STUDYING THE CHARACTERISTICS OF ULTRA SHORT PULSE GENERATED USING MODE LOCK LASER

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Abstract: **Data traffic is predicted to grow further exponentially as a result of the emergence of high-bandwidth consuming applications and services. The fast deployment of different technologies, such as video streaming ,the expansion of major telecommunications infrastructure, etc. has increased the demand for network capacity for delivering the data traffic .Out of various technologies emerged to meet the requirement of increased data capacity., Ultrashort pulse has been most explored as it is being considered the ultimate solution.It is an electromagnetic pulse having time duration in picoseconds or even less. Ultrashort pulses offer high capacity. In this paper, charecteristics of such a pulse generated from fiber ring laser which include active optical modulators of amplitude or phase types, would be reviewed .**

IndexTerms-Communication,capacity,bandwidth,Ultra-shortpulses,Laser.

I. INTRODUCTION

With the advancement of technology in every sector of life, an enormous changehas occurred in the way how people communicate with each other [11]. Previously horses and pigeons were the messengers to transmit information from one place to another. Technology brought quickness in everything including communication [3].

1.1. Communication

Communication is one of the essentialparts of human lives. People communicate with each other to share their opinions, ideas, and feelings. Thus, communication is the exchange of information from one place to another [1]. The main purpose of every communication is to send the information over a long distance while ensuring no damage to it. Thus, all the communication system has only one motive to deliver the accurate information from the sender to the receiver. There is always some medium through which information is transformed from the sender to the receiver [4]. The general communication process has been explained through figure 1.

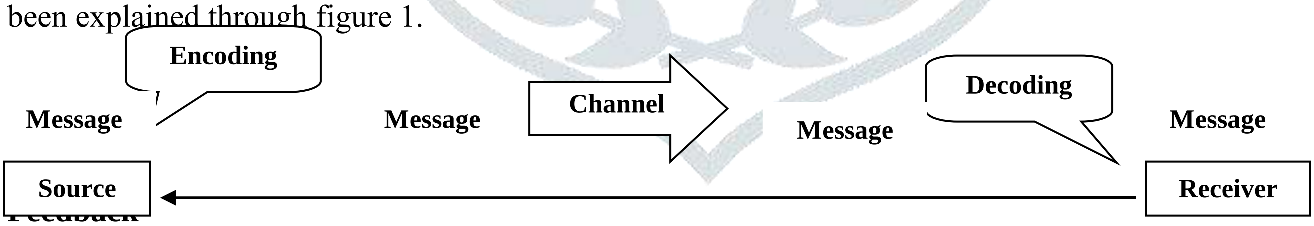


Figure 1.1: The Communication Process

The peoples cannot live without communication. It is the basic need of people to communicate with each other. The exchange of information from one point to another is known as communication [1]. In earlier times, messengers were horses and pigeons or other birds those carried information. This used to be a slow process but human's curiosity to invent and to make life comfortable had made it possible to send and receive data within a blink of an eye.The basic principle of any means of communication is to send information over a long distance without deterioration or attenuation so that the receiver receives the information in the original form.

1.2. Optical Fiber Communication

Optical fiber communication has emerged as one of the fine technique to send information at high data rate with maximum long distance possible. It is one of the most secure ways to communicate. It uses light as a source of communication. The light propagates through the glass fiber from the sender to the receiver while following the principle of total internal reflection.Figure 1.2 representsgeneral structure of an optical fiber.

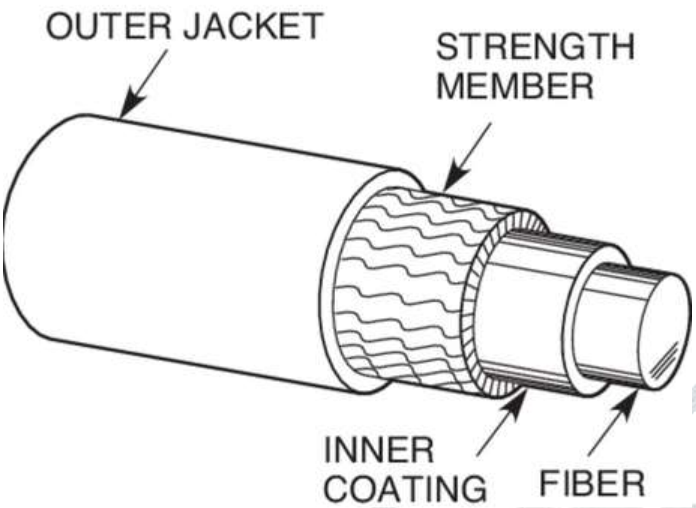


Figure 1.2: Optical Fiber

Optical fibers are very thin and have diameter similar to human hair. It is made up of two cylindrical glasses. The inner core is the one through which the light signal propagates [7]. Next is the cladding surrounded by the core and have a lower refractive index (refer figure 1.3). The light propagates depending on the principle of total internal reflection that occurs in the cladding-core interface [11].

As all communication systems need a medium or channel to send the information, optical fiber communication makes use of light. The information bearing light signal propagates through thin plastic or glass fibers and isdependent on the principle of total internal reflection.[4]

Fiber optic communication systems require light sources which must have

- High efficiency
- Low cost
- Longer life
- Sufficient power output
- Ability to give the desired modulation
- Compatibility with the fibre ends

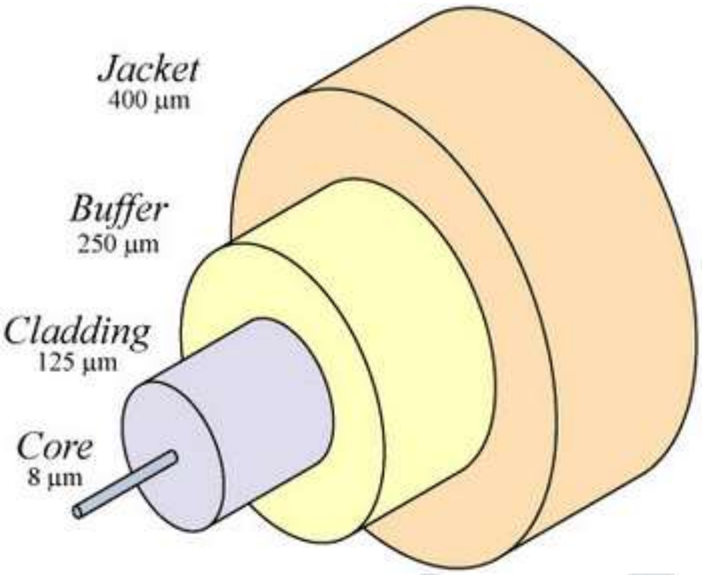


Figure 1.3: Optical Fiber

1.2.1. Transmission Window

There are wavelength bands or windows where attenuations are weakest, thus are the most favorable for transmission due to small transmission loss.This low-loss wavelength region ranges from 1260 nm to 1675 nm and is divided into six wavelength bands or windows. These windows have been standardized currently into defined bands that have been elucidated in table1.1.[2]

Table 1.1: Wavelength bands for fiber applications

Band	Description	Wavelength Range
O band	original	1260 to 1360 nm
E band	extended	1360 to 1460 nm
S band	short wavelengths	1460 to 1530 nm
C band	conventional ("erbium window")	1530 to 1565 nm
L band	long wavelengths	1565 to 1625 nm
U band	Ultralong wavelengths	1625 to 1675 nm

1.2.2. Types of Light Sources in Optical Fiber Communication

For use in optical communications, transmitters need to be designed in such a way that they are compact, efficient, reliable as well as can directly be modulated at high frequencies while operating in an optimal wavelength range.[1]There are two such semiconductor devices most commonly used, that are:

1. Light Emitting Diode(LED)
2. Solid State Lasers

1.2.2.1. Light Emitting Diode (LED)

A LED is abbreviatedas the light emitting diode. LED provides visible light when the electric current is passed through it. The light emitted by the LED is not so bright. The output from the LED range from the red to blue-violet.LED is made up of two elements including p-type and the N-type semiconductors. This two componentsareemployed in the direct contact of each other, and it also forms the region called the P-N junction [13].Figure 1.4 represents theinternal composition of LED.

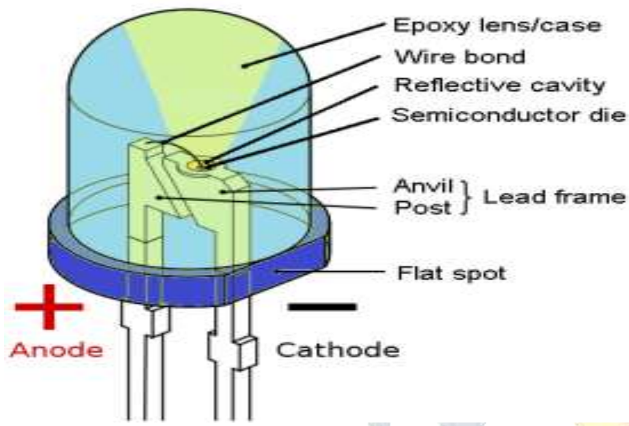


Figure 1.4: Internal composition of a LED

LEDis a two-lead semiconductor device contains a p-n junction diode that emits visible light aselectric current transfers through it via spontaneous emission.When a semiconductor emits lights in a revert to a strong electrical field or an electrical current, then the effect produced is called electroluminescence which is presented in figure 1.5.It is a phenomenon in which voltage is applied to lead so that electrons recombine with electron holes and releases the energy in the form of photons. The emitted light is incoherent with a relatively wide spectral width of 30–60 nm.Thesecommunications LEDs are most commonly made from Indium gallium arsenide phosphide (InGaAsP) or gallium arsenide (GaAs)[1,2].

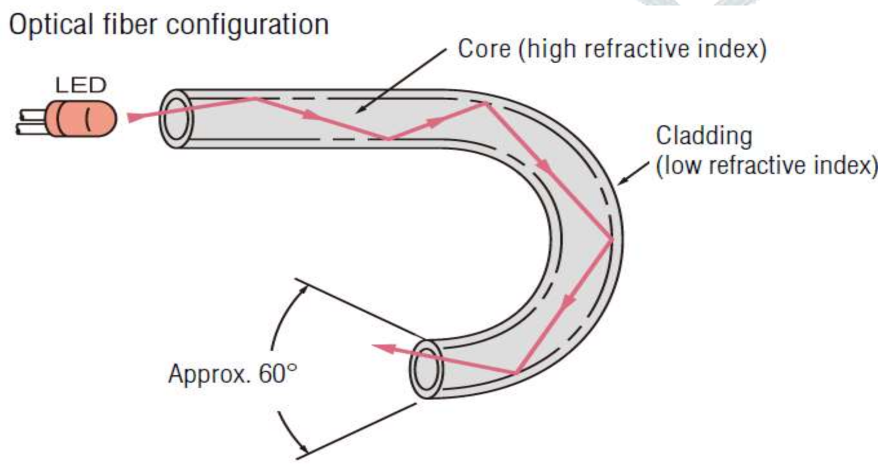


Figure 1.5: LED as a source of light for fiber communication

Benefits of the LED include the following

1. **Low power requirement-** The LED requires littlepower, as it consumes very less amount of energy.
2. **High efficiency-** The power supplied to the LED is directly converted into the radiation with the lowest amount of heat production. In this way, LED has high efficiency.
3. **Long life –** If the installation of the LED done in a better way then it remains safe and function for a long time [9].

Light transmission LED is inefficient, with only about 1% of input power, or about 100 microwatts, eventually converted into launched power which has been coupled into the optical fiber.Hence, LEDs are suitable primarily for local-area-network applications with bit rates of 10–100 Mbit/s and transmission distances of a few kilometers only.Dueof these limitations, LEDs have been largely superseded by Vertical Cavity Surface Emitting Laser devices, which offer improved speed, power,and spectral properties, at a similar cost. These devices couple well to multimode fiber.

1.2.2.2. Light Amplification by Stimulated Emission of Radiation (LASER)

The LASER stands for the 'light amplification by stimulated emission of radiation.'Lasers are one of the most significant inventionsthat developed in the 20th century. The use of laser technology is now common in the field of electronics, computer hardware, medicine and investigational science [8].A laser is a focused beam of photons. It consists one wavelength and one ordinary light which dips on us in many wavelengths. The laser works on the distinct types of effect [5]. The output comes out of the laser is called the electromagnetic field. In the electromagnetic field, all the waves under the laser have the same frequency and the phase. The optical-electronic device generates an arrow beam of monochromatic light with amplifying photons through more energy by impacts with other photons [23]. Basically, it is a device which emits a low-divergent and narrow beam of coherent light by the process of optical amplification which is based on the stimulated electromagnetic radiation emission. Figure 1.6 shows the basic structure of laser. Most light sources produce incoherent light that has a phase which changes randomly with time and position. The optical-electronic device generates an arrow beam of monochromatic light with amplifying photons through more energy by impacts with other photons[3].

