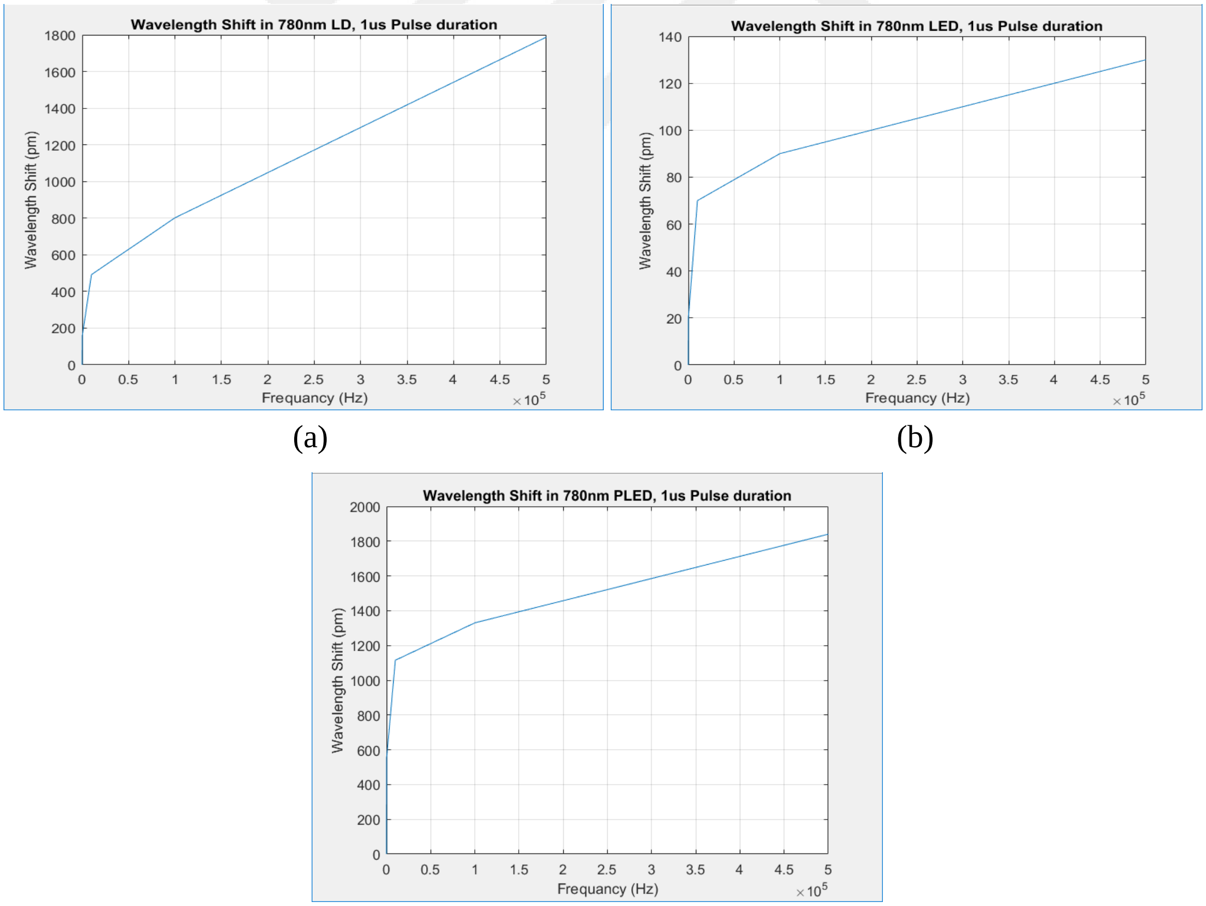
Figure 4.8: The wavelength shift at 1μs pulse duration for 650nm: (a) LD, (b) LED, (c) PLED

4.2.8 LD, LED and PLED at (780nm) and (1μs) Pulse Duration

The 780nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.8 shows the value of shifting with various frequencies, figures 4.9 is illustrated the wavelength shift.

Table 4.8: Wavelength shift for 780nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	1	784.120	0	788.630	0	772.870	0
100	1	784.277	157	788.650	20	773.153	283
10000	1	784.612	492	788.700	70	773.450	580
100000	1	784.922	802	788.720	90	773.985	1115
500000	1	785.908	1788	788.760	130	774.230	1360



(a) (b)

(c)

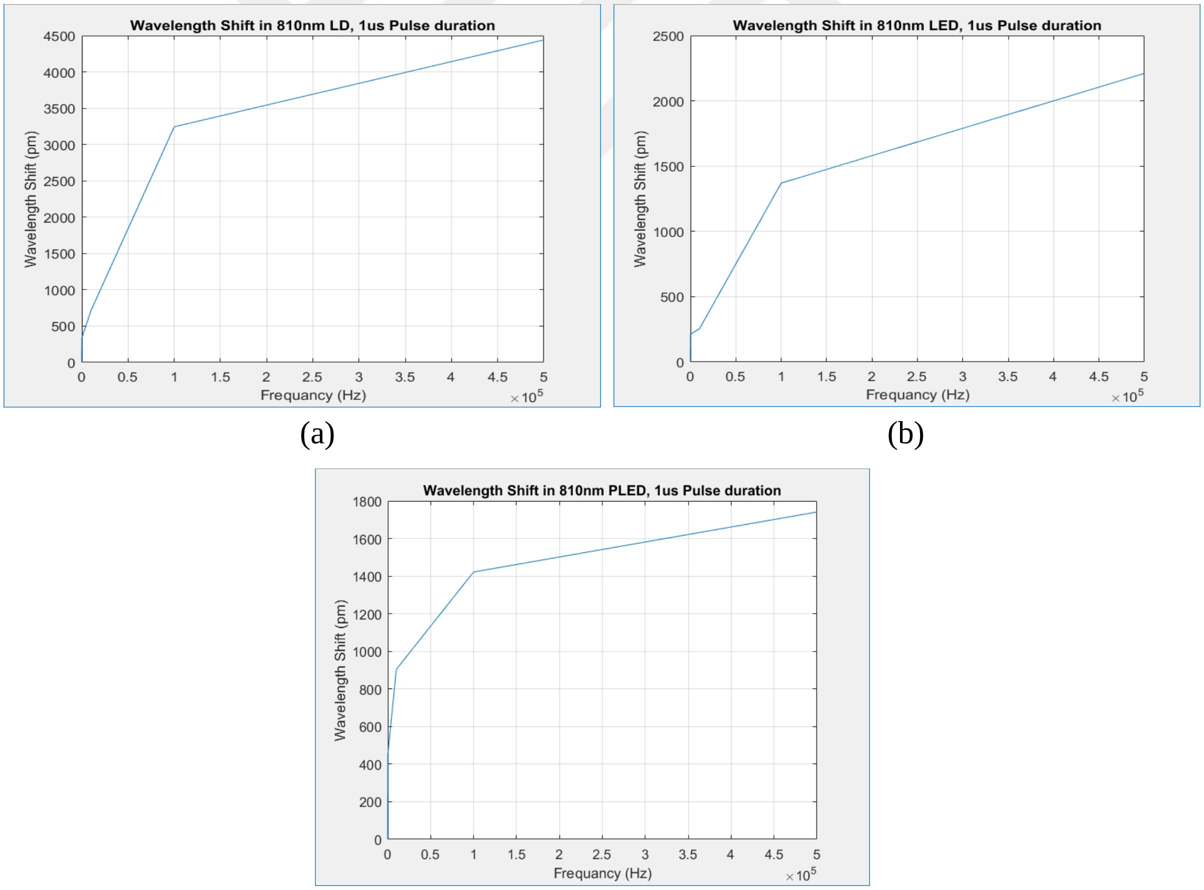
Figure 4.9: The wavelength shift at 1μs pulse duration for 780nm: (a) LD, (b) LED, (c) PLED

4.2.9 LD, LED and PLED at (810nm) and (1μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.9 shows the value of shifting with various frequencies, figures 4.10 is illustrated the wavelength shift.

Table 4.9: Wavelength shift for 810nm LD, LED & PLED as a result of changes of frequencies

Laser Type		Laser Diode		Light Emitting Diode		Polymer Light Emitting Diode	
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)	Wave length (λo) (nm)	Wave length Shift (pm)
10	1	807.540	0	809.520	0	811.217	0
100	1	807.881	341	809.733	213	811.668	451
10000	1	808.256	716	809.775	255	812.121	904
100000	1	810.784	3244	810.890	1370	812.639	1422
500000	1	811.981	4441	811.730	2210	812.958	1741



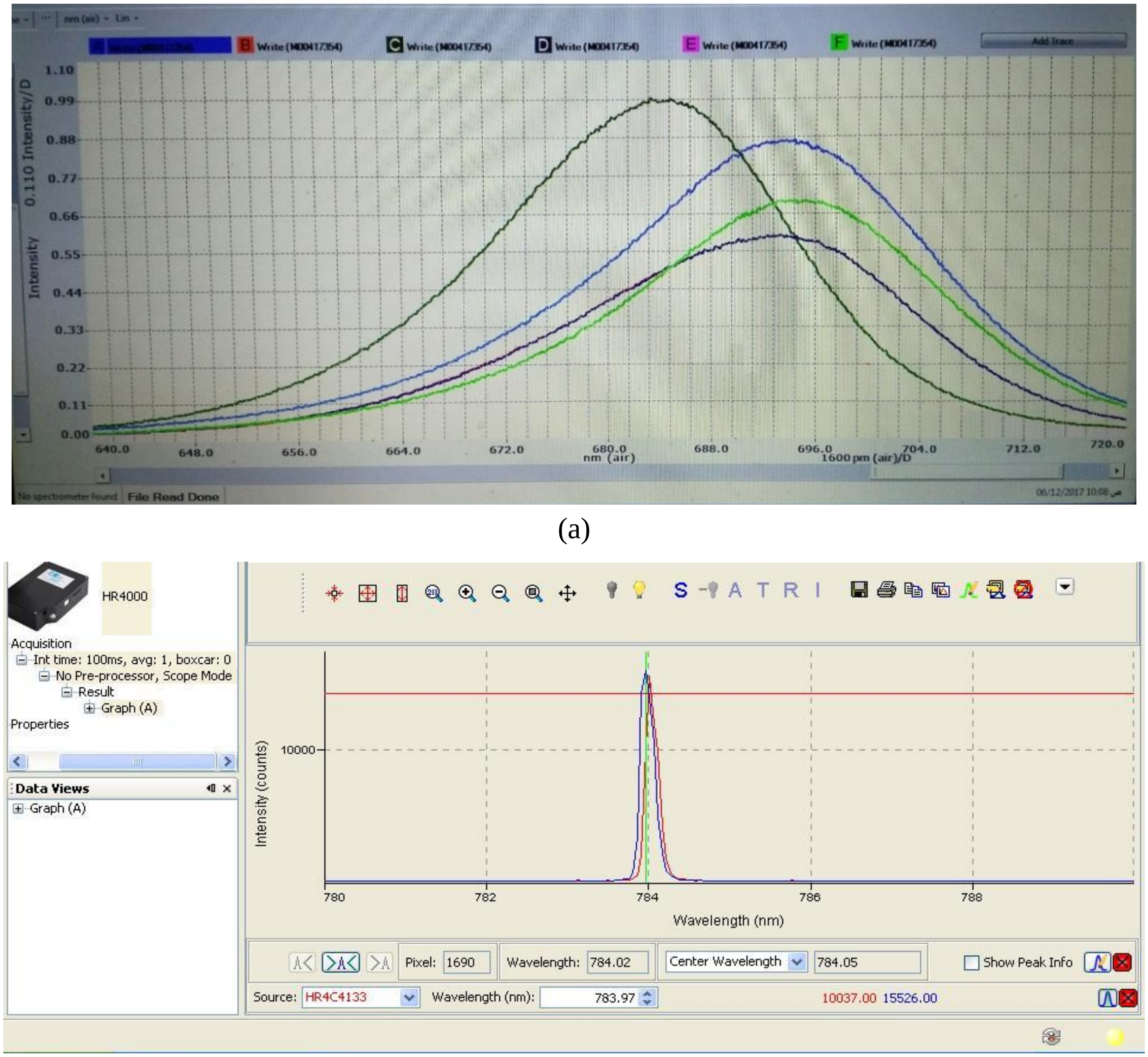
(a) (b)

(c)

Figure 4.10: The wavelength shift at 1μs pulse duration for 810nm: (a) LD, (b) LED, (c) PLED

4.3 THE SPECTRUM SHIFT MEASUREMENT, PULSE BROADENING AND DATA DISTORTION CALCULATION

As described in section 4.2, the result shows that laser pulse is subjected to wavelength shift as increase the frequancy, Howevr, From spectrometer results its appeard that the pulse width has increased as frequancy increased and the intensity decresed. Figure 4.11 shows the spectrophotmeter result for LD as a result of changing in frequancy.



