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High Performance WDM Using Semiconductor Tunable Laser

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Abstract

Advances in optical networking have lead to the explosive growth of communication network. Telecom applications began to drive significant investments into this field to support the perceived need for dynamic network and wavelength reconfigurability in wavelength division multiplexing system (WDM). This system is developed using reconfigurable optical add-drop multiplexes (9R-OADMs) and optical cross connects (OXCs) using tunable lasers. Enterprise gets advantage of reduction in operational cost in such flexible fiber optic network. Tunable laser can reduce operational cost and also support full band tunability over 40.6nm bandwidth centered with low power consumption (less than 2.5w). Ultimately, the performance of optical N/W with existing fiber is improved.

Key Words

WDM (Wavelength division multiplexing), **TLA** (Tunable Laser), **DFB** (distributed feedback laser), **ROADMs** (Reconfigurable optical add drop multiplexers), **OXCs** (Optical cross connects).

I.INTRODUCTION

With the rapid development of the global communications market, especially with the rise of series of new services such as the internet , high quality video conferencing systems, and multimedia systems, etc, the demand for large capacity and high performance network transmission increases explosively. However traditional Synchronous Digital Hierarchy (SDH) and Plesiochronous Digital Hierarchy (PDH) fiber optic transmission systems employ the one fiber one wave mode so that both the transmission capacity and capacity expansion mode cannot meet the requirements due to restrictions of the intrinsic characteristics of devices. Mean while, the huge broadband resources of optical fibers have not been completely utilized. So a new transmission technology WDM (wavelength division multiplexing) technology emerges as the most effective and economic way for capacity expansion of optical fibers, with its unique technological superity, the WDM It is developed to replace the Plesiochronous Digital Hierarchy (PDH) system for transporting larger amounts of telephone technology becomes an approach to rapidly, simply, economically and effectively expands the capacity of the fiber. optical transmission. WDM is a fiber optic communication technology, which enables multiple optical carrier waves bearing electrical information (analogue or digital) to be transmitted over a single optical fiber, so as to realize system capacity expansion. It combines (multiplex) several optical signals with different wavelength together for transmission and then after transmission separates (demultiplexers) the combined optical signals and sends them to different communication terminals. i.e. provides multiple virtual fiber optic channels over a single physical optical fiber, hence saving a great number of optical fiber resources.The Plesiochronous Digital Hierarchy (PDH) is a technology used in telecommunications_networks to transport large quantities of data over digital transport equipment such as fiber optic. The term plesiochronous is derived from Greek plesio, meaning near, and chronos, time, and refers to the fact that PDH networks run in a state where different parts of the network are nearly, but not quite perfectly, synchronised. PDH allows transmission of data streams that are nominally running at the same rate, but allowing some variation on the speed around a nominal rate.

The basic data transfer rate is a data stream of 2048 kilobits/s (kilobits/second). For speech transmission, this is broken down into thirty 64 kbit/s (kilobits/second) channels plus two 64 kbit/s channels used for signaling and synchronization. Alternatively, the whole 2 Mbit/s (megabits/second) may be used for non speech purposes, for example, data transmission.

The exact data rate of the 2 Mbit/s data stream is controlled by a clock in the equipment generating the data. Recently, telecommunications companies have been replacing their PDH equipment with SDH equipment capable of much higher transmission rates. Synchronous optical networking (SONET) and Synchronous Digital Hierarchy (SDH), are two closely related multiplexing protocols for transferring multiple digital bit streams using lasers or light-emitting diodes (LEDs) over the same optical fiber The method was calls and data traffic over the same fiber wire without synchronization problems.

The basic unit of framing in SDH is a STM-1 (Synchronous Transport Module level - 1), which operates at 155.52 Mbit/s. SONET refers to this basic unit as an STS-3c (Synchronous Transport Signal-3, concatenated), but its high-level functionality, frame size, and bit-rate are the same as STM-1.