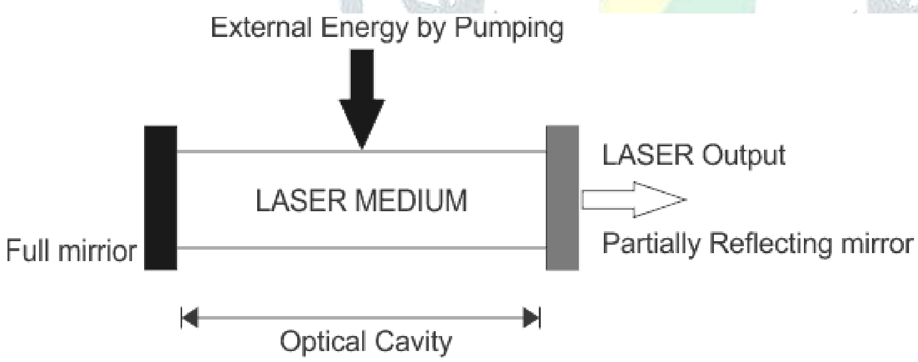


Figure 1.6: Basic Structure of Laser

Laser principle based on three features:

a) Stimulated emission in an amplifying medium

b) Population inversion of electronics

c) An optical resonator

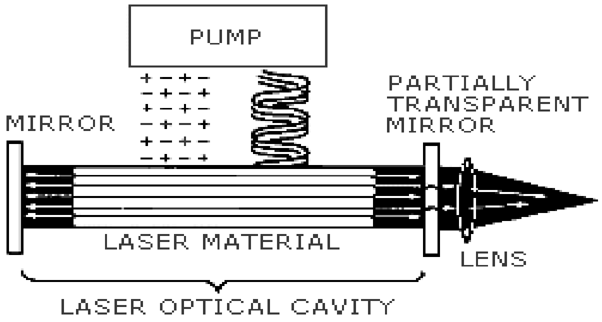


Figure 1.7: Laser Components

The cavity inside the laser contains the gasses, liquids or solids (figure 1.7). The choice of the cavity is based on the wavelength of the output [7]. The cavity has some mirrors inside it which help to reflect or pass the light inside the cavity. The other mirror is partiallyreflective, and it allows only 5 percent of energy to pass into the cavity [25]. Then the energy is produced in the cavity from an external source, and this process is called pumping. When the pumping is in operation, then the electromagnetic field appears inside the cavity with the natural frequency of the particles.

1.2.2.2.1. GAS LASER

The gas laser was the first light laser which operates on the principle of converting electrical energy into the laser light energy. The first gas laser which named as the Helium-neon laser was invented by the American scientist Ali Javan, and the William R. Bennett in 1960[3].Types of Gaslaser are mentioned in table 1. 2.

Table 1.2: Types of Gas Lasers

Laser Gain Medium	**Operation Wavelength(s)**	**Pump Source**	**Applications**
Helium-neon laser	632.8nm	Electrical discharge	Optical demonstrations, Interferometry, copy, Barcode scanning, Holography, Alignment,
Argon laser	514.5 nm, 488.0 nm, 454.6 nm	Electrical discharge	Confocal Microscopy, Spectroscopy pumping other lasers, Retinal phototherapy (for diabetes), Lithography
Carbon dioxide laser	10.6 µm, (9.4 µm)	Electrical discharge	Material processing (welding, cutting, etc.), surgery
Excimer laser	353 nm (XeF), 308 nm (XeCl), 248 nm (KrF), 193 nm (ArF)	Excimer recombination via electrical discharge	Laser surgery,Ultraviolet lithography for semiconductor manufacturing

1.2.2.2.2. SOLID STATE LASER

A solid laser is a laser that uses a gain medium in a solid form rather than in a liquid form. It is used in the dye laser and gas lasers. The solid-state laser consists of the glass and the crystalline material which adds a dopant such as neodymium, chromium, erbium and the thulium(refer figure 1.8) [3].

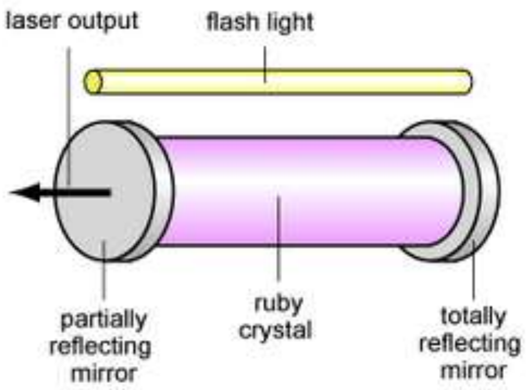


Figure 1.8: Ruby Laser Components

There is hundreds of the solid-state laser used in the media in that laser action has been attained, but only a few types of solid state lasers are in use. The most common solid state lasers listed in table 1.3.

Table 1.3: Types of Solid-State Lasers

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Ruby laser	694.3nm	Flash Lamp	Tattoo removal, Holography. In May 1960,thefirst type of visible light laser was invented.
Nd: YAG laser	1.064 µm, (1.32 µm)	Flash Lamp, Laser Diode	Surgery, Pumping another laser, Material Processing, Laser target designation, Research. It is one of the most com high power lasers.
Erbium-doped glass lasers	1.53-1.56 µm	Laser diode	doped fibers are usually used in telecommunication as optical amplifiers.

1.2.2.2.3 Metal-Vapor Lasers

Ion lasers based on vaporization of a solid or liquid metal, such as cadmium, calcium, copper, lead, manganese, selenium, strontium and tin, vaporized with a buffer gas such helium are categorized under the branch of metal-vapour laser[3]. Some of them are enlisted in table 1.4.

Table 1.4: Types of Metal-Vapors Lasers

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Helium-cadmium (HeCd) metal-vapor laser	325 nm, 441.563 nm	In metal vapor electrical discharge mixed with helium buffer gas	Fluorescence excitation examination, Printing, and typesetting applications (for example,used in U.S. paper currency printing)
Copper vapor laser	578.2 nm, 510.6 nm	Electrical discharge	In dye laser, dermatological uses high-speed photography pump.

1.2.2.2.4 Other Lasers

Some other types of lasers left unclassified in above-mentioned categories are divulged in table 1.5[3].

Table 1.5: Types of Other Lasers

Laser Gain Medium	Operation Wavelength(s)	Pump Source	Applications
Dye Lasers	Usually, broad spectrum is used depending on materials	Flash lamp, another laser	Birthmark removal, Research, SpectroscopyandIsotope separation
Free electron laser	A comprehensive wavelength range (around 100 nm - numerous mm)	Relativistic electron beam	Material science, Atmospheric Research, Medical applications

1.2.2.2.5 Semiconductor Laser

A semiconductor laser emits light through stimulated emission rather than spontaneous emission, which results in high output power (~100 mW) as well as other benefits related to the nature of coherent light. The output of a laser is relatively directional, allowing high coupling efficiency (~50 %) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. Furthermore, semiconductor lasers can be modulated directly at high frequencies because of short recombination time[3].

Commonly used classes of semiconductor laser transmitters used in fiber optics include a vertical-cavity surface emitting laser (VCSEL), Fabry–Pérot laser and Distributed FeedBack (DFB)[3]. Basic Classification is in table 1.6.

Table 1.6: Range of semiconductor lasers

Type of laser	**Operational wavelength**	**Pump source**	**Applications and notes**
Semiconductor laser diode	0.4-20 µm, depending on active region material	Electrical current	Communications, holography, printing, weapons, machining, welding, pump sources for other lasers, high beam headlights for automobiles.
Vertical-cavity surface emitting laser	850-1500 nm, depending on the material	Electrical current	Telecommunication

1.3. Ultrahigh Capacity Demands and Short Pulse Lasers

Data traffic is predicted to grow further exponentially as a result of the emergence of high-bandwidth-consuming applications and services such as Internet protocol television (IPTV), file sharing, high-definition television (HDTV) and image transmission whose compressed bit rate is on the order of Gbps. Apart from it, theexpansion of major telecommunications infrastructure in developing countries also results in huge data traffic.[4]In addition, societies livein an age of trend of using video transmission in globalcommunities has risen tremendously indicating that the bit rate or capacity of the backbone networks must be increased significantly to respond to these demands. The rapid deployment further pushes the demand for network capacity for delivering the data traffic. This developmentis considered as the digital economy of the twenty-first century. The delivery of information at this rate is unheard in the history of human communication, and this would not bepossible if optical fibers, especially the single-mode fibers, were not inventedand exploited over the last three decades.For this invention, Dr. Charles Kaowas awarded the Nobel Prize for physics in 2009. At this data rate of transmission to the home, the bandwidth usage is only a tiny fraction of the huge fiber bandwidth of ~25THz provided by a single-mode fiber. The principal point is how to deliver the services effectively and economically both in the core systems or networks and the last-mile distribution networks. [4]

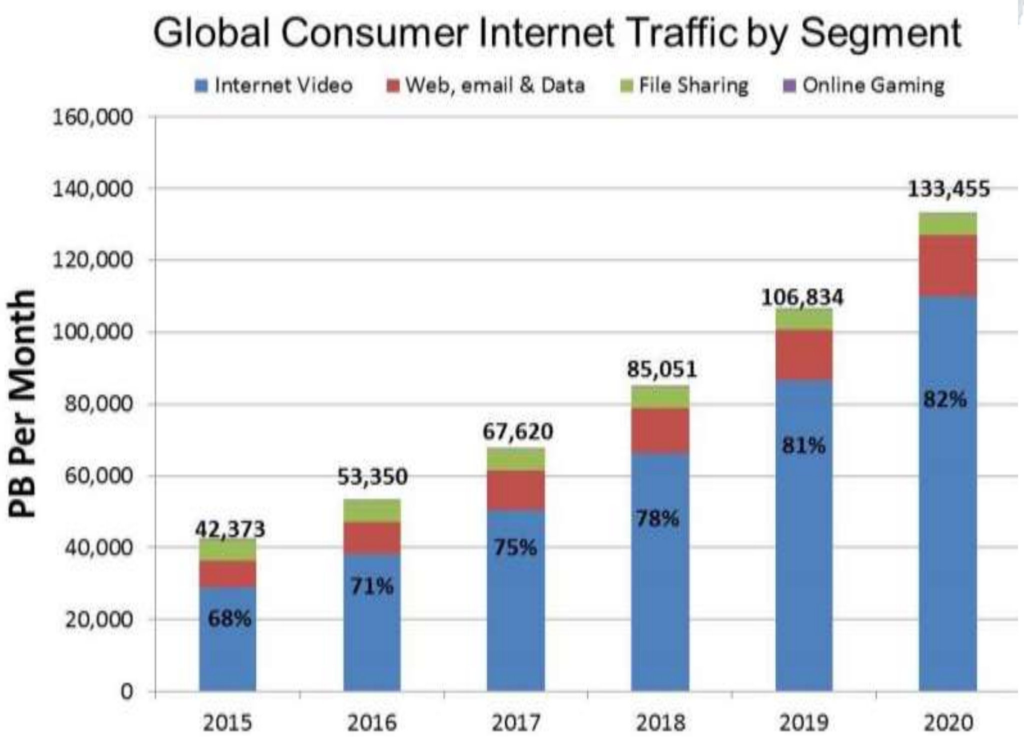


Figure 1.9: Increased internet traffic from 2015 to 2020

Figure 1.9 depicts the increase in the internet traffic from 2015 to 2020. The development of optical communications after the invention of the optical fiber has fulfilled the demand in the past. But to keep up with the exponential growth of data traffic in the near and not-so-near future, more and more hardware components and transmission technologies have to be developed. Wavelength-division multiplexing (WDM) technology which involves combining of a number of wavelengths into the same fiber has successfully increased the fiber capacity by 32 times while it's advanced version that is dense wavelength-division multiplexing (DWDM) by hundred times. However, hindrance occurs at the routers and switches where hundreds of channels must be de-multiplexed for optical-to-electrical conversion, routing, electrical-to-optical conversion, and multiplexing. If the optical signal can be routed/switched directly in the optical domain without the need for O/E,the whole network's speed can further be significantly increased.Optical time-division multiplexing (OTDM) offers promising solution to curb out such limitations in previous technologies. The graph below shows the bandwidth usage pattern for the year 2002 to 2020[4].