Int time: 100ms, avg: 1, boxcar: 0
No Pre-processor, Scope Mode
Result
Graph (A)

Pixel: 1690
Wavelength: 784.02
Center Wavelength: 784.05
☐ Show Peak Info
Source: HR4C4133
Wavelength (nm): 783.97
10037.00 15526.00

(a)

(b)

Figure 4.11: The spectrum window shows the pulse shift and spectrum width shift for:
(a) Thorlabs spectrophotometer window for 650nm laser diode which different frequencies,
(b) HR4000 spectrophotometer window for 780nm laser diode which different frequencies,

As shown from spectrum figure 4.11, its can see that the LD pulse is changes as a result of increase the frequency. It’s clear that the plus is broadening which will be wider and the pulse high which is the intensity is reduced.

Based on equation 2.22, we can compute the length of fiber to dispersion length:

$$\frac{z}{L_D} = \sqrt{\left(\frac{\Delta\lambda}{\Delta\lambda_0}\right)^2 - 1} \tag{4.3}$$

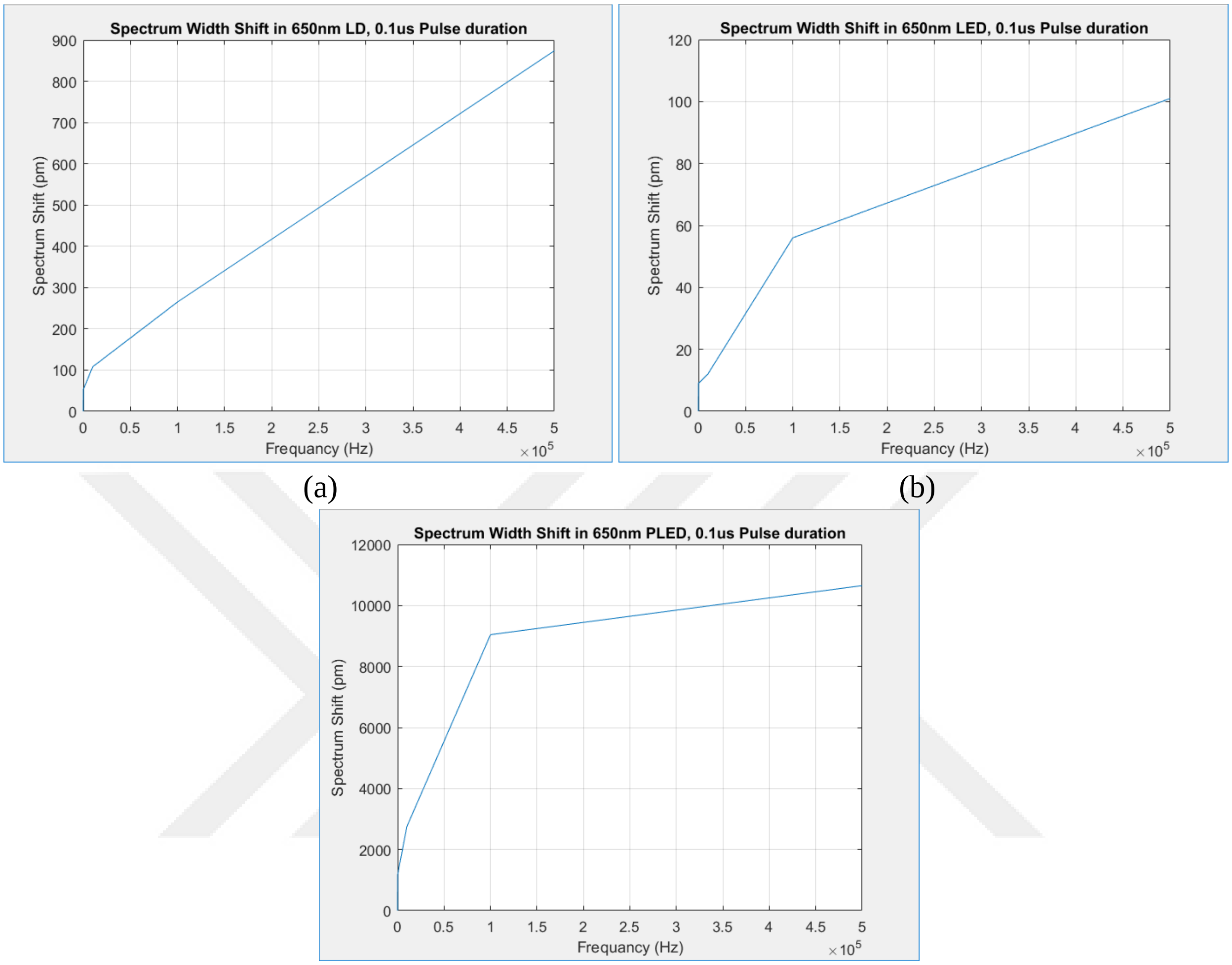
$$P(z) = \frac{P_0}{\sqrt{1 + \left(\frac{z}{L_D}\right)^2}} \tag{4.3}$$

4.3.1 LD, LED and PLED at (650nm) and (0.1μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.10 shows the value of shifting with various frequencies, figures 4.12 is illustrated the spectrum width shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.13.

Table 4.10: Spectrum width shift for 650nm LD, LED & PLED as a result of changes of frequencies

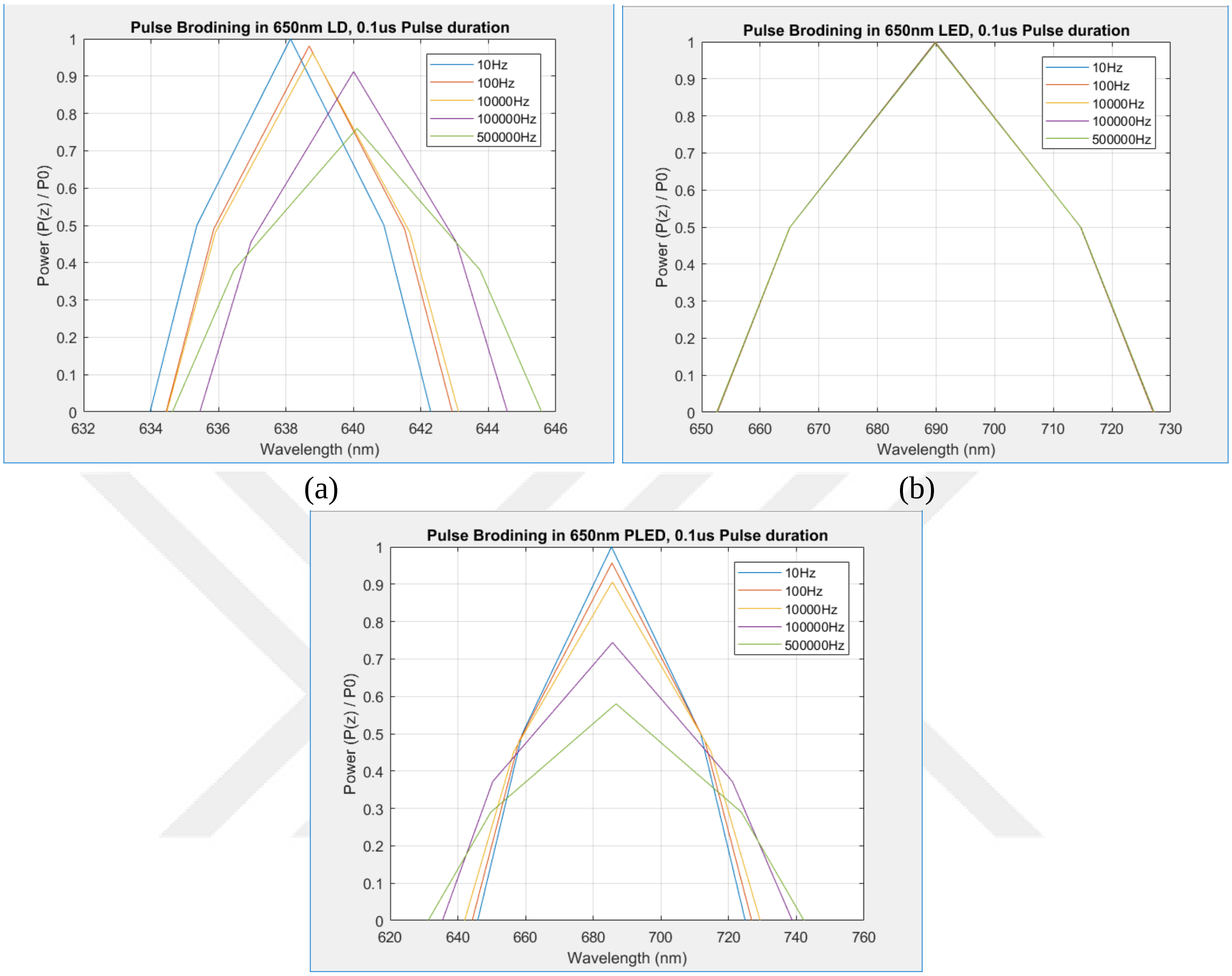
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	$(\Delta\lambda/ \Delta\lambda_0)$	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.1	638. 131	2773	0	1	0	1
100	0.1	638. 687	2826	53	1.019	0.196	0.981
10000	0.1	638. 789	2881	108	1.039	0.282	0.962
100000	0.1	640.004	3038	265	1.096	0.449	0.912
500000	0.1	640.105	3647	874	1.315	0.854	0.760
Light Emitting Diode							
10	0.1	689.851	24766	0	1	0	1
100	0.1	689.913	24775	9	1.0003	0.027	0.9997
10000	0.1	689.936	24788	12	1.0005	0.0316	0.9995
100000	0.1	689.957	24832	56	1.0022	0.0663	0.9978
500000	0.1	689.968	24877	101	1.0041	0.0907	0.9959
Polymer Light Emitting Diode							
10	0.1	685.373	26344	0	1	0	1
100	0.1	685.514	27523	1179	1.0448	0.303	0.957
10000	0.1	685.631	29097	2753	1.1045	0.467	0.906
100000	0.1	685.687	35387	9043	1.3433	0.897	0.744
500000	0.1	686.730	36994	10650	1.4043	0.986	0.712



(a) (b)

(c)

Figure 4.12: The spectrum width shift changes at 0.1μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED



(a) (b)

(c)