Comparing to PDH and SDH system data handling capacity of the WDM system is much greater. This fulfills the increasing demands in telecommunication areas. Fiber bandwidth is not fully utilized in the system like PDH and SDH. WDM supports full utilization of bandwidth. Fiber optic cables which are installed for PDH & SDH systems need not to be replaced as we use WDM system. WDM offers an attractive solution to increasing bandwidth without disturbing the existing embedded fiber, which populates most buildings and campuses and continue to be the cable of choice for the near future.

WDM system is necessary because WDM system avoids new equipment system costs. It saves ongoing maintenance costs on repeater sites. Installing new fiber is a costly operation. Attractively, using WDM, we can benefit much more data rate using a single fiber. WDM systems being deployed today can increase a single fiber's capacity to a throughput of 40 GB/s.

II.HELPFUL HINTS

A. Tables and ,figures

Table 1. Bandwidth efficiency

SONET/SDH	Bit Rate Mbps	Used Bandwidth
STS-1	51	20%
STS-3/STM-1	155	64%
STS-48/STM-16	2488	40%

We can conclude that the bandwidth utilization in SONET/SDH system is very less; in case of WDM system 100% utilization of bandwidth can be achieved. WDM assigns different optical signals to different specific wavelength. The specific wavelength are multiplexed and injected in one fiber.

WDM is a technology that allow us to transmit multiple sources operating at slightly different wavelength containing several independent information streams over the same fiber. Conceptually WDM scheme is same as Frequency Division Multiplexing (FDM) used in microwave radio and satellite system .The WDM standards are developed by International Telecommunication Union (ITU) The concept was first published in 1970, and by 1978 WDM systems were being realized in the laboratory.

Following is the block diagram for WDM System.

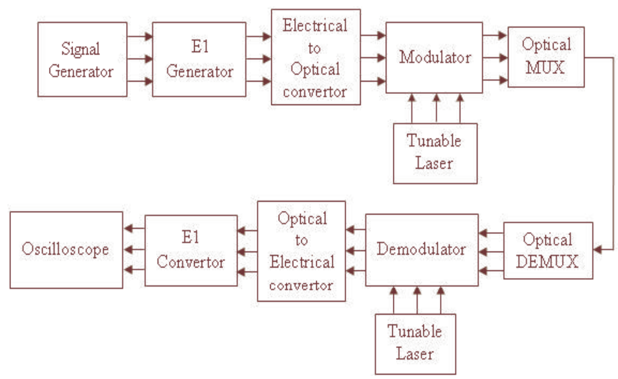

Fig. 1 WDM system

The first WDM systems only combined two signals. Modern systems can handle up to 160 signals and can thus expand a basic 10 Gbit/s fiber system to a theoretical total capacity of over 1.6 Tbit/s over a single fiber pair.

WDM offers an attractive solution to increasing LAN bandwidth without disturbing the existing embedded fiber, which populates most buildings and campuses, and continue to be the cable of choice for the near future. By multiplexing several relatively coarsely spaced wavelengths over a single, installed multimode network, the aggregate bandwidth can be increased by the multiplexing factor i.e. two to four wavelengths per fiber. [1] [4] The original WDM systems were dual-channel 1310/1550 nm systems. WDM, DWDM and CWDM are based on the same concept of using multiple wavelengths of light on a single fiber, but differ in the spacing of the wavelengths, number of channels, and the ability to amplify the multiplexed signals in the optical space. According to ITU-T normal WDM consists of 2 channels. The CWDM is defined as the technology multiplexing from 4 to 8 channels. The DWDM consists of up to 160 channels.

CWDM

Originally, the term "coarse wavelength division multiplexing" was fairly generic, and meant a number of different things. In general, these things shared the fact that the choice of channel spacings and frequency stability was such that erbium doped fiber amplifiers (EDFAs) could not be utilized. Prior to the relatively recent ITU standardization of the term, one common meaning for coarse WDM meant two (or possibly more) signals multiplexed onto a single fiber, where one signal was in the 1550 nm band, and the other in the 1310 nm band.