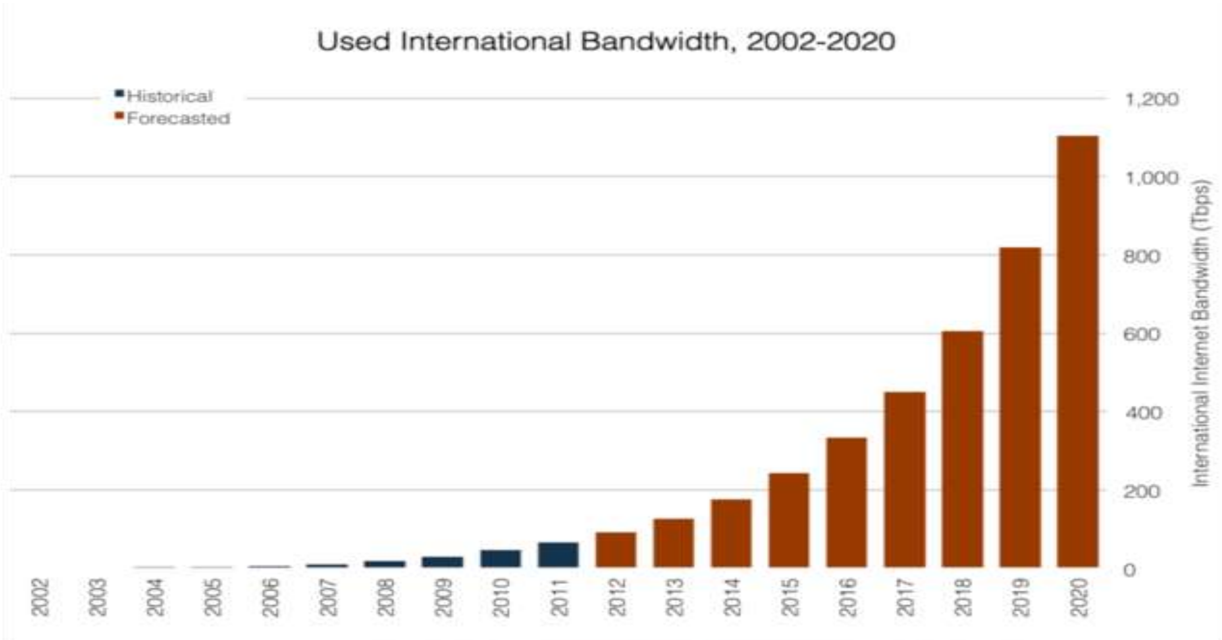


Figure 1.10: Bandwidth usage pattern from the year 2002 to 2020

1.4. Optical Time Domain Multiplexing

In Optical Time Domain Multiplexing (OTDM) multiple data channels are transmitted in the duration optical pulses in the form of ultra-short thatare inserted into a particular high-speed data stream throughexactcontrol of their qualified delay in the time domain.An optical gate is used at the receiving end for subsequent processing to get one base rate stream from the total data stream [4]. The OTDM operating principle is illustrated in figure 1.11: -

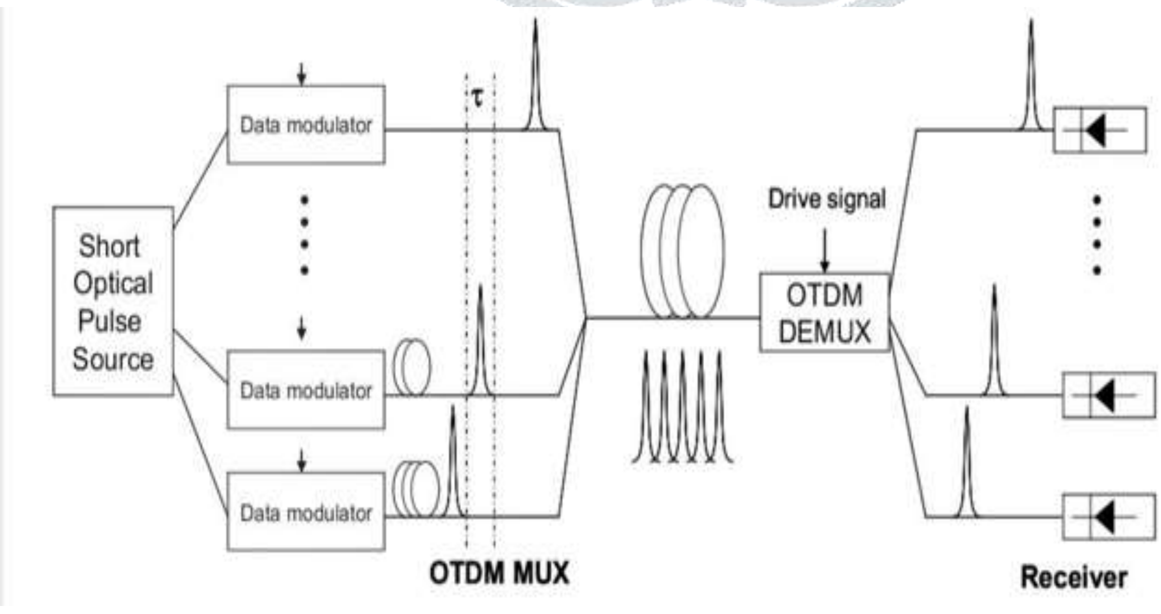


Figure 1.11: Operating Principle of OTDM

These types of systems operate at a much higher speed higher (>100Gb/s) than that of electronic components. In this several types of technologies are needed to realize high-speed OTDM systems which include short Optical Pulse Source, high-speed de-multiplexing, high repetition rate, ultrashort pulse, accurate dispersion compensation and clock recovery. In the generation of ultrashort optical pulses with have multiple-gigabits recurrence rate is important for ultra-high bit rate optical communications which are for the Tbps opticalfiber systems of next generation. A mode offers a potential source of the pulse train of light- locked fiber that is an electromagnetic pulse whose period is the degree of a picosecond (10^{-12} second) or less and they also have a broadband optical spectrum. These types of repetitive pulse sequences are generated by locking into one of the longitudinal modes of a ring laser, whether it be a semiconductor-based structure or a fiber-based.[4]

1.5. Mode-locked Lasers

A fundamental schematic mode-locked lasers as shown in figure 12 consists of a nonlinear waveguide section, an amplifying device to compensate for the energy loss as well as to provide sufficient gain to induce the nonlinear effects, a tuning section to generate the locking condition of the light wave energy to a particular harmonic, an input and output coupling section for tapping the laser source, and an optical modulator to generate the repetition rate in association with the locking mechanism.All these optical components are interconnected by a ring of single-mode optical fiber. [4]

The pulse repetition rate generated by the above convention technique is often limited by the operating frequency of theoptical modulator embedded in the ring resonator which can be outstripped by using the nonlinear parametric amplification and the degenerate four-wave mixing (FWM) phenomenon in a special optical waveguide and the mechanism of rational frequency detuning, as well as the interference between the modulated pump signals via an optical modulator.Amplifying Resonance ring is basic of fiber ring laser.[4]

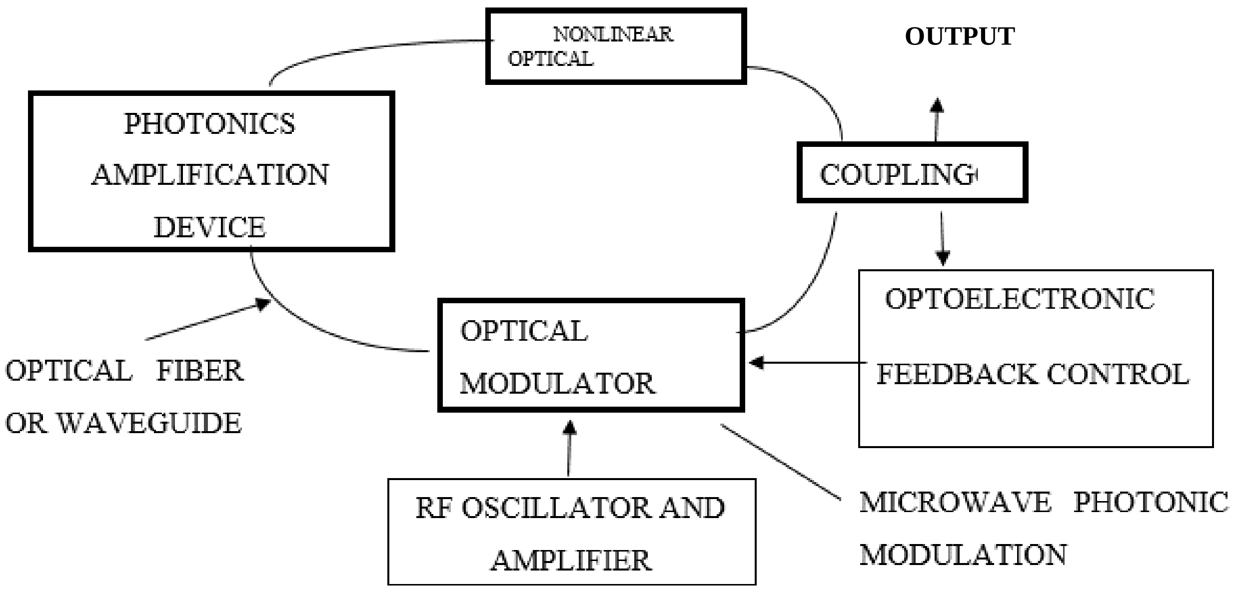


Figure 1.12: Schematic diagram of a generic mode-locked laser for generation of a multi-gigahertz repetition rate pulse sequence

There are certain discrete energy levels in a particle that electrons can occupy. When electrons receive energy from other sources such as an electronic or optical source, they jump from a lower level to higher levels. The electrons at high-level states *Ei* are excited electrons, and they can randomly jump back to a lower energy state *Ej* without any stimulating source. When this happens the electrons release the energy in the form of a photon and this random jumping process is called spontaneous emission, and the phases of the released photons are random. Frequency can be calculated from:

Where *v* is the released photon's frequency

h is Planck's constant

Ei and *Ej* are the energies of the electron at level *i* and *j*, respectively.

$\upsilon = (E2 - E1) / h$(1.1)

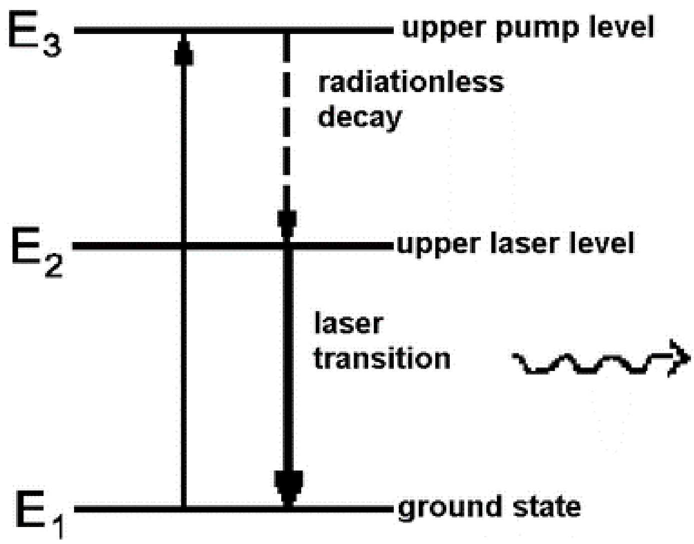


Figure 1.13: Energy level diagram of a particle and photon emission

By contrast, when a photon enters a medium with excited electrons ,it will cause a stimulated emission as the electron transits to a lower level and releases a new photon. The photons released through this emission have the same energy and phase as those of the stimulating photon. They then stimulate new emission and hence more, and more photons are generated as shown in figure 1.13. Therefore, the optical signal is amplified, and the medium with electrons pumped into excited states is called an amplifying medium.

The amplifying medium is now put inside a cavity formed by two mirrors to form a typical laser. One of the mirrors totally reflects the light, while the other reflects part of the light and transmits the rest to the output. The photons initially emitted from the spontaneous emission process are amplified when traveling through the amplifying medium via the stimulated emission. The photons are reflected back and forthbetween the mirrors and grow exponentially if their frequencies or wavelength satisfy the phase condition.