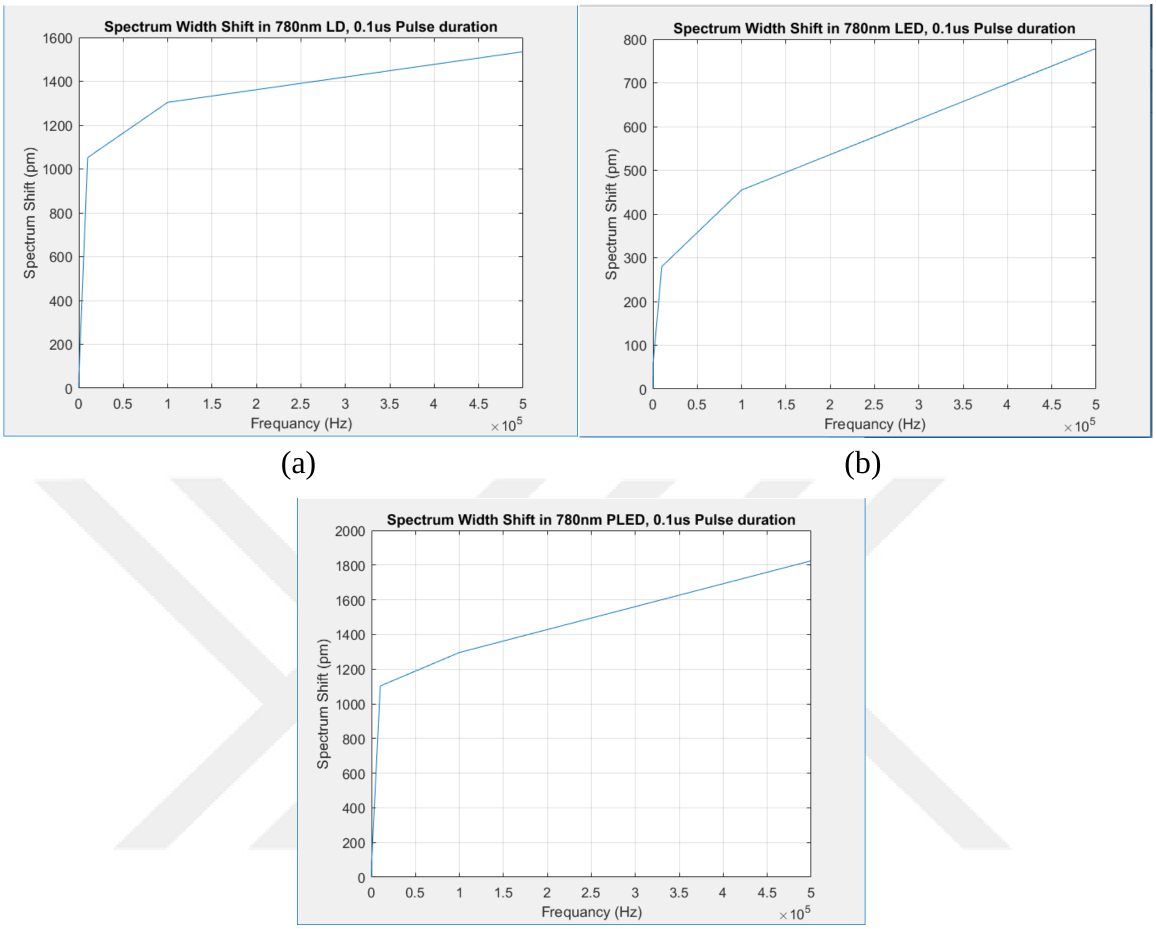
Figure 4.13: The pulse broadening and distortion for different frequencies at 0.1μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED

4.3.2 LD, LED and PLED at (780nm) and (0.1μs) Pulse Duration

The 780nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.11 shows the value of shifting with various frequencies, figures 4.14 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.15.

Table 4.11: Spectrum width shift for 780nm LD, LED & PLED as a result of changes of frequencies

Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	$(\Delta\lambda/ \Delta\lambda_0)$	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.1	784.030	1812	0	1	0	1
100	0.1	784.097	2342	530	1.292	0.818	0.774
10000	0.1	784.583	2864	1052	1.581	1.224	0.633
100000	0.1	784.981	3116	1304	1.720	1.399	0.581
500000	0.1	785.873	3347	1535	1.847	1.553	0.541
Light Emitting Diode							
10	0.1	788.642	14834	0	1	0	1
100	0.1	788.685	14891	57	1.0038	0.087	0.996
10000	0.1	788.701	15114	280	1.0189	0.195	0.981
100000	0.1	788.722	15289	455	1.0306	0.250	0.970
500000	0.1	788.764	15613	779	1.0525	0.328	0.950
Polymer Light Emitting Diode							
10	0.1	772.872	21812	0	1	0	1
100	0.1	773.169	21893	81	1.0037	0.086	0.996
10000	0.1	773.461	22915	1103	1.050	0.322	0.952
100000	0.1	773.945	23108	1296	1.059	0.350	0.944
500000	0.1	774.018	23637	1825	1.084	0.417	0.923

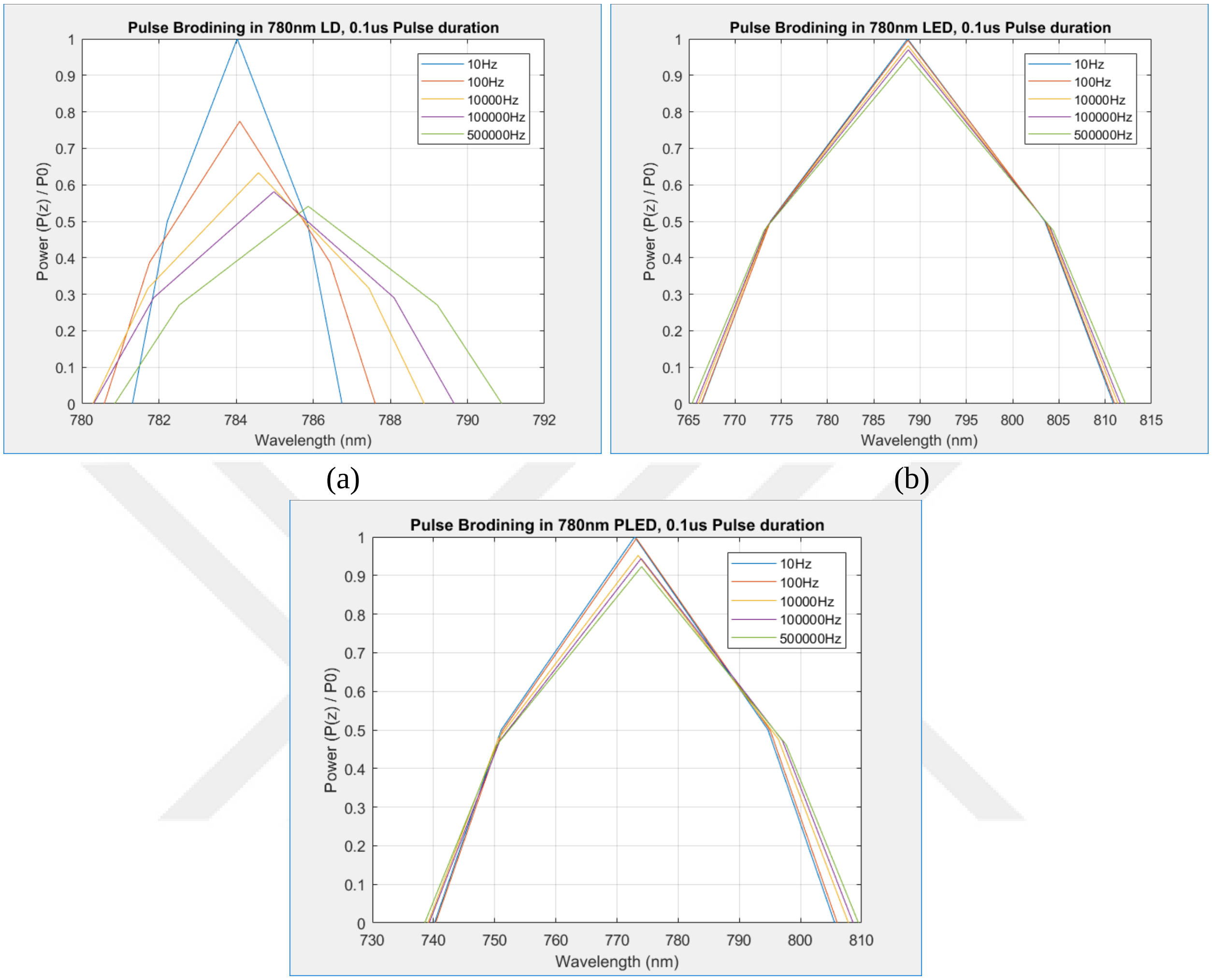


(a)

(b)

(c)

Figure 4.14: The spectrum width shift changes at 0.1μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED



(a) (b)

(c)

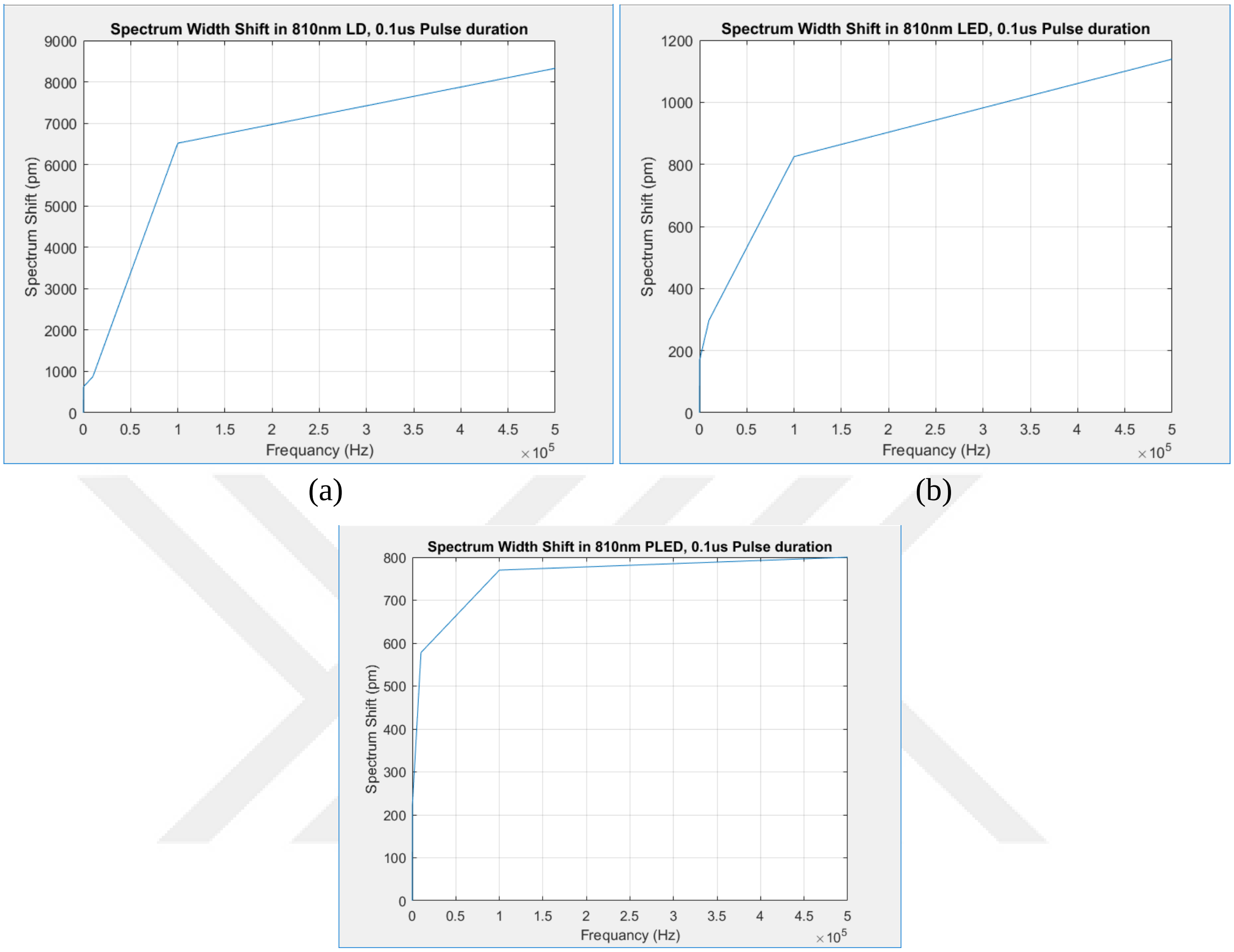
Figure 4.15: The pulse broadening and distortion for different frequencies at 0.1μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED

4.3.3 LD, LED and PLED at (810nm) and (0.1μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.12 shows the value of shifting with various frequencies, figures 4.16 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.17.