In 2002 the ITU standardized a channel spacing grid for use with CWDM (ITU-T G.694.2), using the wavelengths from 1270 nm through 1610 nm with a channel spacing of 20 nm. (G.694.2 was revised in 2003 to shift the actual channel centers by 1, so that strictly speaking the center wavelengths are 1271 to 1611 nm.) Many CWDM wavelengths below 1470 nm are considered "unusable" on older G.652 specification fibers, due to the increased attenuation in the 1270-1470 nm bands. Newer fibers which conform to the G.652.C and G.652.D standards, such as Corning SMF-28e and Samsung Widepass nearly eliminate the "water peak" attenuation peak and allow for full operation of all 20 ITU CWDM channels in metropolitan networks. he main characteristic of the recent ITU CWDM standard is that the signals are not spaced appropriately for amplification by EDFAs. This therefore limits the total CWDM optical span to somewhere near 60 km for a 2.5 Gbit/s signal, which is suitable for use in metropolitan applications. The relaxed optical frequency stabilization requirements allow the associated costs of CWDM to approach those of non-WDM optical components.

CWDM is also being used in cable television networks, where different wavelengths are used for the downstream and upstream signals. In these systems, the wavelengths used are often widely separated, for example the downstream signal might be at 1310 nm while the upstream signal is at 1550 nm.

CWDM STANDARDS

According to ITU-T CWDM consists of channels which are spaced 20nm wide. The channel width is 13nm. CWDM uses 2nd and 3rd window of operation. Thus the channels start from 1270nm and continue up to 1610nm.There are 18 distinct centre wavelengths in this bandwidth. This complete bandwidth of operation is further divided into 3 distinct bands-

O-band (1290nm,1310nm,1330nm and 1350nm).

E-band(1390nm,1410nm,1430nm and 1450nm).

S+C+L-band(8 wavelengths from 1470nm to 1610nm)

Normally the CWDM used nowadays uses up to 8 channels. In this project 4 channel CDWM is implemented.

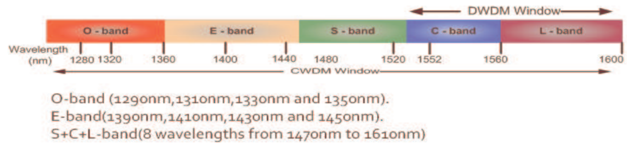

Figure 2: Various Bands Of Operation In CWDM

Table 2 COMPARISON BETWEEN CWDM AND DWDM

	CWDM	DWDM
Channel width	13nm	1nm
Channel spacing	20nm	0.8nm
Number of channels	4 to 18	Up to 160
Optical amplifiers	Not used	Used
Range	Up to 120km	Up to 500 km
Power /wave length	1.6w	5w
Wavelength drift	-+6.5nm	-+0.16nm

Apart from these CWDM offers numerous advantages over DWDM, which makes it the preferred choice for implementation.

Cost: Less expensive hardware in CWDM. DWDM uses cooled DFB lasers which are more costly. Price of DWDM transceivers is 4-5 times that of CWDM ones. CWDM filters are 50 % less expensive than DWDM ones.

Power requirements: DWDM lasers are temperature controlled. Cooler monitor and control circuitry consume 5w of power per wavelength while CWDM requires only about 1.6w.

Physical size: CWDM lasers are smaller than DWDM lasers. CWDM lasers are 2cm long 0.5cm in diameter. DWDM lasers are 4cm long, 2cm thick and 2cm wide. Size of the transceiver used for DWDM is about 5 times the size of CWDM.

Hence, for medium ranges i.e. up to 120km, CWDM offers a cost effective,

CWDM SOURCES-

Transmitters use either laser diodes or LEDs as sources; where LEDs are normally reserved for short-haul applications with a reach of just a few hundred meters, lasers make up the majority of sources used in medium and long reach systems. Even among the different available laser types, there are significant differences in performance and care must be taken in their selection, depending on the particular application. In general, FP lasers, vertical surface emitting lasers (VCSELs) and DFB lasers are primarily used in transmitters, with higher performance fiber Bragg grating lasers (FGLs) and electro-absorption-based externally modulated lasers (EA-EMLs) are used less frequently. Table below summarizes the laser types. The requirements for using lasers in CWDM applications are based on the following criteria:

Performance requirements for lasers in metro CWDM and access are less demanding than for long haul applications due to shorter transmission distance and less transmission capacity (lower bit-rates and wide channel spacing).