$\omega = N \pi c / nL$(1.2)

where,

L is the cavity length

N is an integer number; c=3×108 m/s is the speed of light in vacuum

n is the refractive index of the medium or the effective refractive index ofthe guided mode if the medium is an optical waveguide

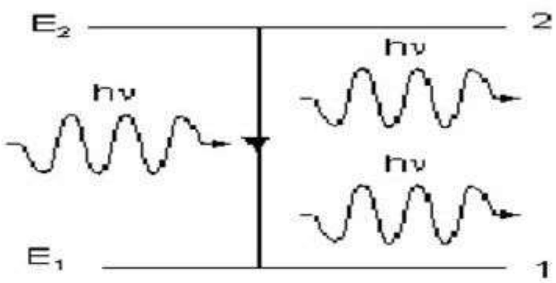


Figure 1.14: Stimulated emission and energy levels in an amplifying medium

Figure 1.15: Schematic diagram of a basic laser system

Figure 1.14 and 1.15 depicts the general diagram of a basic laser system and the energy levels in amplifying medium. It can be seen that the laser can generate alight wave in a wide spectral range of wavelength that satisfies the cavity resonance conditions. These are longitudinal nodes. Alternatively, the laser can be designed to oscillate at multiple longitude modes, but those modes are controlled so that sequences of very short pulses can be generated. A techniqueto generate a short pulse is the Q-switching in which the quality factor Q of the optical resonator can be lowered to prevent the laser from oscillating during the energy-pumping period. This results in anexponential growth of theintracavity intensity, and the laser delivers a pulse of high intensity and short duration. However, the q-switching technique can just generate pulse no shorter than a few nanoseconds. For generating picoseconds pulse, node-locking techniques are commonly employed. Active modulation in fiber laser cavity assists the concentration of the energy circulating in the ring into specific pulses distributed evenly in time. The active modulation can be amplitude, phase or frequency[4].

A terahertz-repetition-rate laser can be implemented using parametric amplification in a section of a special optical waveguide, which can be a highly nonlinear dispersion-flattened and dispersion-shifted fiber optical waveguide or an integrated optical waveguide. Parametric amplification is achieved by mixing four waves at three different frequencies based on the nonlinear intensity-dependent change of the waveguide refractive index. Under a perfect phase-matching condition, a signal at the frequency $f_s$and a pump source at the frequency $f_p$mix and modulate the refractive index of the nonlinear optical waveguide section in such a way that a third lightwave, also at f_p, creates sidebands and this process results in the generationof an idler with gain represented in equation 1.3[2,4].

$$f_p \pm (f_s - f_p) \qquad (1.3)$$

In an active ring laser, the repetition frequency, which is generated by locking at a harmonic, is determined by the modulation frequency of the modulator. The modulation frequency f_m is as presented in equation 1.4.

$$f_m = qf_c, (1.4)$$

where$f_c$is the fundamental resonant frequency of the waveguide ring determined by the length of the laser cavity (the ring length) and *q* is the order of the harmonics of the cavity's longitudinal modes[4].

By applying a small deviation of the modulation frequency $\Delta f = fc/N$ (N=large integer), the modulation frequency becomes $f_m = _q fc + f_c/N$. Thisleads to an N times increase of the repetition rate, with the repetition rate expressed as in equation1.5.

$$f_R = Nf_m. \qquad (1.5)$$

The schematic diagram (Figure 1.16) shows the experimental setup according to which the modulation of the pump source can be implemented using a step recovery diode (SRD) which would produce a very short pulse and a low repetition rate to modulate the amplitude of the pump lightwave via an optical modulator of moderately wide bandwidth. That is, the bandwidth limitation of the modulator in conventional mode-locked lasers can be overcome[4].

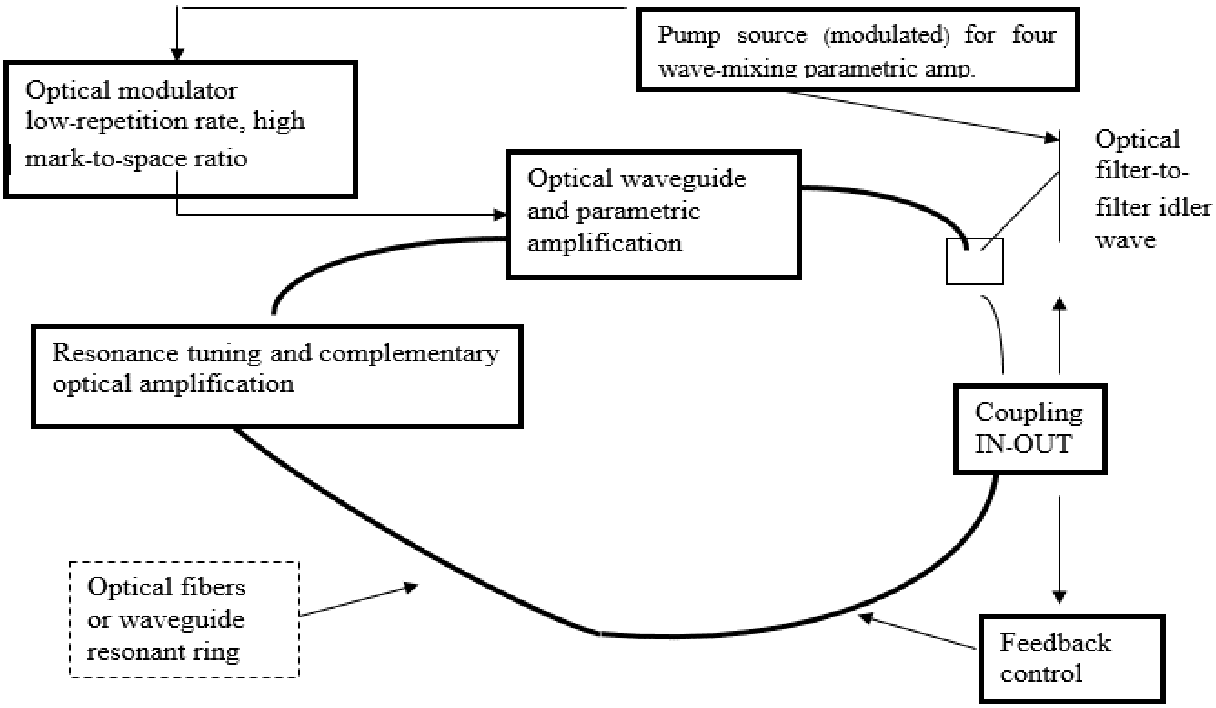


Figure 1.16: Structure of a mode-locked laser using parametric amplification

As picosecond pulse generation in the bulk laser can frequently be reliable in a concentrated absorber action, so we cannot be ignored the dispersive and nonlinear effects in a fiber laser, even in the multipicosecond domain. Logically, the simplest and the easiest method that leads to the soliton fiber laser (Figure 1.17), where the current pulse also is known as circulating pulses are quasi-soliton pulses[4].

In the passive mode-locking, the artificially concentrated absorbers employed on the Kerr nonlinearity, are used mostly. One solution is to manipulate the non linear polarization rotation. In polarization rotation, the device is polarized by rotating it about a different axis through the laser beam. Polarization method in some length of fiber undergoes a complex rotation, which depends on the optical power due to self-phase and cross-phase modulation. In the end, the pulses are passedthrough a polarizing element that changes the polarization to power transmission [1,2,4].

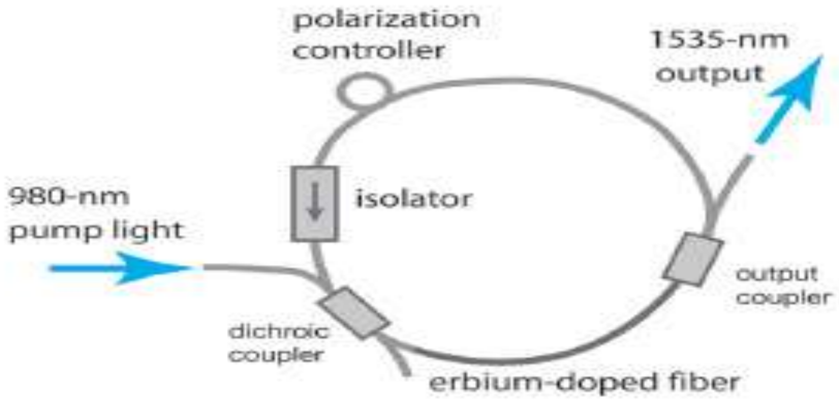


Figure 1.17: Soliton Fiber Laser

1.6. Laser Resonators

The next term is Laser Resonators also knows as Optical Resonators, uses optical isolator that serves as the polarizing component. The polarization controller is kept in a way that the peak of pulse experiences all the lower losses compared to the pulse wings. However, the optimum adjustment is depending on both the bending of fiber as well as on temperature. As a result, these lasers are unstable in the environment. Hence, they require a wisely temperature-stabilized environment or infer quenttuning. The other type of artificial concentrator absorber is the nonlinear fiber loop mirror that could be shown into a figure-eight fiber laser depicted in the figure 1.18 below [5].

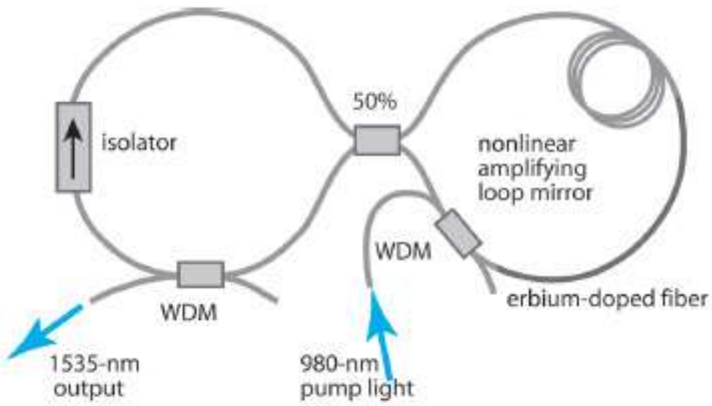


Figure 1.18: Figure-Eight Fiber Laser

The main laser resonator is on the left side of the above figure, whilethe ring on the right side is a nonlinear amplifying fiber loop. Laser resonator pulsesare divided into two parts and are propagating through the nonlinear loop in the opposite directions. These pulses encounter different nonlinear phase shifts which one is initially amplified in the erbium-doped fiber and after that spreads through a lengthier part of the nonlinear fiber, whereas the other one spreads by fiber with a lower energy. So, the interference condition to recombine the two pulses together at the fiber coupler in the centerdevelops power-dependent,for a definite power level, maximum of the power could be directed downward in the laser resonator. We could view in the figure-eight laser could be prepared with polarization-maintaining fiber so that it becomes stable in the working environment [5].

1.7. Applications Ultrafast Fiber Lasers

- Ultrafast fibre lasers are basic building blocks of many photonic systems that used in industrial, medical as well as in the scientific application.
- Measuring the fundamental constants of nature ultra-high-speed optical communications.

  - Mode-locked fiber lasers are based on telecom components, which have been developed for reliable and long-term operation.

  - The laser output is naturally fiber-coupled. Hence, compatible with telecom systems [3].

1.8. Advantages of Ultrafast Fiber Lasers

- The Largergain bandwidth of rare-earth-doped fibers, normally tens of nanometers that enable the generation of femtosecond pulses.
- Low pump powers because of the high gain efficiency of active fibers which helps to activate such lasers having flow pump powers and to allow intracavity optical components with comparatively high optical losses. Such as, specific optical filters or arrangements for dispersion compensation cannot be used in bulk lasers.
- Fiber laser structures could be made-up with low cost and could be very condensed and uneven; mainly when free-space optics are not used.
- Double-Cladfibersprovide high output powers [7,8].

1.9. Disadvantages Ultrafast Fiber Lasers

- The performance of femtosecond and picosecond mode-locked fibre lasers and amplifiers is in several cases severely restricted by the strong nonlinearity of fibres, and sometimes also by the chromatic dispersion.
- Another disadvantage is it results from uncontrolled double refraction of fibers if they are not polarization maintaining[3].

CHAPTER 2

The summary of previous studies about the generation and detection of the ultrashort pulses has been summarized sequentially in this chapter. Based on the previous studies, the present research concentrated on evaluating the suitable method for generating and detection of the ultrashort pulses. In this chapter, various objectives of the present research work including the methodology of present work using MATLAB and OptiSystem for generating and detection of the ultrashort pulses to accomplish the suitable results has been also mentioned.

2.1 LITERATURE SURVEY

Bradley, D., & Durrant, A. (1968) analyzed generation of ultra-short dye laser pulses by mode-locking. The mode locking is carried out in that situation when transmitting time of ruby and dye laser cavity are equal. Organic dye laser when optically pumped by a huge pump laser pulse then it produces a high range of frequencies between 4000 Angstrom to 11000 Angstrom. Hence the output spectrum is usually of a wide range. The output of width depends on two factors. The two factors are cavity length and the pumping intensity [29].