Table 4.12: Spectrum width shift for 810nm LD, LED & PLED as a result of changes of frequencies

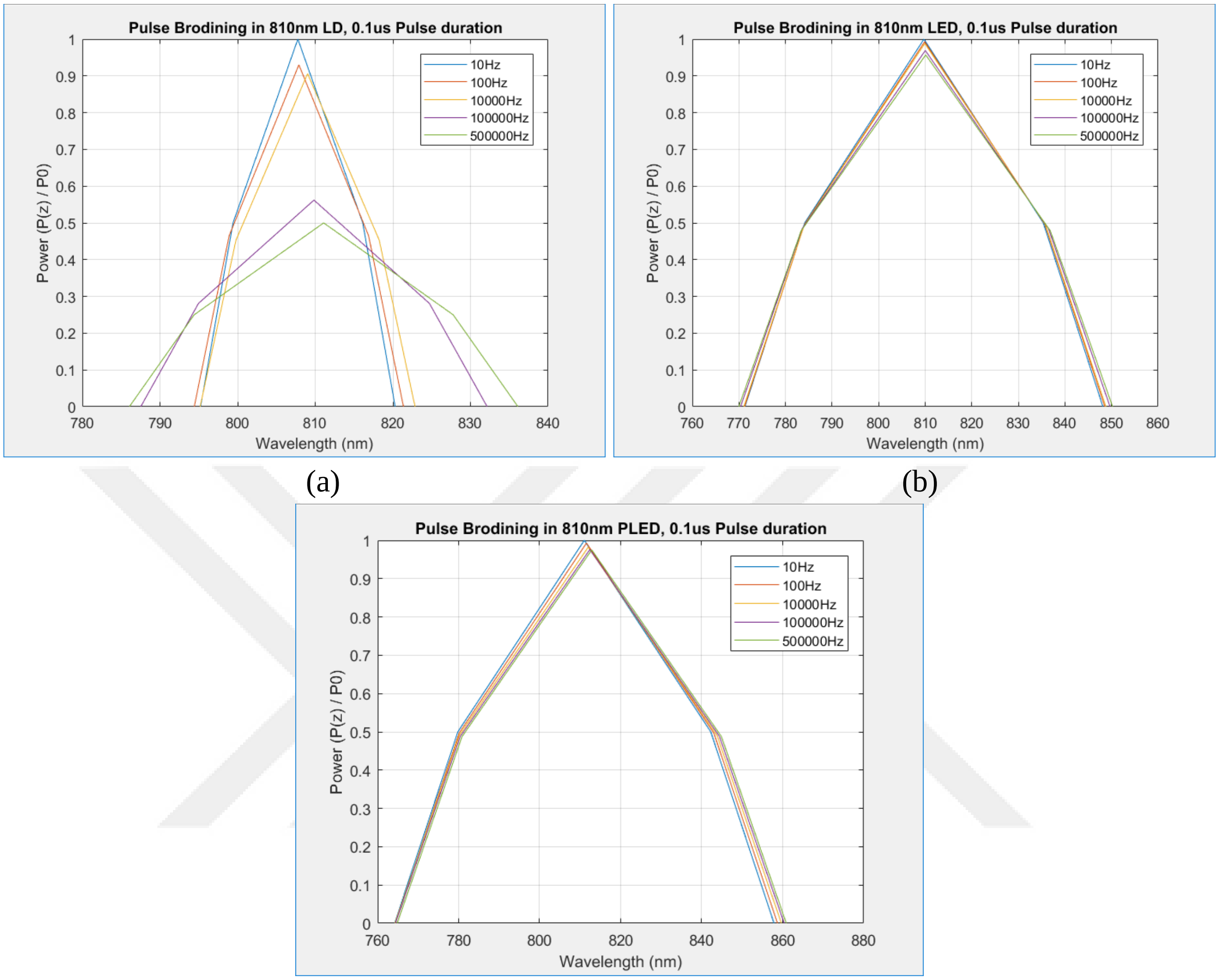
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	(Δλ/ Δλ$_0$)	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.1	807.766	8355	0	1	0	1
100	0.1	807.894	8984	629	1.075	0.395	0.930
10000	0.1	809.017	9227	872	1.104	0.468	0.906
100000	0.1	809.835	14873	6518	1.780	1.473	0.562
500000	0.1	811.086	16683	8328	1.997	1.728	0.500
Light Emitting Diode							
10	0.1	809.730	25613	0	1	0	1
100	0.1	809.883	25783	170	1.007	0.115	0.993
10000	0.1	809.918	25911	298	1.012	0.153	0.988
100000	0.1	810.020	26438	825	1.032	0.256	0.969
500000	0.1	810.105	26752	1139	1.044	0.302	0.957
Polymer Light Emitting Diode							
10	0.1	811.018	31216	0	1	0	1
100	0.1	811.563	31437	221	1.0070	0.119	0.993
10000	0.1	811.975	31794	578	1.0185	0.193	0.982
100000	0.1	812.388	31986	770	1.0250	0.223	0.976
500000	0.1	812.853	32016	800	1.0256	0.227	0.975



(a) (b)

(c)

Figure 4.16: The spectrum shift changes at 0.1μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED



(a) (b)

(c)

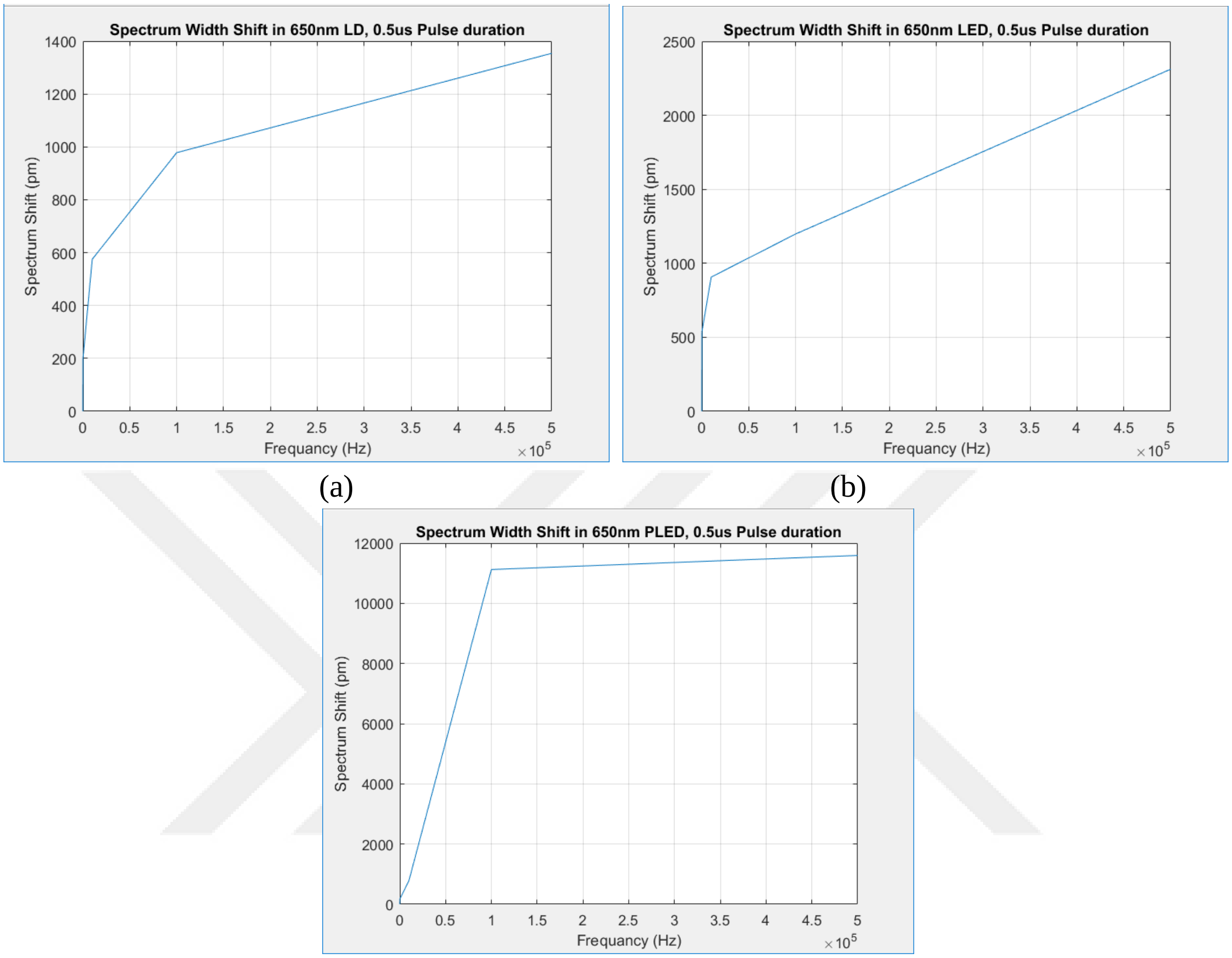
Figure 4.17: The pulse broadening and distortion for different frequencies at 0.1μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED

4.3.4 LD, LED and PLED at (650nm) and (0.5μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.13 shows the value of shifting with various frequencies, figures 4.18 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.19.

Table 4.13: Spectrum width shift for 650nm LD, LED & PLED as a result of changes of frequencies

Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	(Δλ/ Δλ$_0$)	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.5	638.353	2628	0	1	0	1
100	0.5	638.733	2827	199	1.076	0.396	0.930
10000	0.5	638.916	3203	575	1.219	0.697	0.820
100000	0.5	639.986	3606	978	1.372	0.940	0.730
500000	0.5	640.878	3982	1354	1.515	1.138	0.660
Light Emitting Diode							
10	0.5	689.768	23565	0	1	0	1
100	0.5	689.898	24102	537	1.023	0.215	0.978
10000	0.5	690.232	24472	907	1.038	0.280	0.963
100000	0.5	690.567	24763	1198	1.050	0.323	0.952
500000	0.5	690.742	25877	2312	1.098	0.454	0.911
Polymer Light Emitting Diode							
10	0.5	687.550	25644	0	1	0	1
100	0.5	687.735	25823	179	1.007	0.118	0.993
10000	0.5	688.270	26433	789	1.030	0.250	0.970
100000	0.5	688.657	36765	11121	1.433	1.027	0.698
500000	0.5	689.020	37233	11589	1.452	1.053	0.689

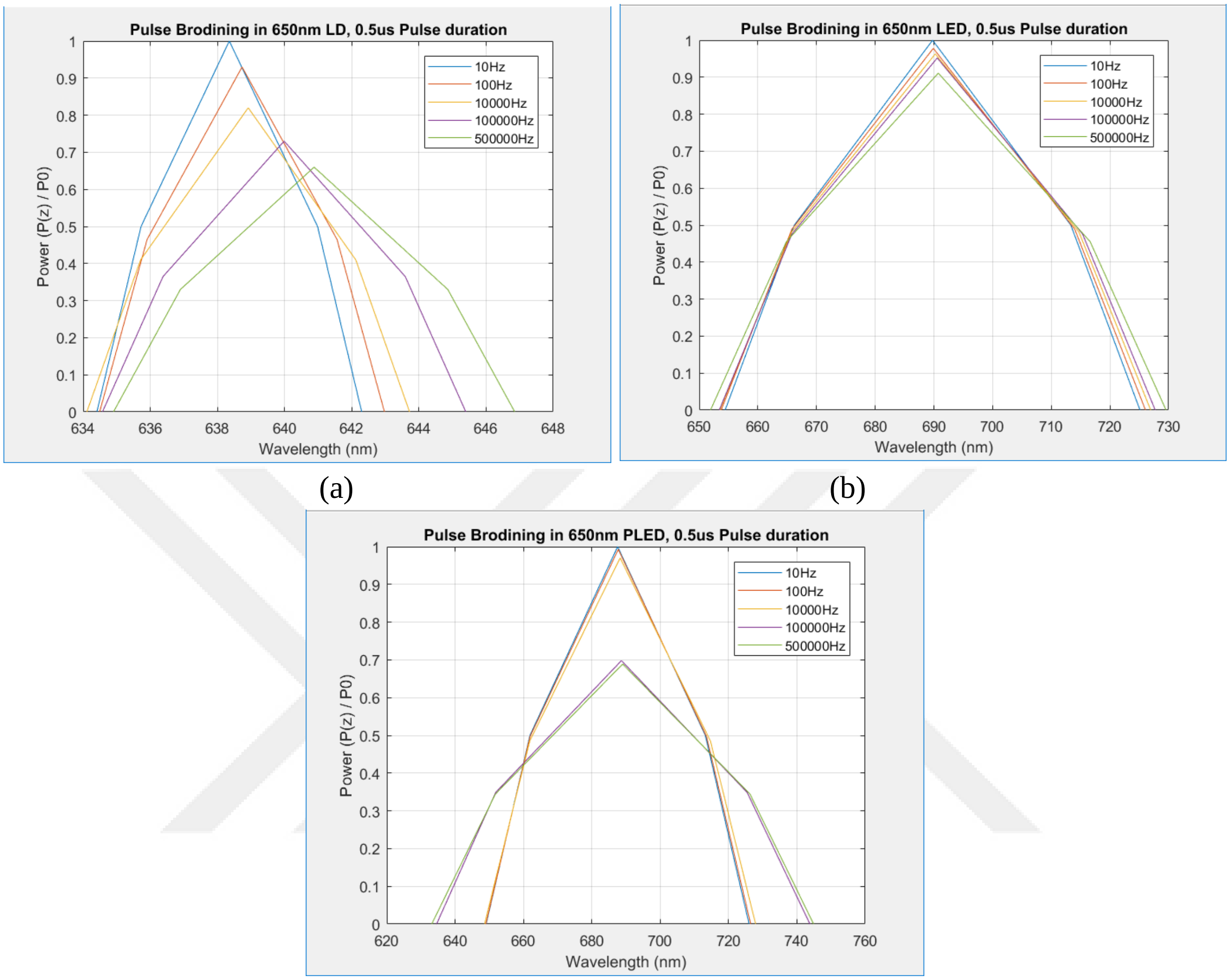


(a)