Main requirement is low cost with low power consumption, small footprint, interoperability, simple design being secondary considerations.

Uncooled lasers can further reduce costs and equipment space.

Consequences and challenges for low-cost lasers: low output power, high transient chirp due to direct modulation, no temperature stabilization, integration in transceiver packages necessary, simple packaging with often limited radio frequency (RF) performance, optical coupling with no isolator, and no active control of laser performance.

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Overview of Light Sources

Type	Relative Cost	Output Power (dBm)	Wavelength Range (nm)	Modulation	Application
LED	very low	<0	850	155 Mb/s	LAN
Fabry Perot	low	3	850, 1310	2.5 Gb/s	access
VCSEL	low	0	850, 1310, 1550	up to 10 Gb/s	access
DFB	medium	6	1270–1610	direct: 2.5–10 Gb/s	CWDM, metro
FGL	medium	3	1550	2.5 Gb/s	metro
EA-EML	high	0	1310, 1550–1590	2.5–40 Gb/s	metro regional

Table 3: Over View of Light Sources

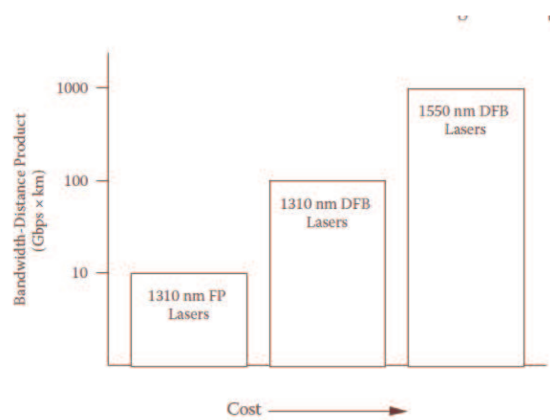

Figure 3:Comparison between FP lasers and DFB lasers

Fabry Perot Laser

FP lasers are based on GaAs material and are some of the simplest lasers for optical communication systems. Within the gain band, several longitudinal modes experience lasing condition simultaneously so that the resulting spectral width is typically 2 to 3 nm. Commonly, 10 mA threshold current for lasing are expected with 5 to 10 mW maximum output power. For increasing currents, the number of modes also increases, resulting in a broadened spectrum. Due to a simple design, without an optical isolator at the output, the FP lasers are less sensitive to reflections. Laser without temperature stabilization experiences a wavelength drift with temperature. The center wavelength shifts by 0.4 nm toward longer wavelengths when the operating temperature increases by 1° C. The application of FPs to CWDM is rather limited due to the broad linewidth and hence high sensitivity to chromatic dispersion, coupled with a significant wavelength temperature dependence. Practically, the FP sources find their way into single wavelength links in short reach applications; exact span is dependent on the bandwidth of the link. The low dispersion tolerance confines the operation close to the dispersion minimum of the optical fibers, for example, 1310 nm for standard singlemode fiber (SSMF). Therefore, these lasers might be useful for the client interface of a CWDM system or any other forms of low-cost data interconnection. Future devices with a lower driving voltage and lasing threshold might allow simplified control electronics, and designing a reduced spectral width < 2 nm could also overcome the severe dispersion limitation of current devices.

Vertical Cavity Surface Emitting Laser

The vertical cavity surface emitting laser (VCSEL) is a lasing device where the light is emitted perpendicular to the layer structure [2]. One-step epitaxy manufacturing of the VCSELs allows a cost advantage for these devices. In contrast to the FP lasers, the short cavity only supports a single lasing mode. The lasers have a low threshold< 1 mA and are available for direct modulation at bit-rates from 55 Mb/s to 2.5 Gb/s. Experiments at 10 Gb/s have been performed where the signals have been transmitted over 8.8 km SSMF at 1550 nm using an InPbased VCSEL. Without temperature control, the VCSEL has been shown to operate up to 90°C, making it suitable as a low cost source with a very small footprint. Despite the recent progress, the use of VCSELs in full-spectrum CWDM systems remains challenging since the lasers are available only around 850, 1310, and 1550 nm. The devices are uncolored with a wide wavelength specification. This coupled with a wavelength drift of 0.1 nm/°C make the spectral