Kuizenga, D. J (1977) analyzed the generation of the short impulse for laser fusion in an actively mode-locked Nd: YAG LASER. It works on the principle of the pre-lase period. It has three main conditions that short one envelope should approach a steady state value after the number of round trips. The pre-lase period must also be long enough for the pulses to become transformed in a limit. Secondly, the spectrum is the factor of two from the steady states transformed limited spectrum after a few round trips. The third is, when the laser is on the threshold pulse at the start of the pre-lase period; there is a usual relaxation oscillation. The research concluded all this by using different formulas [28].

M. Nakazawa, T. Yamamoto, and K.R. Tumaura (2000) proposed a method for Ultra-high-speed OTDM transmission using reverse dispersion fiber and conventional single-mode fiber. The proposed modified pulse modulation technique assisted in reducing the pulse broadening from 200fs to 20fs. The phase modulator used was extracted at the DI-NOLM while being driven at the 10GHz clock. The proposed technique was helpful in diminishing the dispersion from erbium-doped. In this way, the 1.28Tbit/s signal was successfully remitted over 70 Km with optical time division multiplication technique, and single wavelength channel.Third- and fourth-order simultaneous dispersion compensation was used with a 10GHz synchronous phase modulator. The input pulse width was 380fs, and the transmitted pulse width was 400fs. But bit error rate of less than one was over-served with all 128 channels demultiplexed to 10Gbit/s [9].

Hay, N.et al. Marangos, J (2001)analyzed High-order harmonic generation from organic molecules in ultra-short pulses from the molecular system of near-infrared high-intensity laser pulses of 70fs and 240fs duration. The molecular systems described in this research were cyclohexane (cyclic) and n-hexane (linear), the alkanes cyclopropane and the aromatics benzene and naphthalene. The harmonic intensities in this research were measured as the function of ellipticity of the laser polarization and function of laser intensity. The results were compared in this research with xenon atom. The harmonic generation from the organic systems is same to the xenon for 70fs pulses which indicated an atom-like behavior for the molecules when the duration of the laser pulse is less as compared to the fragmentation timescale of the molecules. Harmonic intensities were measured in the function of laser intensity. The research used polarization method; it works on different properties like molecular properties, electronic structure, and behavior of ionization and fragmentation in larger systems. The results concluded that the molecules remain integral during the interaction, leading to atom-like 240 D high-order harmonic generation.

The results indicated the significant divergences between suppression of HHG and molecules with HHG efficiencies in the larger species. This research also described the divergence in the context of molecular properties, the behavior of ionization and fragmentation and electronic structure which leads to the enhancement of field ionization in the larger systems. This research also shows that the dependence of polarization ellipticity of HHG produces the less sensitive molecules to the polarization as compared to the xenon atoms. Results also demonstrated that HHG molecules exposed to the ultrashort pulses which are a powerful tool help in the understanding the electron dynamics of molecules which were exposed to an intense field [26].

K.K. Gupta, N. Onodera, K.S. Abedin, and M. Hyodo (2002)proposed a technique to generate optical pulses which are highly stable in timing jitter and amplitude noise. The research focused on demonstrating the repetition frequency multiplication using the optical filtering in AM mode-locked fiber ring lasers. The optical filtering was accomplished through FFP (Fabry-Perot filter). This Fabry–Perot filter is inserted into the ring to equalize the pulse amplitudes in the rational harmonic laser. A modulation signal of 869.284 MHz was used to generate a 3.477-GHz optical pulse train. The generated optical pulses were highly stable with only 0.93% amplitude noise, 1.2 ps of timing jitter and large suppression of super-mode noise [10].

Gupta, K.et al. (2002) analyzed pulse repetition frequency multiplication using intra cavity optical filtering in the AM Mode-Locked Fiber Ring Laser and demonstrates that the generated optical pulses are extremely steady in timing jitter and amplitude noise. An experiment was performed in which RF modulating signals were applied to Mach-Zehnder modulator that generated optical pulse trains with repetition rates equal to FSR of the FFP. The pulse generated was a high degree of pulse stability of low noise, amplitude noise, phase noise, or timing jitter. With the help of modulation signal of 869.284 MHz, 3.477 GHz optical pulse train, 3.48GHz free spectral range fourth sub-harmonic multiple of FFP was produced. The results indicated that the generated optical pulses produce the high degree pulse stability with a timing jitter of 1.2 ps, a low amplitude noise of 0.93%, large suppression of super mode noise [24].

Bech, H., & Leder, A. (2004) analyzed the time-dependent formation of the scattered light through the numerical investigation. To analyze the difference in the time between the signals of a higher order of refraction and reflection, calculation utilized the Mie theory. With the help of Mie theory, numerical results were calculated by the time-resolved scattered light analysis which evaluated the temporal sequence of the scattered light generation of particle characterization. In this research, fs laser pulses were used for the incident field which was converted through Fourier transform into the frequency domain.

A Mie-calculation was accomplished with each of the spectral components which resulted in scattered light or scattered light of individual scattered light order alternatively. Using the principles of geometrical optics, corresponding optical path lengths of light rays were computed. To take into account the single order of the scattered light, Debye series expansion was used. The time-resolved scattered light was analyzed in this research through the inverse transform and superposition into the time domain. The temporal sequence of pulse-induced scattered light creation for reflection and refraction was represented as the detection angle function. The diameter of the particle determined the difference in time between the scattered light signals and the reflection signal of the refraction when the difference in optical path length is known. These path lengths were determined with the principles of geometric optics which arises by detection of a various scattered light order under the same scattering angle. The temporal sequence of separated, scattered light orders and the temporal sequence of the pulse-induced total scattered light were induced through the surface waves. In this way, the results demonstrated the generation of pulse-induced scattered light for the first and second order of refraction [23].

J. Cloweset al. (2005)proposed theNd-doped fiber laser. The laser was able to generate 170 fs pulses with an output power of 0.8 W and spectral range of 920 nm. In order to reduce the unwanted gain, the finite cut-off wavelength of the fundamental mode was obtained. It was accomplished with the use of W-type refractive index profile of the doped core. In this way, unwanted gain at 1064 nm was easily suppressed. Both the high power amplifier and master source were connected to each other using high power isolator. There was a mechanical contact between the high power isolator and the master source. In this way, low coupling loss was achieved while preserving the high reflectivity of the dichroic mirror. Though Sapphire lasers are also capable of covering the same spectral range, the proposed laser is much more efficient and compact to this conventional laser [13].

J. Limpert, F. Röser, T. Schreiber and A. Tünnermann (2005)reviewed the accomplishments, applications and scaling potential of the high energy ultrafast fiber laser systems. The power scaling is one of the major issues that occur because of the thermo-optical effects. The proposed rare-earth-doped double clad fiber effectively resolved this issue with its geometry. In this way, therare-earth-doped double clad fiber fundamental requirement for broad bandwidth short pulse amplification and very high single-pass gain. It can transmit the signals at large length through the low intrinsic loss characteristics.

Along with this, a large wavelength is covered through the absorption spectrum. The long fluorescence lifetime and the small quantum defect leads to high energy storage capability and high efficiency respectively. In this way, the proposed rare-earth-doped fiber was superior in comparison with other solid-state laser concepts. But the major issue was that nonlinearity could damage the fiber because of the severe pulse distortions [14].

Jens Limpert, Fabian Roser, Thomas Schreiber, and Andreas Tunnermann (2006)reviewed the benefits of the ultrafast fiber laser systems and compared them with bulk solid-state lasers. Their high single-pass gain, heat dissipation capability, broad gain bandwidth, simplicity, robustness, and compactness make the fiber lasers more attractive for the host of applications. Rare earth doped photonic crystals fiber proposed the different properties that allow an upward scaling of performances than conventional fiber lasers. The transfer of additional functionality and their protracted optical parameter range to the fiber showed that such type of systems has the huge potential to scale the performance of next-generation laser systems throughmicro-structuring. This research demonstrated high energy and high power photonic crystal fiber laser, and amplifier systems with the advantages of an air-clad PCF with an extended mode field area and very high pump core NA of a single-mode core.

This research also describes the disadvantages of the ultrafast fiber laser systems. Experimental methods also discussed the innovative fiber designs. This research reviews all the achievements, challenges, and perspectives of amplification in fibers and ultrashort pulse generation. The results indicated that the pulse fiber laser systems deliver high average powers, high pulse energies, high precision micromachining, and high repetition rates. The author demonstrated the rare-earth-doped fiber lasers with continuous wave output power and diffraction-limited beam quality. The results also indicated that fiber lasers create a power-scalable solid-state laser to produce intense pulses from a fiber. This research also helped in overcoming the various limitations of pulses. The novel experimental approaches and fiber designs proposed toward laser systems having high pulse energies and average powers [15].

J. M. D. Cruz, V. V. Lozovoy and M. Dantus(2006) reviewed the issues of ultrashort pulses while applying to biological tissue. The research found that ultrashort pulses are difficult to manipulate when used with biological tissue. The research proposed a method to attain full benefits of ultrashort pulses. The proposed method is based on the coherent control that assists in correcting the phase distortions that emerge as a result of high NA (numerical aperture) microscope objectives. The research recommends various useful phase functions to gain selectivity. But it can only be accomplished if there are perfect optimization and no moving part. They also demonstrated that how phase functions can be used to minimize the damage in multiphoton excitation.

From this research, it is concluded that TL pulses are not ideal for the multiphoton imaging due to the induce multiphoton damage. Some strategies were suggested in this research in order to attain the selective two-photon excitation in environment-sensitive probes. This research also presented the selective suppression of the three-photon process which can be attained by maintaining the same efficiency as it is in two-photon excitation. From the result, it is declared that it is very difficult to deliver the accurately shaped pulses which are required for the two-photon activation with the help of thick scattering biological tissue. To enhance the application of two-photon imaging for two-photon photodynamic therapy and cancer detection, suppression of multiphoton induced damage and selective two-photon excitation are used [21].

Limpert, J.et al. (2006) presented main advantages of ultrafast fiber laser systems compared to bulk solid-state lasers. The research proved that the fiber laser constitutes a power-scalable solid-state laser concept. To produce penetrating pulses from fiber, some limitations have to overcome. The research presented the achievements, challenges, and viewpoints of ultrashort pulse generation and amplification in fibers. Rare-earth doped photonic crystal fibers used by them offers several unique properties which permit an upward scaling of performance related to conventional fiber lasers. The results concluded that the short pulse fiber laser systems would deliver very high average powers and high repetition rates in a grouping with high pulse energies.

In this research, the Fiber laser system proposed the exclusive properties for the amplification of ultrashort pulses which has the high powers. Two methods were used,i.e.,fiber-based chirped pulse amplification system and the amplification of linearly chirped parabolic pulses. At 75 MHz repetition rate, the amplification of linearly chirped parabolic pulses helps in producing the 17-W normal power of linearly chirped parabolic pulses. Also, the diffraction-limited beam quality was generated in the large-mode-area ytterbium-doped fiber amplifier. The results indicated that 60% efficiency of recompression of these types of pulses gives 80fs pulses which have a peak power of 1.7 MW. This research indicated that diffraction grating compressor is a key element which consists highly efficient transmission grating used in fused silica. [25]

F. Yoshino, H. Zhang and A. Arai (2009) presented ultrashort pulse fiber laser with the unique micro-marking feature, Switchable Inner Micro-Marking (Swimm), in various industrially important transparent materials. The research explained that how ultrashort pulse lasers are capable of producing high peak power while utilizing modest average power. Thus, these ultrashort pulse lasers can be used on transparent materials and material modifications. The proposed Fiber laser model is designed for the medical diagnostics, imaging metrology,laser material processes, and scientific research [16].

The study suggested that adjusting various features of pulse fiber laser such as pulse energy, focusing conditions and other processing parameters, well-defined material modifications can easily be created. Also, proper control of processing conditions helps to produce features which are tough to see under normal and ambient lighting [16].

M. E. Fermann and I. Hartl (2009) reviewed the use of fiber laser technology in different applications of ultrafast optics. A unique level of utility is proposed by ultrafast fiber lasers for advanced and commercial scientific applications of the ultrafast optics. The distribution of ultrafast fiber lasers to the scientific and commercial empires was enabled through many advances in ultrafast optical science and fiber laser technology. In this research, extraordinary power levels can be produced in the spectral range from XUV to the THz region. New developments in the fiber phase control techniques and the fiber technology helps in improving multi-core fibers, ultra large core fiber amplifiers, microstructured fibers in the hyperspectral range. The hyperspectral domain leads in many advances in science and technology and also enables the novel applications in the industrial domain. The study focuses on discussing the core enabling fiber technologies. These technologies included all-fiber dispersion control, large-core fibers, highly nonlinear and fiber amplifiers. The study focuses on a system developed about the fiber frequency combs and passively mode-locked fiber lasers. Along with this, coherent supercontinuum generation has been explained in depth. At last, various techniques have been represented for controlling the phase of fiber amplifiers and fiber lasers [17].