(b)

(c)

Figure 4.18: The spectrum shift changes at 0.5μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED



(a) (b)

(c)

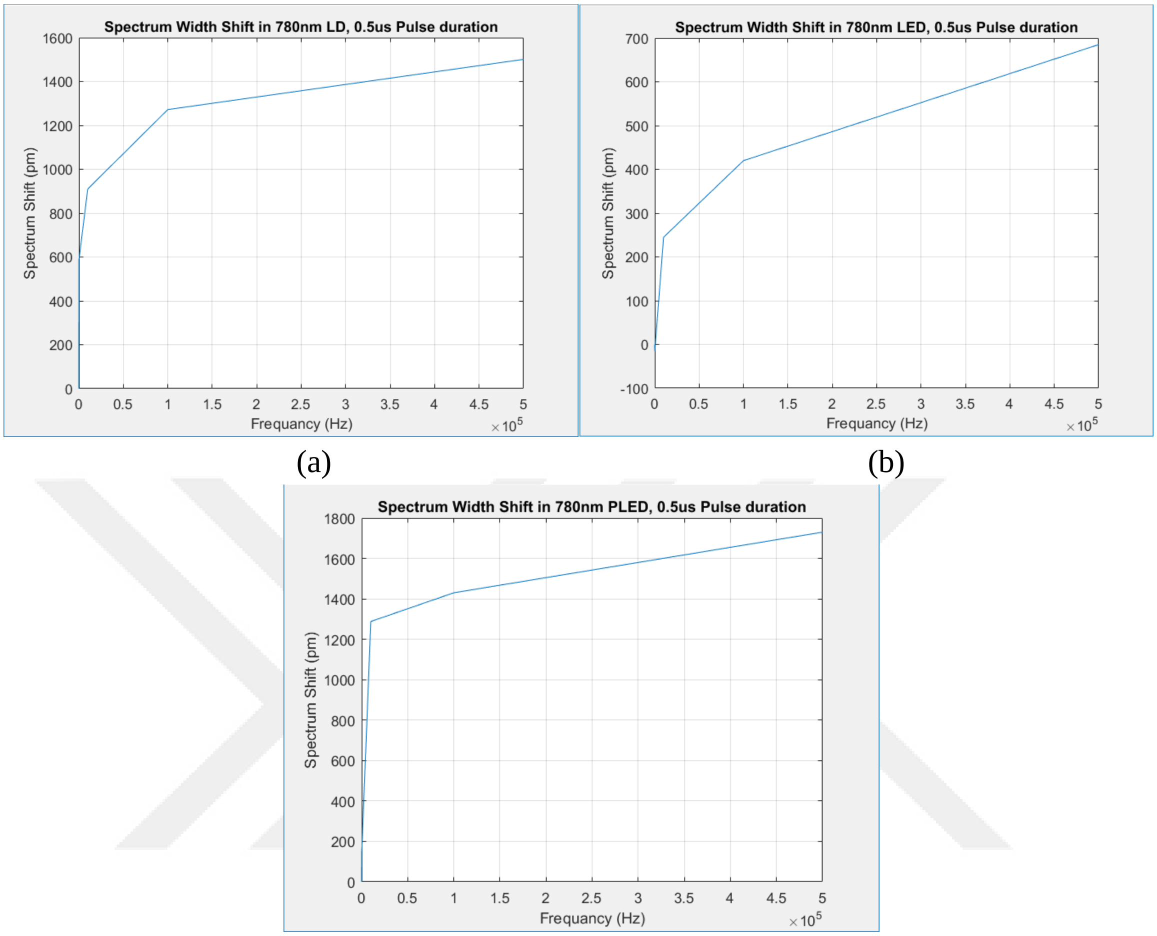
Figure 4.19: The pulse broadening and distortion for different frequencies at 0.5μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED

4.3.5 LD, LED and PLED at (780nm) and (0.5μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.14 shows the value of shifting with various frequencies, figures 4.20 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.21.

Table 4.14: Spectrum width shift for 780nm LD, LED & PLED as a result of changes of frequencies

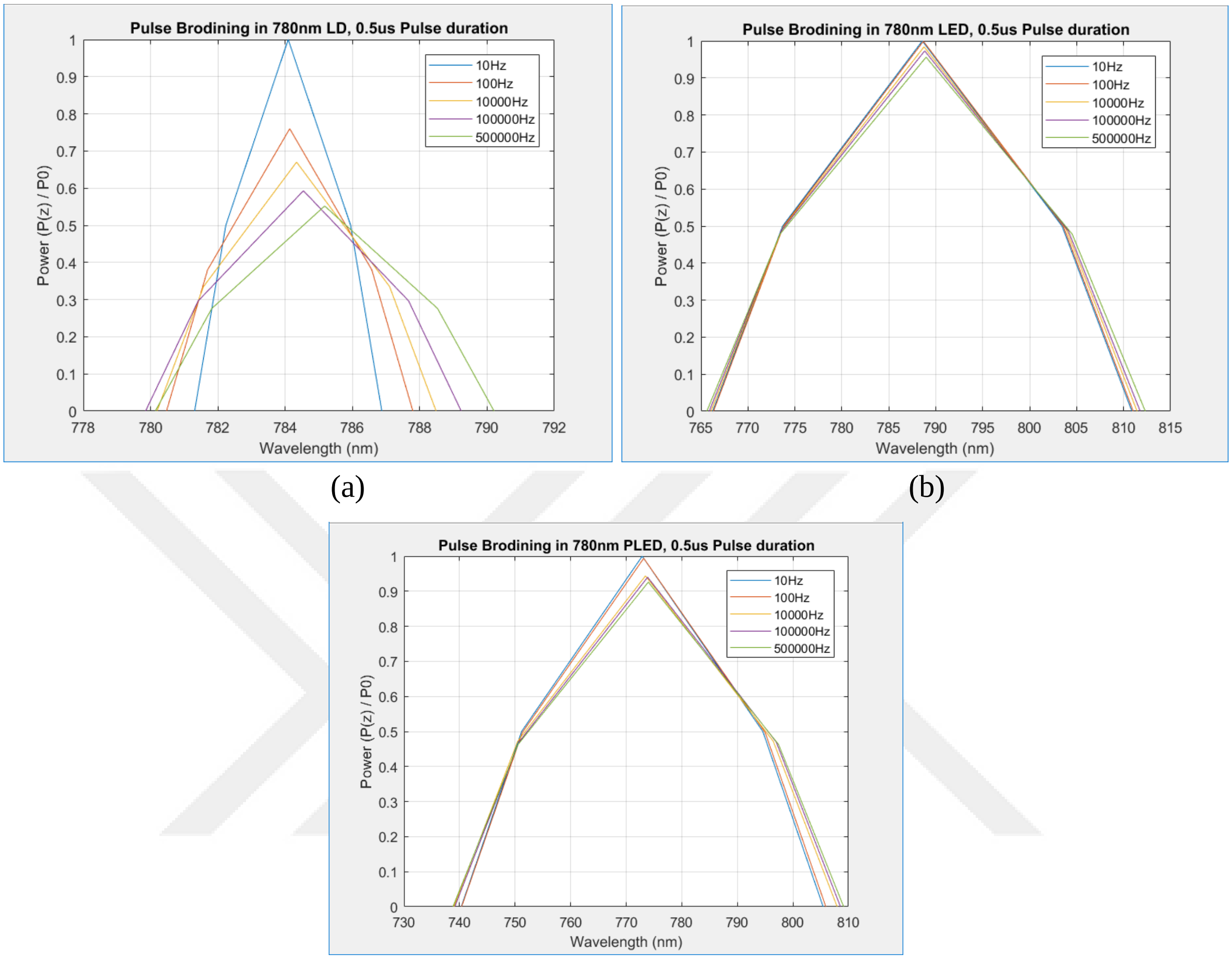
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	$(\Delta\lambda / \Delta\lambda_0)$	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.5	784.090	1854	0	1	0	1
100	0.5	784.134	2440	586	1.316	0.855	0.759
10000	0.5	784.338	2764	910	1.490	1.105	0.671
100000	0.5	784.541	3126	1272	1.686	1.350	0.593
500000	0.5	785.173	3355	1501	1.810	1.508	0.552
Light Emitting Diode							
10	0.5	788.564	14875	0	1	0	1
100	0.5	788.675	14896	25	1.0014	0.053	0.999
10000	0.5	788.750	15120	245	1.0165	0.182	0.984
100000	0.5	788.820	15295	420	1.0282	0.234	0.973
500000	0.5	788.965	15560	685	1.0461	0.306	0.956
Polymer Light Emitting Diode							
10	0.5	772.875	21710	0	1	0	1
100	0.5	773.150	21850	140	1.0065	0.114	0.994
10000	0.5	773.465	22998	1288	1.0593	0.350	0.944
100000	0.5	773.851	23140	1430	1.0659	0.370	0.940
500000	0.5	773.973	23440	1730	1.0797	0.407	0.926



(a) (b)

(c)

Figure 4.20: The spectrum shift changes at 0.5μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED



(a) (b)

(c)