Esirkepov, T. Z., et al. (2009) analyzed ultra-short Gamma-ray and X-ray pulses producing High-power laser-driven source. This research suggested various concepts of the double-sided mirror. Double Doppler Effect method was used in this research in which a relativistic flying mirror reflects the counter-propagating electromagnetic radiation. In this method, a relative mirror reflects a counter-propagating electromagnetic radiation that results in intensification and frequency multiplication. On the other hand, ultra-intense co-propagating electromagnetic wave gives its energy to the mirror.

In the inverse double Doppler effect, the mirror acquires the energy from the ultra-intense co-propagating electromagnetic wave. The flying mirror results in high-density thin plasma slab which accelerates the radiation pressure in the dominant regime. At the flying mirror, the high harmonics frequencies are generated by relativistically strong counter-propagating radiation which undergoes multiplication using the same factor as the reflected radiation fundamental frequency. The results indicated that it is equal to the quadruple of the square of mirror Lorentz factor. Also, it was concluded from the results that the source of ultra-bright gamma-ray and high-power coherent X-ray radiations cover the way towards penetrating nonlinear quantum electrodynamics processes [30].

M. Mielke et al. (2010)demonstrated an all-fiber erbium amplifier system. The system is capable of producing 100 pulses with high beam quality, an autonomous control system and more significantly with only femtosecond class pulse width. The research describes the laser platform performance as well as its thermal effects on the structure through in-depth analysis. Along with this, it has been estimated that Radiance lasers operate continuously around the clock without used by users. It needs the intervention of human only one time in approximately 27,000 hours. The applications and critical performance data associated with the Radiance ultrafast lasers has been presented.

The ultrafast lasers which were based on integrated software controls and fiber optics architecture has the crucial role in the spread of the lasers for industrial and commercial applications. The main issue in this research is to produce the suitable pulse energy from the single mode fiber amplifiers which have less cross-sectional area. They are used to achieve all tuning and control processes using the robust software and internal electronics. This research also presented an all-fiber erbium amplifier system which generated >100 μJ per pulse using femtosecond class pulse width, an autonomous control system and excellent beam quality. The author presented the laser platform perform in this research and described the lifetime and reliability for ultrafast lasers [18].

Ponomarenko, O (2011) analyzed core-electron tunneling interaction with X-ray and XAU radiations in diatomic systems. The research described that intense X-ray fields might cause core-hole tunneling on a timescale which would result in changes of diffraction patterns of X-ray probe pulse. In the experiment performed, it was difficult to characterize nature of core- hole state. So, crystallographic form factors are not applicable for one-shot diffraction experiment. The effects of coherently induced by intense laser field depend on field parameters and properties of molecules. The results showed coherent suppression of core-hole delocalization dynamics using XUV laser fields.

This research helped in developing the novel techniques which allows tracing the time evaluation of electronic density in a molecular system with X-ray free electron and HHG lasers which produce ultra-short pulses. This research also determines the signatures of core-electron transitions throughout the probe pulse. The results indicated that the intensity of XFEL emission is enough to impact the field-induced bound-state tunneling of core hole states which were created through one-photon ionization. This research also presented various effects of field-induced core-hole transport on the X-ray scattering properties in the molecular system. This research presented the impact of field-induced core-hole transport on X-ray scattering properties in the molecular systems. In this research, inter-well tunneling of a core electronic density is focused by Coulomb barrier between nuclei in single-electron dicarbon ion of XUV laser field. The calculations indicated the coherent suppression of core-hole delocalization dynamics through XUV laser fields. This research also presented the reconstruction of molecular structures through the analysis of scattering data in the single-shot XFEL experiments [22].

Feng, H., Zhao, W., Yan, S., & Xie, X. P. (2011) analyzed generation of 10GHz Ultra-Short Pulses with the Low Time Jitter with Actively Mode-Locked Fiber Laser by using the cross-mode modulation. This research helped in attaining the 8.3_ps ultrashort pulse at 10 GHz repetition rate by time jitter with active mode-locked fiber ring laser. The ring cavity laser is mode-locked through a semiconductor optical amplifier which is built on cross-gain modulation.The amplitude modulator which works as the external optical pulses are used in external CW source for the modulation with radio frequency signal. It is injected into the fiber ring cavity to attain the active mode locking. In this, they searched for the relationship between the line width of external modulation continuous wave source and performance of an actively mode-locked fiber laser. They resulted that the ultrashort pulse at high repetition rate with low time jitter could be generated by the optimization of the continuous wave laser source, which means it has a potential application in all optical communication networks.

The results of the laser output characteristics specified that line width of employed CW source affects the properties of the ultra-short pulse like time jitter and phase noise. Through the optimization of the CW laser source, an ultrashort pulse is generated at low time jitter and high repetition rate. [27]

M. M. Mielke, et al. (2013)described that compelling economics, unparalleled precision, and new materials flexibility are the three main aspects that have been validated in commercialmicro fabrication. Fabrication process impact includes a dramatic reduction of post-processing requirements for metal devices since toxic side effects, such as recast and dross can be substantially condensed. There are various materials such as brittle dielectrics and polymers whose machining and modification is very difficult. But these materials can be easily modified through the femtosecond laser methods. It helps to reduce the complexity and the direct labor. In this way, femtosecond laser materials processing is cheaper, better and fast way to fabricate parts with high precision.

In this research, robust telecom components, embedded software control and Fiber optic architecture ensure the performance standards, ease of use, and the reliability of the manufacturing settings. Femtosecond laser microfabrication tools make it accessible for the industry. The application of femtosecond lasers to modern manufacturing was based on new flexibility and unparalleled precision, and compelling economics. These types of new capabilities have the many opportunities in the application of bioscience, aerospace, medical devices, consumer electronics, and automotive components [19].

X. Liu, et al. (2015) proposed a distributed ultrafast fiber laser which was based on a linearly chirped fiber. The proposed laser is highly stable and simple. The DUF lasers provide the ultrafast pulsed source with changeable and controllable cavity frequency, stable operation, and low cost. This research also proposed DUF fiber laser which is based on linearly chirped fiber Bragg grating in which the total cavity length is changeable.

The result indicated that the total cavity length of DUF fiber laser is changeable linearly as the function of pulse wavelength.It is unique from the conventional concentrated ultrafast fiber lasers. The spectral sidebands are enhanced in DUF fiber laser due to the CW and pulse components. It was also found that the sidebands have the same round-trip time even they have the different refractive index and round-trip distances. The results also indicated that the bandwidth of first-order sidebands is narrow. The pulse shaping of the DUF fiber laser directs from the dissipative processes with the phase modulations. They are diverse from the net-normal-dispersion lasers or common net-anomalous-dispersion [20].

Yulong Su et al. (2017) proposed a multiple wavelength methods for ultrashort pulse generation. The proposed scheme was based on active mode locking integrated with four-wave mixing (FWM). The aim of this scheme was to generate the ultra-short pulses with high repetition rate and multiple wavelengths. The pulses are analyzed on the basis of power, SNR values at different wavelengths and frequency. The experiment was performed using apulse width of 44.37 ps, 47.89 dB SNR, and 552.7 fs RMS time jitter. The results observed that the proposed schemes had shown promising results in terms of high-quality, and stable multiple wavelength pulses that can be applied in the fields of optical communications and fiber sensing. [31]

CHAPTER 3

EXPERIMENTAL GENERATION AND DETECTION OF ULTRASHORT PULSES

The overall work was done in the MATLAB and the OptiSystem Software. In this project, basically, the co-simulation of MATLAB is done which means that Optisystem is calledfrom the MATLAB Software.After the Co-Simulation, the plots of Optical-time domain visualize and optical Spectrum analyzerwere shown through the MATLAB Software. Now let us discuss the MATLAB and the OptiSystem Software in details.

3.1 *MATLAB*

MATLAB is high performance, fourth-generation programming language. MATLAB stands for matrixlaboratory. MATLAB was developed by LINPACK and EISPACK projects and was originally written to offer access to Matrix software, which represents the advances in software for matrix computation. MATLAB has IDE (Integrated Development Environment). MATLAB contains various toolboxes which make it useful in every field of Engineering, Research Work, and Industrial Work and the education also. MATLAB is now a day used in various educational areas as, MATLAB can easily solve linear equations, algebraic equations, Differentiation, and Integration. MATLAB is used by various researchers and scientists in different fields like Signal Processing, Control Engineering, and Image Processing.
MATLAB has various uses, which include:

1. Algorithm development
2. Math and computation
3. Simulation, and prototyping
4. Application development Environment like Graphical User Interface building
5. Scientific and engineering graphics
6. Data analysis, exploration, and visualization
7. Solving Differentiation and Integration

MATLAB is used in various industries like

1) Aerospace Industries: For mathematical modeling, MATLAB is used in Aerospace Industries.
2) Automobile Industries: for Simulation purposes
3) Embedded systems
4) Computational Science

MATLAB SYSTEM includes three main parts:

1) MATLAB Working Environment

These contain set of tools on that the user can work. It includes managing the variables in the workspace. It has various tools for managing, developing and debugging M-files.

2) Graphics Handling

This includes the MATLAB graphicssystem; it has high-level commands for 2-D and 3-D image processing and data visualization. It allows its user to build the complete GUI (Graphical User Interface) on the MATLAB application.

3) API (Application Program Interface)

In this library of MATLAB, it allows its user to write FORTRAN and C programs that can interact with MATLAB. It also has the facility for reading and writing MAT files.

4) Co-Simulation of MTALB with Optisystem

Co-Simulation of MATLAB with the OptiSystem is considered as the useful method. Like in this case, the firstcreation of a COM server running OptiSystem was done. Then the opening of the Optisystem model file with the proper file name from the MATLAB was done. After that, specify the parameters that are varying like in this case, the iterations are varied from 0 to 1295. Now, the results were transferred from the Optisystem to the MATLAB. Along with that the components that are used to get the parameters are also transferred. Finally, the code will run and will give the results in the form of plots. The first plot is the Pulse plot with Time in seconds vs. Power in dBm. The second plot isalso of the pulse with Wavelength in meters versus Power in dBm.

3.2 OptiSystem

The optical communication system is increasing day by day with more complexity. It is not possible nowadays to design and analysis these systems, which contains nonlinear devices which are highly sophisticated. As a result, our main task is to perform efficiently with the help of new software tools like Optisystem.
In Optisystem, we have various visualizers for analyzing the output in the graphical form. The visualizers which Optisystem has are BER analyzer which shows us the eye diagram and its various plots like the height of eye diagram, BER values, Q factor values.
The other visualizers are Constellation diagram, Spatial visualizer and much more.
Main Features of the Optisystem are as following:

1) **Component Library**

The Component Library of the Optisystem includes hundreds of the components, which are both electrical as well as optical components. All the components are carefully validated to give the best results.

2) **Mixed Signal Representation**

Mixed Signal Representation is the important feature of the Optisystem. It handles the mixed signal formats for both the optical and the Electrical signals.

3) **User Defined Components**

In the Optisystem, there is the availability of the user-defined component also. In this, the user can create new components based on user-defined libraries. The user can also Co-Simulation with the other tools like Simulink or MATLAB.

4) **Quality and Performance**

Optisystem can calculate the parameters like Q-factor and BER (Bit Rate Error) in order to predict the overall system performance.

5) **Data Monitors**

The user can select any component and save the data and then can monitor it after the simulation stops. The user can attach any number of visualizers to monitor the results at the same port.

6) **Measured Components**

The Optisystem also allows its user to enter parameters that can be measured from the real device.

7) **Parameters Sweep**

The Simulation of the Optisytem model can be repeated with the iterative variation of the parameters. This is known as asweep. The user can combine multiple parameters sweep also.

8) **Multiple Layouts**

There is the option of creating the multiple designs in the same project. This makes the user to design and to modify the design in the more efficient way.

9) **Report Page**

The Report page is also provided in the Optisystem which allows its user to represent any set of parameters and the results also. The user can also represent the 2D or the 3D plots in the report page.

10) **Bill of materials**

There is one option available in the Optisystem regarding the cost of the components. It also provides its user the well-maintained table regarding the cost of every component.

3.2.1 Benefits of Optisystem

- There are automatic optimization and scanning of parameters.
- The optisystem software is low cost and is rapid.
- System performance of Optisystem is easy and quick.
- It has a huge library of Optical and Electrical Components.

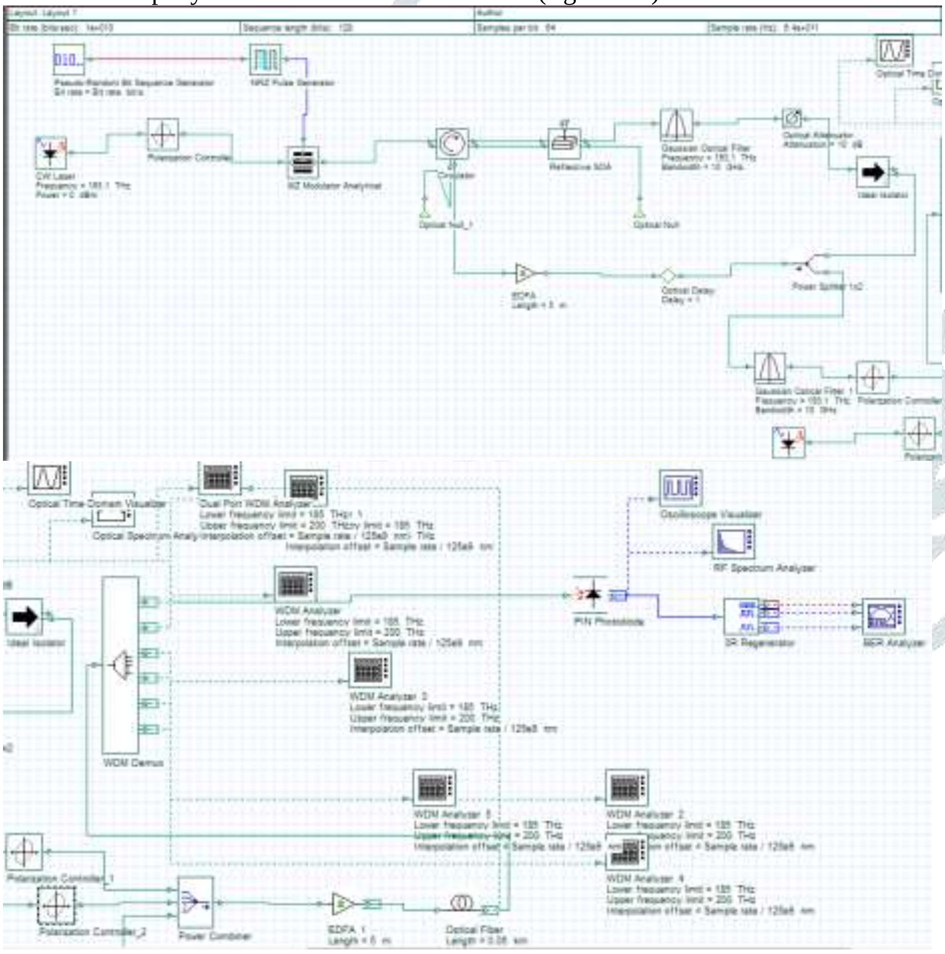
- The process is fast, and it takes less time to get the final results.
- The overall representation of the model is smooth.

3.2.2 Applications of Optisystem

1) Designs ofTDM (Time Division Multiplexing) and WDM (Wavelength Division) Multiplexing) can be done in Optisystem.
2) We can design FSO (Free Space Optics) based system in Optisystem.
3) ROF (Radio over Fibre) systems can also be designed in optisystem.
4) Various transmitter and receiver circuits can also be designed in Optisystem.
5) Design of Dispersion based map is also possible in Optisystem.

***3.3** OptiSystem Model*

The overall Optisystem Model is as shown below (figure 3.1)



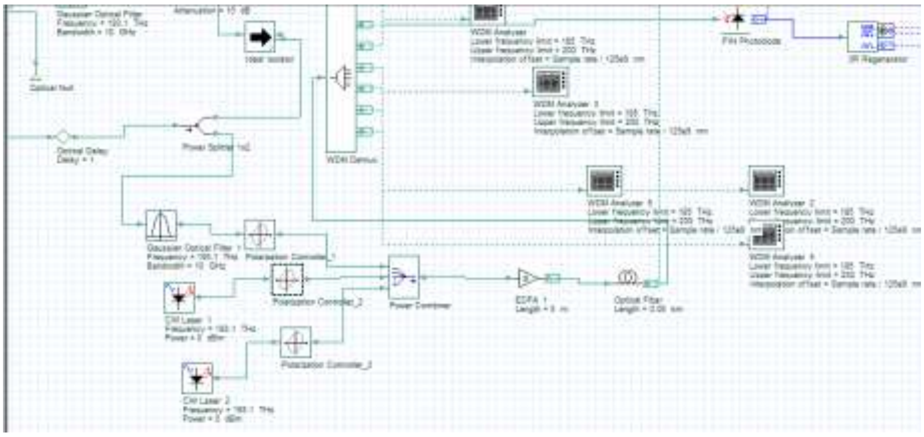


Figure 3. 1:*OptiSystem Model*

The overall model represents the fiber laser, which is based on the mode locking and is capable of producing Ultra-ShortPulses using saturable absorber. The system is composed ofa theoptical fiber amplifier, DC components, and an undoped fiber. The main component is the Saturable absorber which is used to generate the optical pulse and to achieve mode locking.The white light source which is used in the starting of the model is to provide the noise that will initialize the pulse generation.

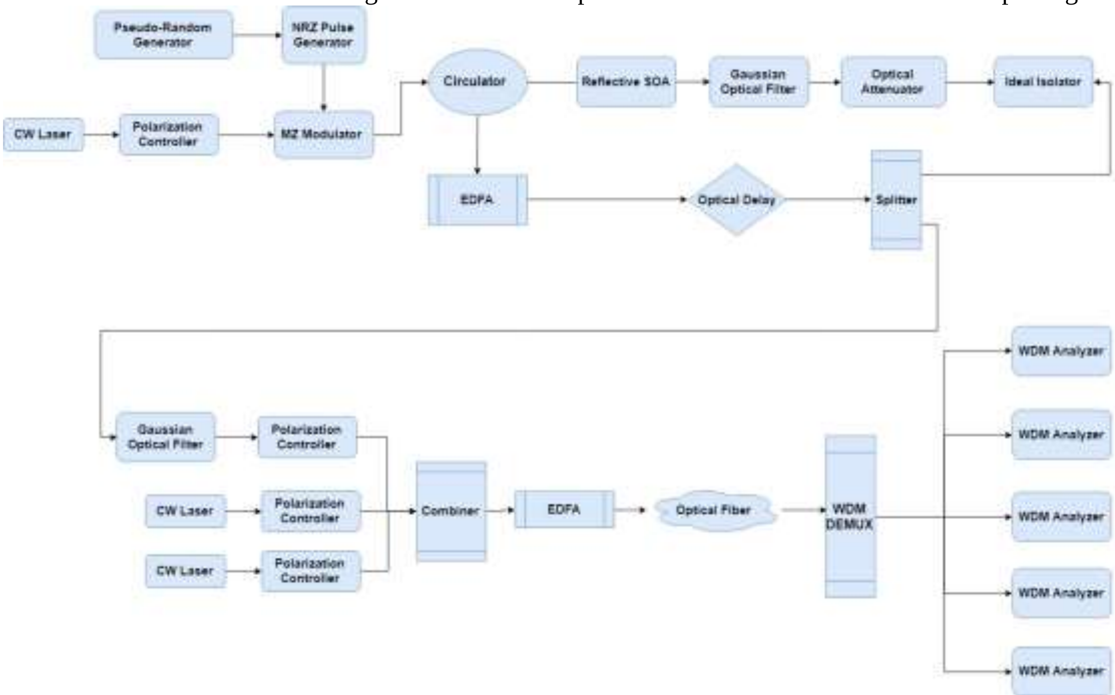


Figure 3. 2: *Block diagram of proposed model*

The various components that are used in the model are:

1) **NRZ Pulse Generator**

NRZ stands for Non-Return to Zero. It creates a sequence of NRZ (Non-Return to Zero) pulses.

2) **Mach Zehnder Modulator**

MZ Modulator stands for Mach-Zehnder Modulator. It is the kind of modulator and has twoarms which help in splitting the signal into two parts. One input to MZ Modulator is given bythe polarization Controller and other by the NRZ pulse generator. It is used to control the amplitude of the optical signal.

3) **EDFA**

EDFA stands for Erbium-Doped Fiber Amplifiers. When the signal is traveling through the fibers at considerable distances, it becomes essential to amplify the signal. For that purpose, the EDFA is used in the circuits; they will provide the amplification to the signal at long distances. The output from the circulator is directly connected to the EDFA, after this, the output of the EDFA is given the electrical delay.

4) Optical Fiber

Optical Fiber is considered as the medium of transmission of the information. The light signal can be sent very easily through it with fewer losses. The input to the Optical Fiber is given by the EDFA,and the length of optical fiber is taken as 0.005 kilometers which are connected to the EDFA of length 0.005 Kilometers.

5) PIN Photodiode

It is the kind of the photodetector which is used to convert optical signals into the electrical signals. In this case, the input to the Pin Photodiode is given by the one end of the X-coupler. The output from the Pin Photodiode can be analyzed in the RF Spectrum Analyzer and the Oscilloscope visualizer.

6) Optical Spectrum Visualizer

This is the visualizer which is used to visualize the output optical spectrum. It is connected to the PIN Photodiode.

7) RF Spectrum Analyser

It is the analyzer which is used to analyze the output RF Spectrum. It is connected to the PIN Photodiode.

CHAPTER 4

RESULTS AND DISCUSSIONS

The overall model represents the fiber laser, which is based on the mode locking and is capable of producing Ultra-ShortPulses using saturable absorber. The system is composed of theopticalfiber amplifier, DC components, and an undoped fiber. The main component is the Saturable absorber which is used to generate the optical pulse and to achieve mode locking. The white light source which is used in the starting of the model is to provide the noise that will initialize the pulse generation. Here are the plots of the final results obtained from the experimental model.

1) Oscilloscope Visualizer

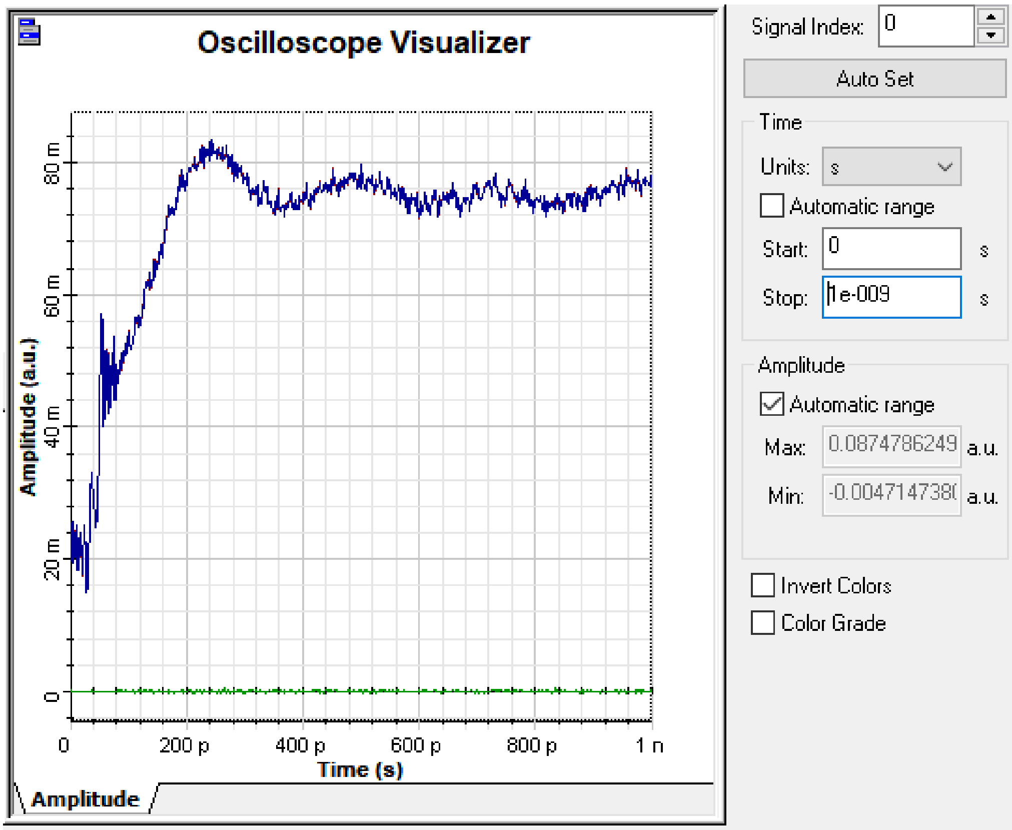


Figure 4. 1:*Amplitude vs. Time plot*

The above plot represents the pulse trace. We have the highest peak amplitude value of 82 m at 0.3 nanoseconds. After time 0.3 ns, the plot goes to some decreasing value and ends at wavelength 78 m.