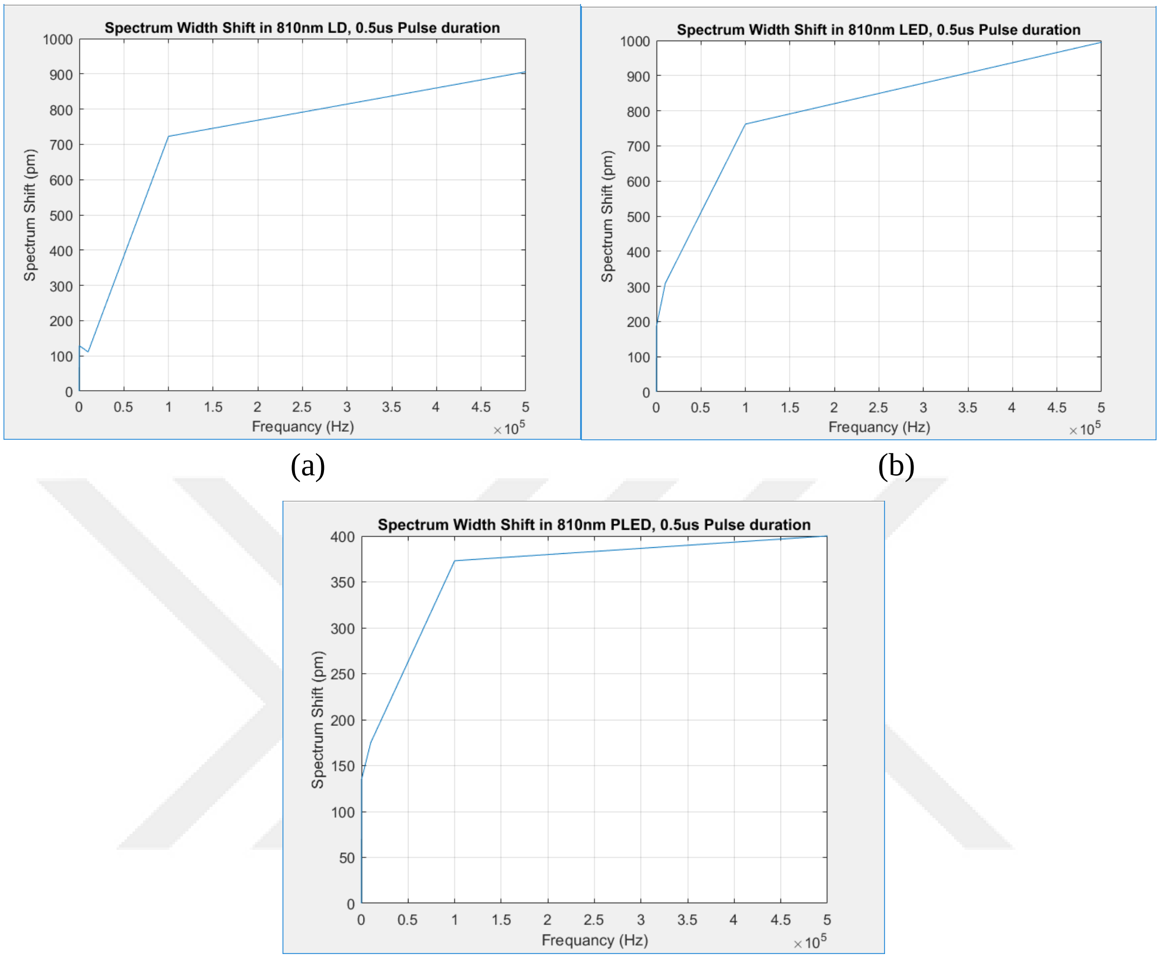
Figure 4.21: The pulse broadening and distortion for different frequencies at 0.5μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED

4.3.6 LD, LED and PLED at (810nm) and (0.5μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.15 shows the value of shifting with various frequencies, figures 4.22 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.23.

Table 4.15: Spectrum width shift for 810nm LD, LED & PLED as a result of changes of frequencies

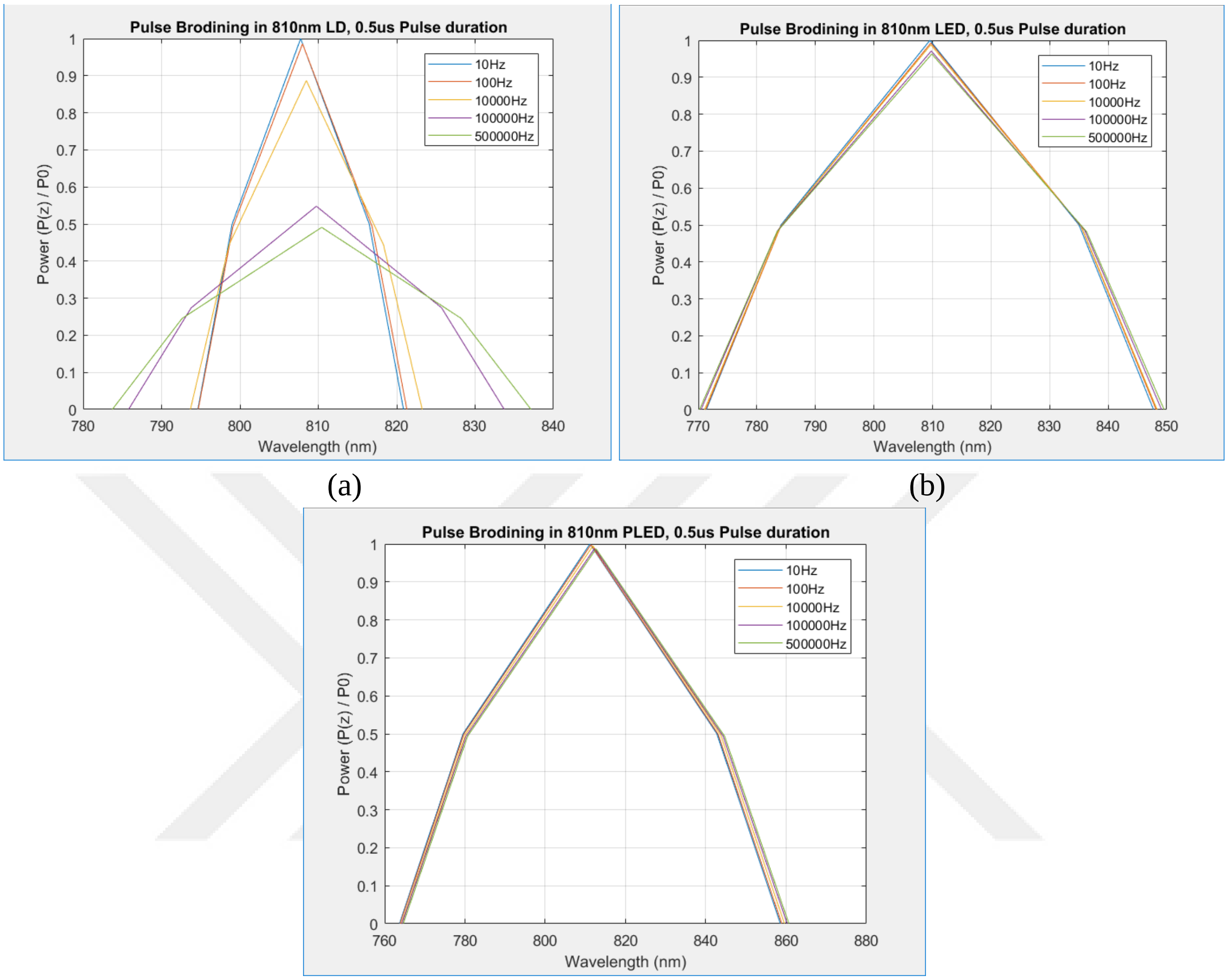
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	$(\Delta\lambda / \Delta\lambda_0)$	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	0.5	807.750	8745	0	1	0	1
100	0.5	807.986	8874	129	1.0148	0.172	0.986
10000	0.5	808.465	9857	1112	1.1270	0.520	0.887
100000	0.5	809.753	15973	7228	1.8266	1.529	0.548
500000	0.5	810.426	17803	9058	2.0358	1.773	0.491
Light Emitting Diode							
10	0.5	809.558	25456	0	1	0	1
100	0.5	809.724	25643	187	1.0073	0.122	0.993
10000	0.5	809.710	25765	309	1.0121	0.156	0.988
100000	0.5	809.785	26218	762	1.0299	0.246	0.971
500000	0.5	809.880	26451	995	1.0391	0.282	0.963
Polymer Light Emitting Diode							
10	0.5	811.128	31615	0	1	0	1
100	0.5	811.360	31680	55	1.0021	0.065	0.998
10000	0.5	811.875	31790	175	1.0055	0.105	0.995
100000	0.5	812.280	31988	373	1.0117	0.154	0.988
500000	0.5	812.650	32015	400	1.0127	0.160	0.987



(a) (b)

(c)

Figure 4.22: The spectrum shift changes at 0.5μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED



(a) (b)

(c)

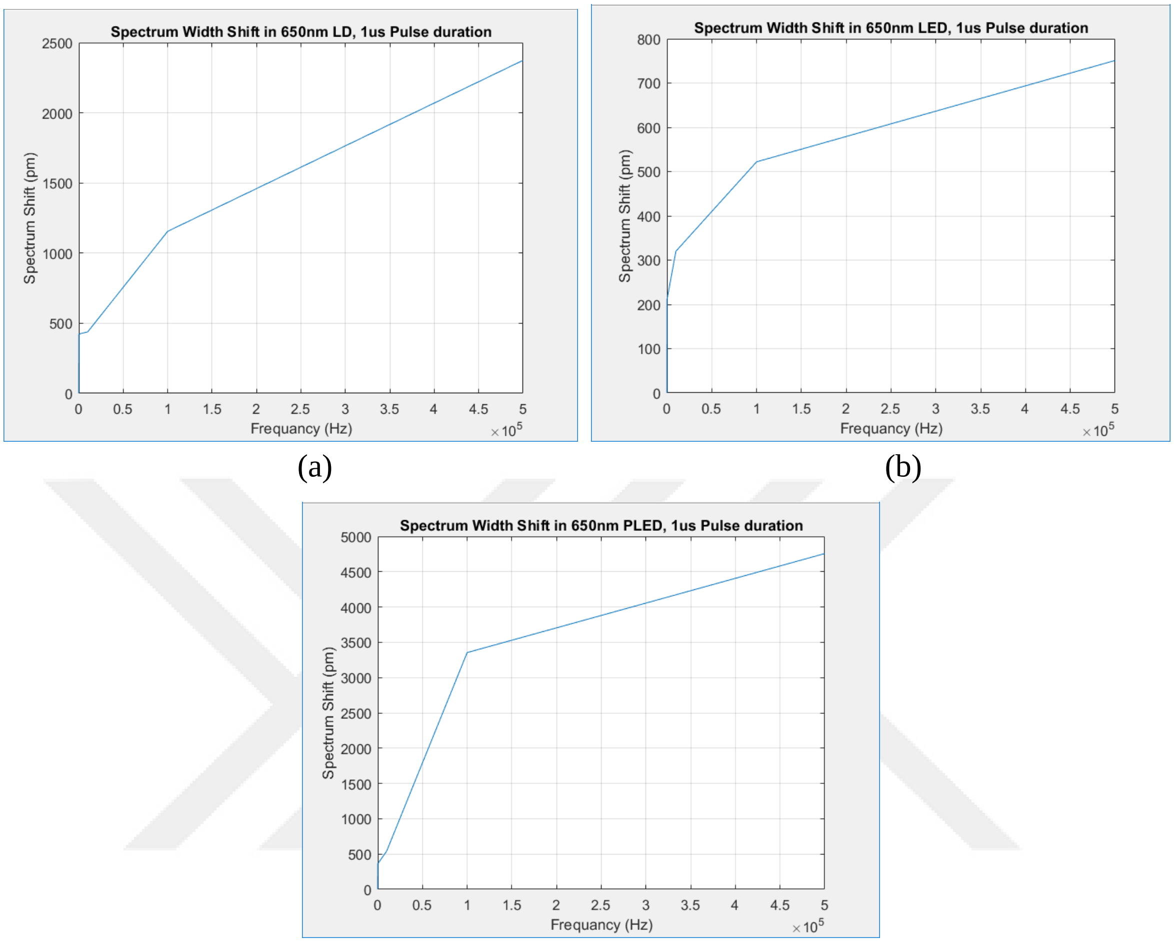
Figure 4.23: The pulse broadening and distortion for different frequencies at 0.5μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED

4.3.7 LD, LED and PLED at (650nm) and (1μs) Pulse Duration

The 650nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). Thorlabs spectrophotometer has been used to monitor the optical signal. Table 4.16 shows the value of shifting with various frequencies, figures 4.24 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.25.

Table 4.16: shifting value in LD of 650nm wavelength as a result of changes of frequencies

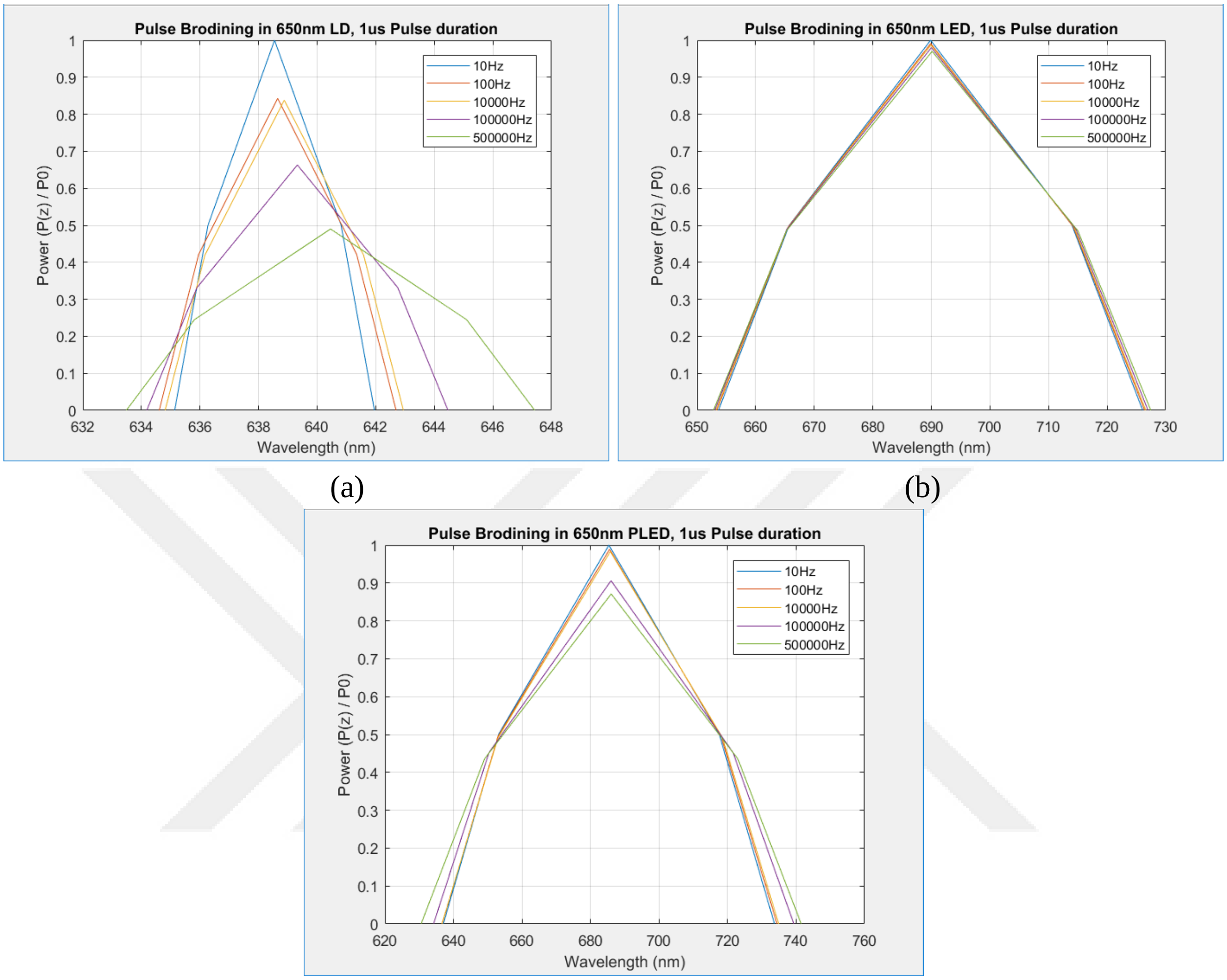
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	($\Delta\lambda/ \Delta\lambda_0$)	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	1	638.545	2273	0	1	0	1
100	1	638.651	2696	423	1.186	0.638	0.843
10000	1	638.876	2711	438	1.193	0.650	0.838
100000	1	639.324	3428	1155	1.508	1.129	0.663
500000	1	640.455	4647	2374	2.044	1.783	0.490
Light Emitting Diode							
10	1	689.860	24134	0	1	0	1
100	1	689.880	24345	211	1.0087	0.133	0.991
10000	1	689.920	24454	320	1.0133	0.163	0.987
100000	1	689.992	24656	522	1.0220	0.209	0.980
500000	1	690.125	24885	751	1.0131	0.251	0.970
Polymer Light Emitting Diode							
10	1	685.365	32223	0	1	0	1
100	1	685.563	32586	363	1.0112	0.150	0.989
10000	1	685.771	32765	542	1.0168	0.184	0.983
100000	1	685.987	35577	3354	1.1041	0.468	0.906
500000	1	686.030	36980	4757	1.1476	0.563	0.871



(a) (b)

(c)

Figure 4.24: The spectrum shift changes at 1μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED



(a) (b)

(c)

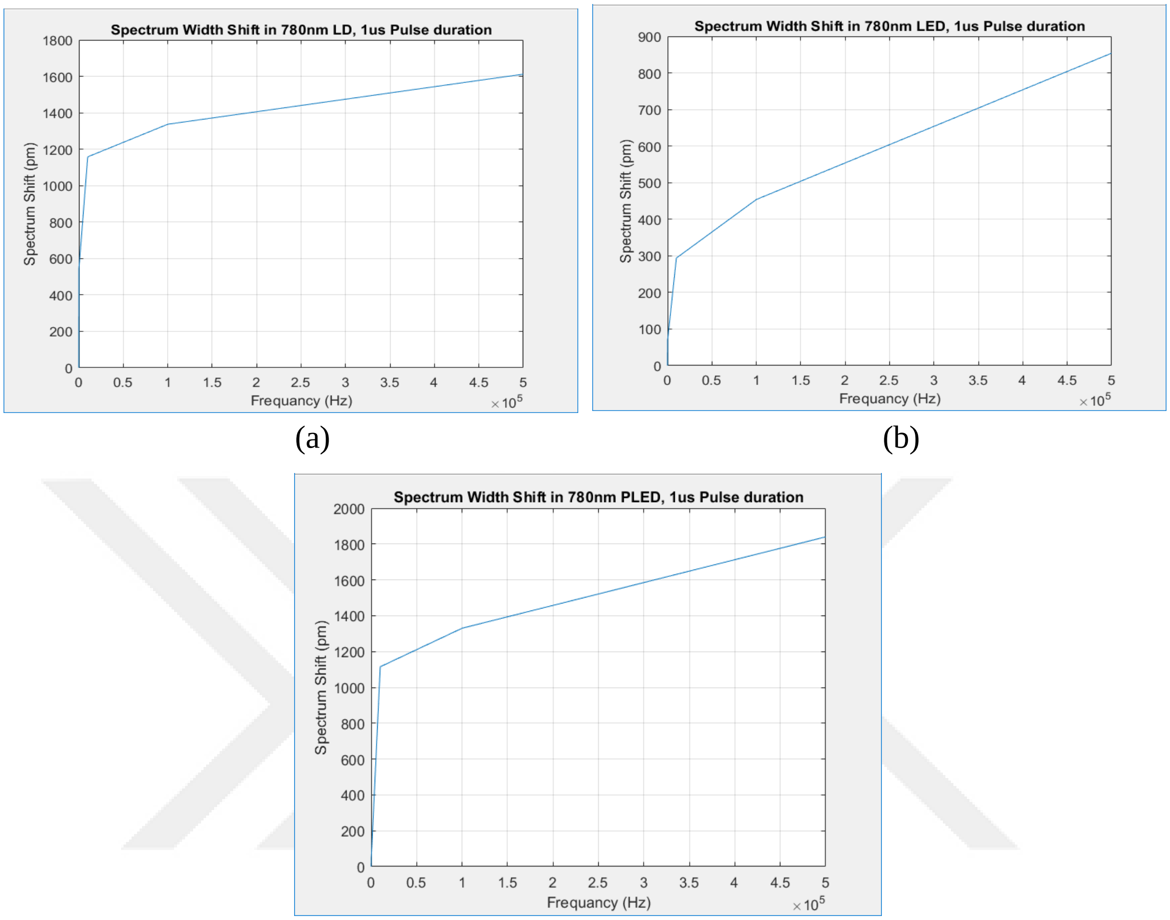
Figure 4.25: The pulse broadening and distortion for different frequencies at 1μs pulse duration for: (a) 650nm LD, (b) 650nm LED, (c) 650nm PLED

4.3.8 LD, LED and PLED at (780nm) and (1μs) Pulse Duration

The 780nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.17 shows the value of shifting with various frequencies, figures 4.26 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.27.

Table 4.17: Shifting value in LD of 780nm wavelength as a result of changes of frequencies

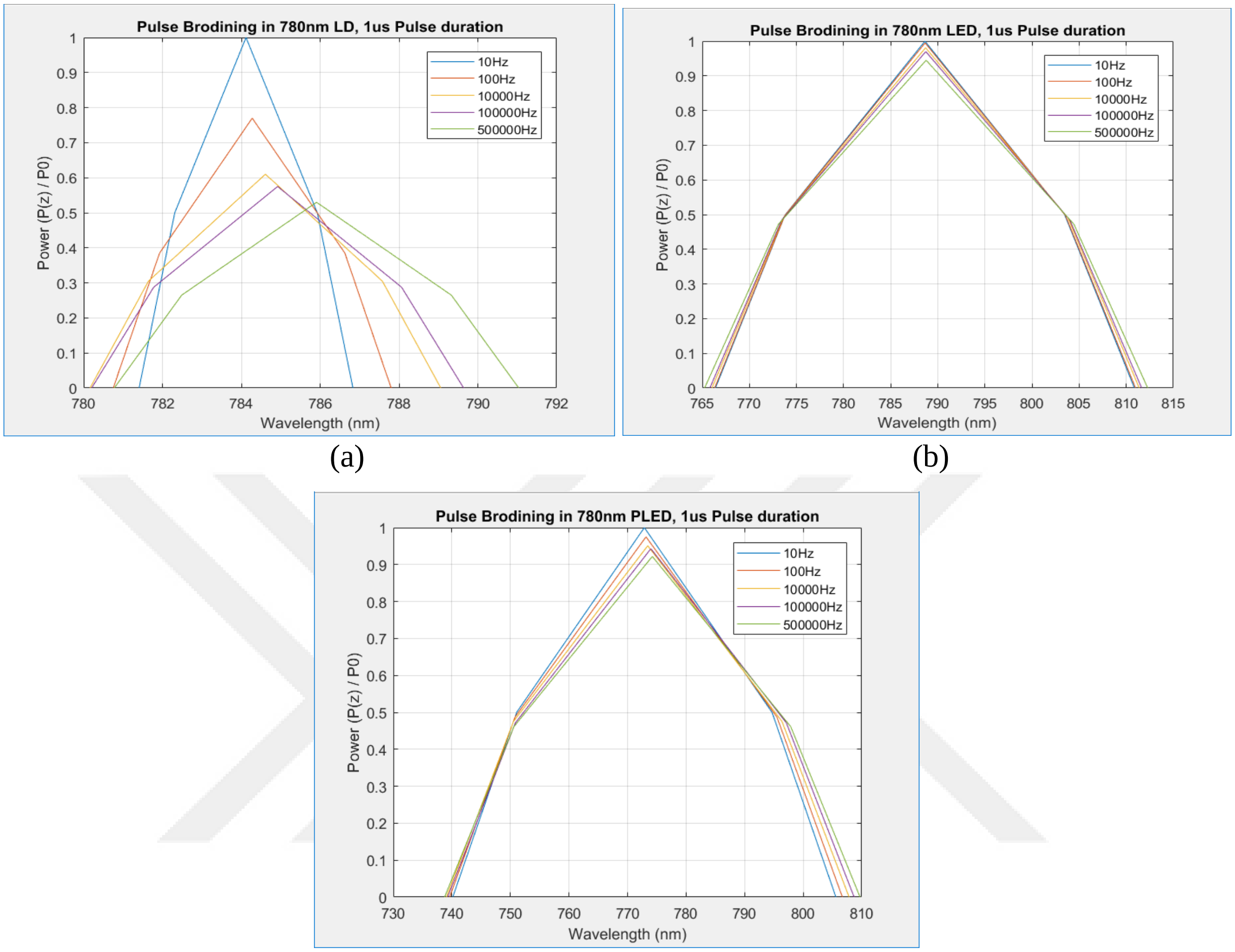
Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	(Δλ/ Δλ$_0$)	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	1	784.120	1808	0	1	0	1
100	1	784.277	2350	542	1.299	0.83	0.770
10000	1	784.612	2966	1158	1.640	1.30	0.610
100000	1	784.922	3145	1337	1.739	1.423	0.575
500000	1	785.908	3420	1612	1.891	1.606	0.530
Light Emitting Diode							
10	1	788.630	14821	0	1	0	1
100	1	788.650	14890	69	1.005	0.096	0.995
10000	1	788.700	15115	294	1.020	0.200	0.981
100000	1	788.720	15275	454	1.031	0.250	0.970
500000	1	788.760	15675	854	1.058	0.344	0.945
Polymer Light Emitting Diode							
10	1	772.870	21810	0	1	0	1
100	1	773.153	22358	548	1.025	0.225	0.975
10000	1	773.450	22925	1115	1.051	0.323	0.951
100000	1	773.985	23140	1330	1.061	0.355	0.943
500000	1	774.230	23650	1840	1.084	0.419	0.922