2) Optical-Time Domain Visualizer

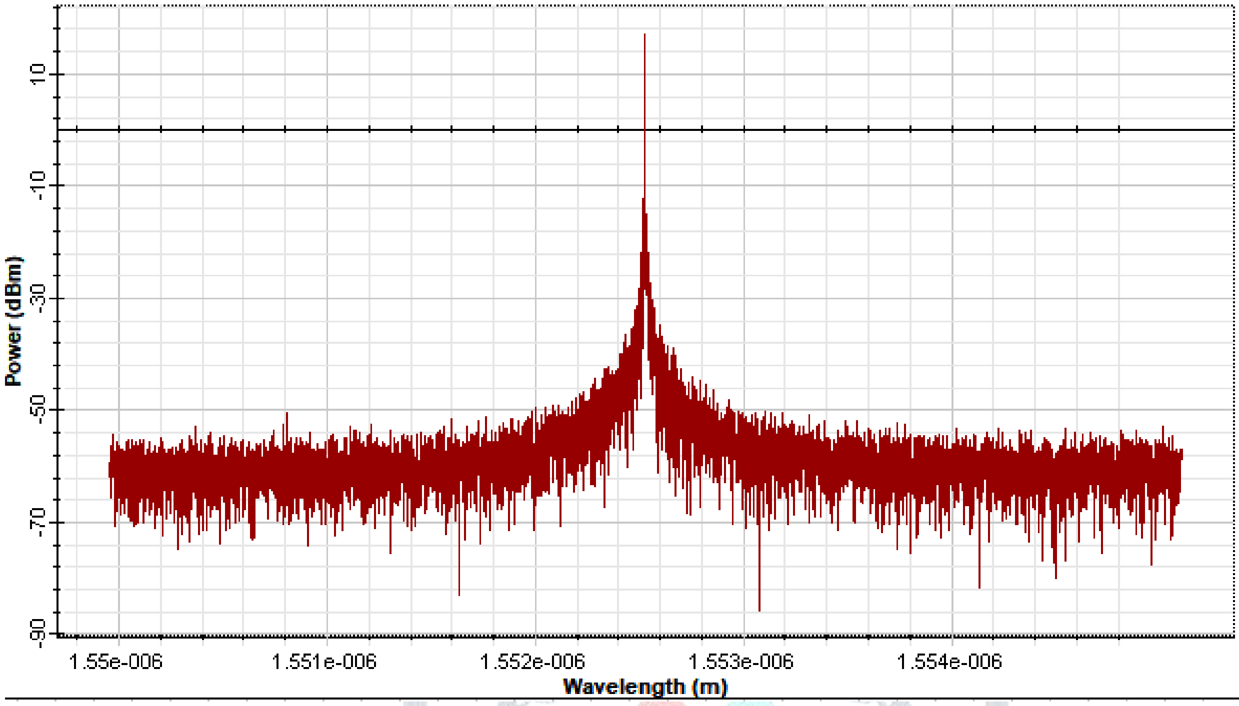


Figure 4. 2:*Wavelength vs. Power plot*

Table 5. 1:*Power in dBm vs. wavelength in micrometers*

WAVELENGTH (µm)	POWER(dBm)
Before 1.5525µm	Increasing
1.5525µm	Reaches peak value of 10dBm
After 1.5525µm	Decreasing

The above plot was plotted in the Optisystem Software. This is the plot representing the Ultra Pulse having the Power in dBm verses. wavelength in micrometers. This shows the highest peak point at Power 10 dBm and a wavelength of 1.5525micrometers. Before this point, the waveform is in increasing direction, and after this point, it got decrease to the power of -80 dBm.

3) RF Spectrum Analyzer

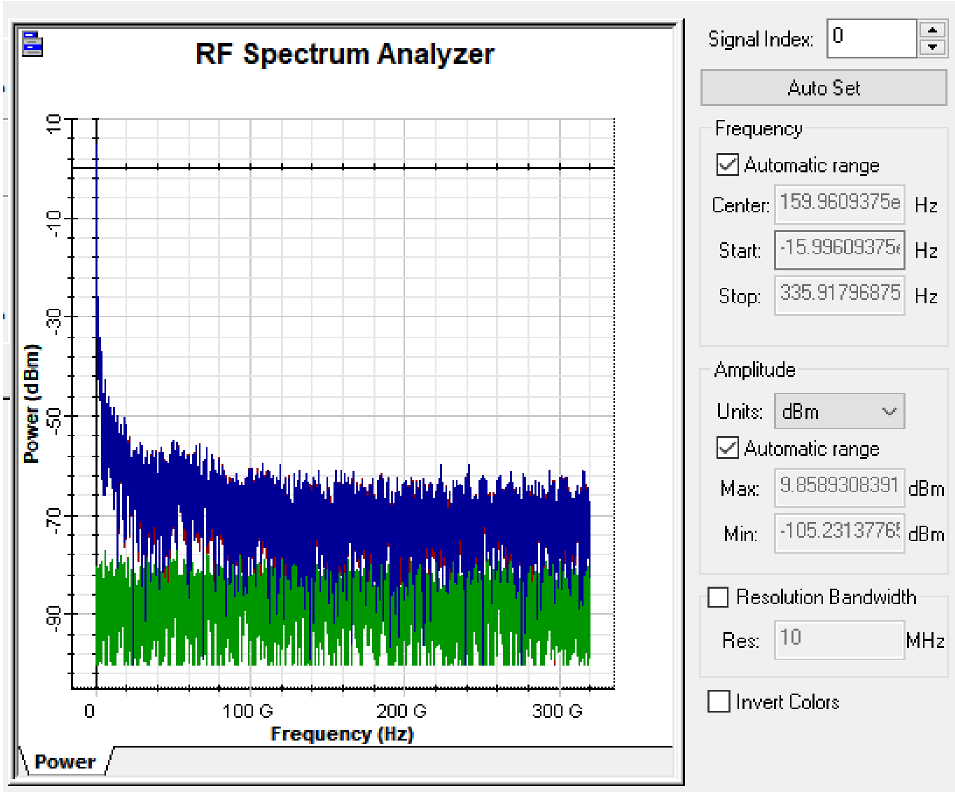


Figure 4. 3: *Frequency vs. Power plot*

The above plot shows the RF Spectrum. It represents the Power values in dBm with respect to the Frequency in GHz. The plot has the maximum value at 10 dBm for the frequency value as zero. The blue portion of the plot represents the power, and the green portion is the noise in the image.

We have then compared the plot of SNR versus lasers. The plot is generated with the help of MATLAB.

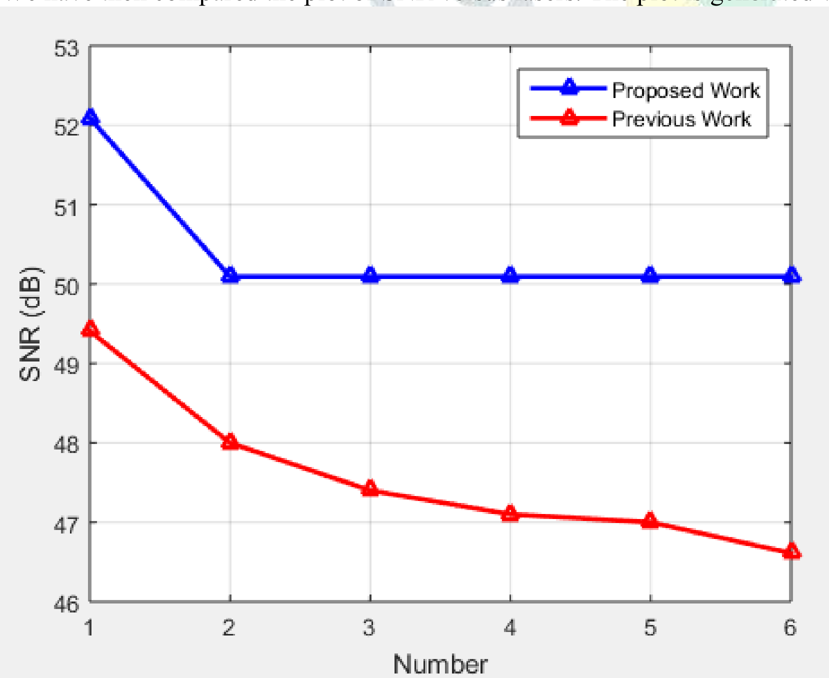


Figure 4. 4: *SNR comparison plot*

In the above plot, it can be analyzed that for the number value as 1; we are getting the SNR value as 52 dBm, and for the same number, previous resultant values were 49.5 dBm [31]. For all the values our SNR curve is higher as compared to the previous results in the same field [31].

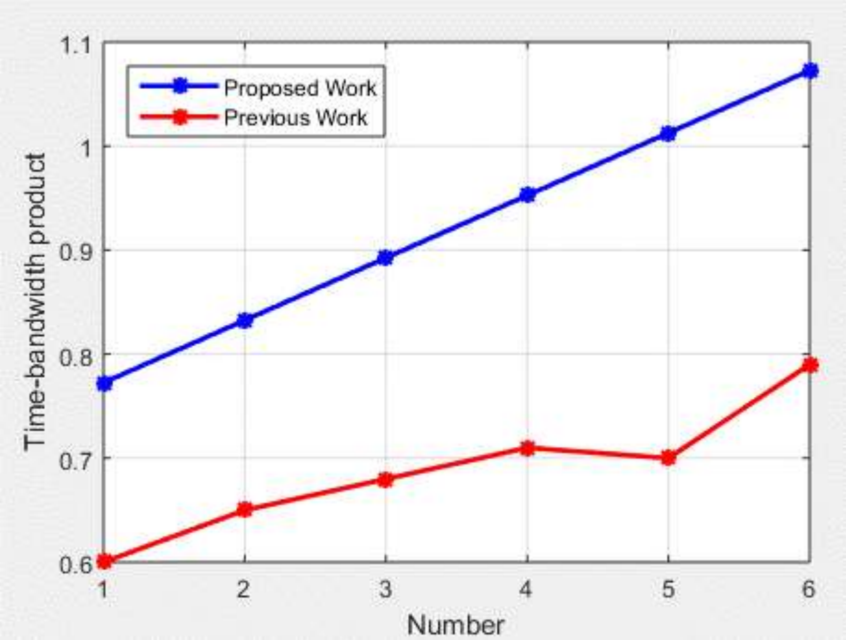


Figure 4. 5:*Time-Bandwidth Product plot*

The above-shown plot is the Time bandwidth plot, which is plotted with respect to the different lasers. In our results, we are getting the Time bandwidth as 0.77 for the laser, and in the previous work [31], the value is 0.6 for the first laser. For all the numbers, out the plot is showing the increasing values as compared to the previous research [31] in the same field.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

With the advancement in technology, major changes in the way of communication havebeen identified. Technology decreased the time taken by the information to flow from one place to another to a great extent. Optical fiber communication is one of that technology that helps to transmit the information in few seconds while ensuring high security and reliability. LED and the laser is the major source of information transmission in the optical fiber communication. This research reviewed various sources used in the optical fiber communication. Further, the researchanalyzed different type of lasers along with their application areas and benefits**.** With the results of previous studies which have been done to identify the effective techniques utilized in the optical fiber communication, this research proceeded the further research on the ultrashort pulse generation and detection using fiber lasers with themode-locking method**.** The highest SNR achieved in current work is 52 dBm and time-bandwidth product as 0.77 for laser 1. For another laser as well, the achieved results are higher than the previous results [31].

5.2 Future Scope

The development of optical communications after the invention of the optical fiber has fulfilled the demand in the past. But to keep up with the exponential growth of data traffic in the near and not-so-near future, more and more hardware components and transmission technologies have to be developed. The proposed model of generating Ultrashort pulsed using fiber laser attempted to overcome the restrictions of ultra-short fiber laser system to deliver high power and repetition rates in future with acombination of high pulse energies. This model could meet the demand of applications which require high processing speed and high capacity.

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