(a) (b)

(c)

Figure 4.26: The spectrum shift changes at 1μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED



(a) (b)

(c)

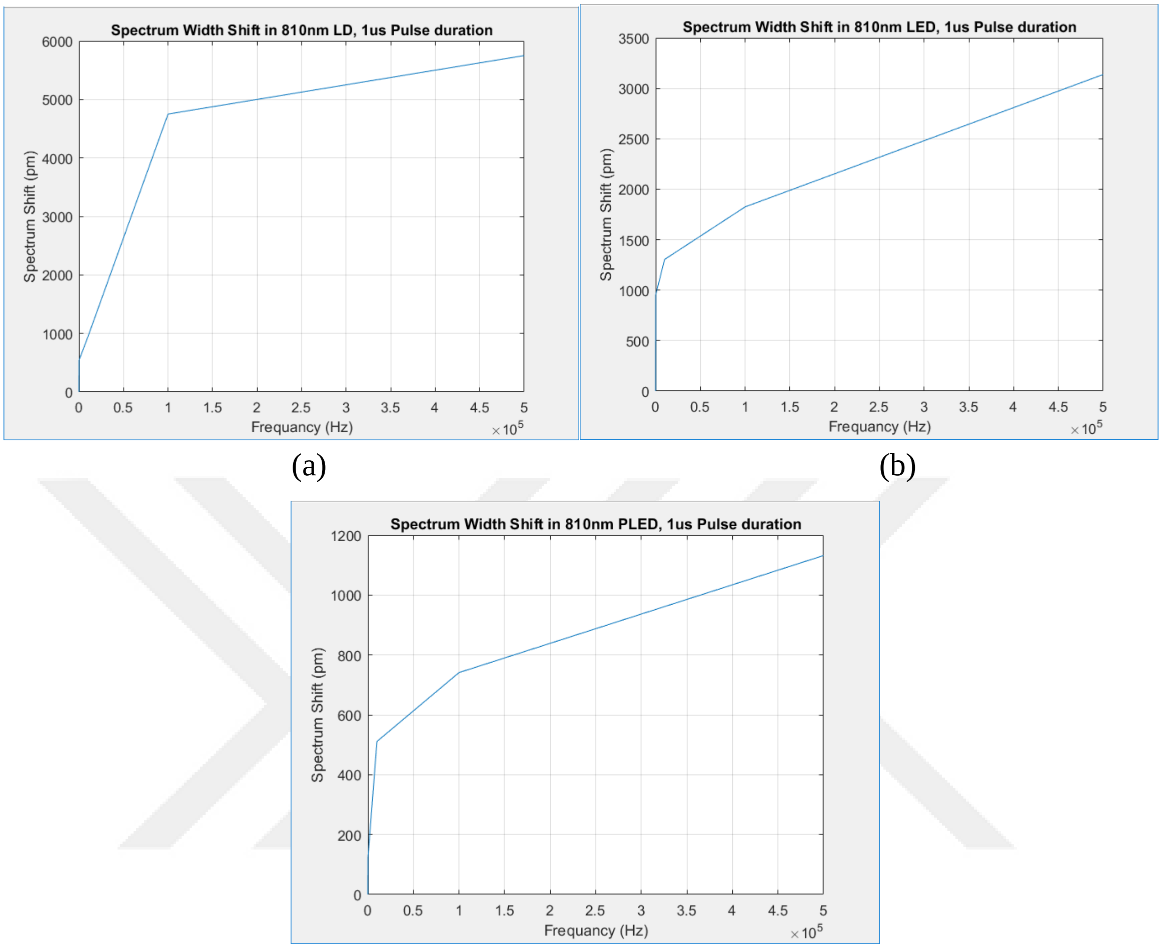
Figure 4.27: The pulse broadening and distortion for different frequencies at 1μs pulse duration for: (a) 780nm LD, (b) 780nm LED, (c) 780nm PLED

4.3.9 LD, LED and PLED at (810nm) and (1μs) Pulse Duration

The 810nm LD, LED and PLED has been used as a light source in oscillation circuit (transmitting circuit). HR4000 spectrophotometer has been used to monitor the optical signal. Table 4.18 shows the value of shifting with various frequencies, figures 4.28 is illustrated the wavelength shift. The pulse broadening caused by distortion for LD, LED and PLED is shown in figure 4.29.

Table 4.18: shifting value in LD of 810nm wavelength as a result of changes of frequencies

Freq. (Hz)	Pulse duration (us)	Wave length (λo) (nm)	Spectrum width (Δλ) (pm)	Spectrum width shift (pm)	(Δλ/ Δλ₀)	$\frac{z}{L_D}$	$\frac{P(z)}{P_0}$
Laser Diode							
10	1	807.540	8405	0	1	0	1
100	1	807.881	8945	540	1.064	0.364	0.940
10000	1	808.256	9344	939	1.112	0.486	0.899
100000	1	810.784	13880	4750	1.651	1.314	0.605
500000	1	811.981	15980	5750	1.901	1.617	0.526
Light Emitting Diode							
10	1	809.520	24613	0	1	0	1
100	1	809.733	25563	950	1.04	0.280	0.963
10000	1	809.775	25917	1304	1.053	0.330	0.950
100000	1	810.890	26438	1825	1.074	0.392	0.931
500000	1	811.730	27750	3137	1.127	0.521	0.887
Polymer Light Emitting Diode							
10	1	811.217	31245	0	1	0	1
100	1	811.668	31368	123	1.004	0.089	0.996
10000	1	812.121	31756	511	1.016	0.182	0.984
100000	1	812.639	31986	741	1.024	0.219	0.977
500000	1	812.958	32377	1132	1.036	0.272	0.965

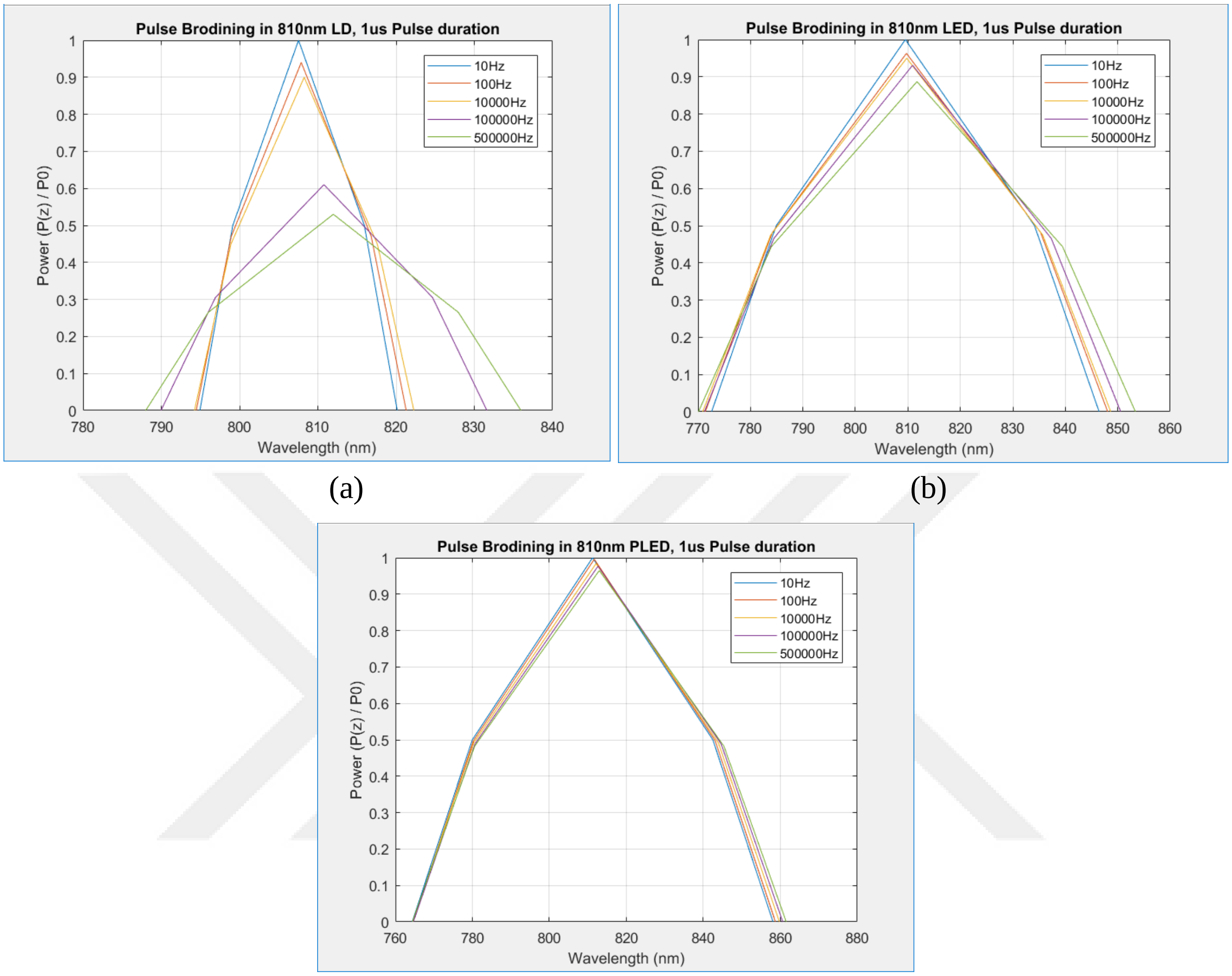


(a)

(b)

(c)

Figure 4.28: The spectrum shift changes at 1μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED



(a)

(b)

(c)

Figure 4.29: The pulse broadening and distortion for different frequencies at 1μs pulse duration for: (a) 810nm LD, (b) 810nm LED, (c) 810nm PLED

As shown from results, it can have observed that all optical sources are subject to optical width shift as increase of frequency that cases increase of source temperature. The results show that the all optical sources subject to broadening and it effected by both frequency and time duration which is increased by increases of these factors. Thus, the path length to distortion length $(\frac{z}{L_D})$ of optical sources is increases, which mean reduce in path length that data can be transferred before subject to dispersion and then distortion of data. The result show that he both optical sources LED and PLED are stable with frequency more than LD, However, LED is relatively being more stable than other which is recorded small changes in both wavelength shift and spectrum width shift.

5. CONCLUSIONS

The spectral amplitude of the negative factors in optical communication systems may cause losing of data as a result of the interference of data transfer in the transport medium, such as optical fiber or air, which suffer from an additional spectrum broadening in the bandwidth due to the difference in speed when pass in different medium. From the results, the optical emitter was the best in terms of the stability of the semiconductor laser and was always shifted towards the red wavelength with the amplitude of the beam, which leads to interference in patterns and loss of data. It is clear that the emitter was wide-band but with high stability in the pattern and therefore preferred in communication systems but requires the addition of optical filters to determine the spectral bandwidth and avoid loss at very high frequencies.

From results, it can observed that all optical signals are suffer from an beam expanding and subject to red shift that is more in LD and it less in LED. We can conclued them in following points

1. The LD spectrum shows that LD has unstable behavior as increases of frequency, while the LED spectrum show that LED is more stable than LD and PLED and got a best result at all frequencies,
2. As increases of frequency, the temperature of light source will be increases which is the main factor causes the spectrum shift and expansion.
3. In order to minimize the red shift and spectrum broadening, there is a need to utilize cooling technique LD can become more stable when using cooling techniques.

The suggestion for future works is to investigate the ability to use organic light emitting diode and polymer light emitting diode in optical communication systems. In addition, it can study the best optical sources that can be used in free space optical communication system and study some important factors that effect on increases the range of transmission.

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