overlap with CWDM multiplexer passbands an issue. Another challenge is the relatively low output power of a VCSEL, typically less than 0 dBm. Apart from current short-reach transceivers for LAN/SAN/datacom applications at 850 nm, VCSELs offer a replacement option for existing FP lasers with comparable cost but improved performance. They can be used wherever the low

output power is acceptable. Future developments might address the output power issue or tunability to cover a wider spectral bandwidth, thus adapting it closer to the requirements needed for CWDM sources.

Distributed Feedback Laser

DFB lasers are the workhorse in WDM systems, both as cooled and uncooled devices. They are used for all applications ranging from metro to long-haul. This laser type is based on a Multiple Quantum Well (MQW) structure as the gain medium with a superimposed grating structure as a wavelength selective element to accurately filter out a single longitudinal mode at which the device is emitting its signal. Due to the more complicated structure, the DFB is more expensive than FP or VCSEL lasers. In the case of high performance, the laser is externally modulated with a separate modulator, a technique mostly used for ULH applications. In metro or CWDM systems where reach is shorter, the technique of direct modulation is employed where the data signal modulates the optical output power via the driving current. The clear advantage is in the simplicity since no additional modulator is needed at the laser output. This aspect is particularly important when no amplifier is available and the link budget is solely determined by the laser output power and the receiver sensitivity. DFB lasers are commonly used for wavelengths within the C-band (1530 to 1565 nm) and also around 1310 nm for legacy systems. Their application is often extended into the L-band and, in some cases, any other wavelengths from 1310 to 1610 nm.

Tunable laser

A tunable laser is a laser whose wavelength of operation can be altered in a controlled manner. While all laser gain media allow small shifts in output wavelength, only a few types of lasers allow continuous tuning over a significant wavelength range.

There are many types and categories of tunable lasers. They exist in the gas, liquid, and solid state. Among the types of tunable lasers are excimer lasers, CO_2 lasers, dye lasers (liquid and solid state), transition metal solid-state lasers, semiconductor diode lasers, and free electron lasers. Tunable lasers find applications in spectroscopy, photochemistry and optical communications.

Types of tunability-

Single line tuning

Since no real laser is truly monochromatic, all lasers can emit light over some range of frequencies, known as the line width of the laser transition. In most lasers, this line width is quite narrow (for example, the 1064 nm wavelength transition of a Nd:YAG laser has a line width of approximately 120 GHz, corresponding to a 0.45 nm wavelength range).Tuning of the laser output across this range can be achieved by placing wavelength-selective optical elements (such as an etalon) into the laser's optical cavity, to provide selection of a particular longitudinal mode of the cavity.

Multi-line tuning

Most laser gain media have a number of transition wavelengths on which laser operation can be achieved. For example, as well as the principal 1064 nm output line, Nd:YAG has weaker transitions at wavelengths of 1052 nm, 1074 nm, 1112 nm, 1319 nm, and a number of other lines. Usually, these lines do not operate unless the gain of the strongest transition is suppressed, e.g., by use of wavelength-selective dielectric mirrors. If a dispersive element, such as a prism, is introduced into the optical cavity, tilting of the cavity's mirrors can cause tuning of the laser as it "hops" between different laser lines. Such schemes are common in argon-ion lasers, allowing tuning of the laser to a number of lines from the ultraviolet and blue through to green wavelengths.

Narrowband tuning

For some types of lasers the laser's cavity length can be modified, and thus they can be continuously tuned over a significant wavelength range. Distributed feedback (DFB) semiconductor lasers and vertical cavity surface emitting lasers (VCSELs) use periodic distributed Bragg reflector (DBR) structures to form the mirrors of the optical cavity. If the temperature of the laser is changed, thermal expansion of the DBR structure causes a shift in its peak reflective wavelength and thus the wavelength of the laser. The tuning range of such lasers is typically a few nanometres, up to a maximum of approximately 4 nm, as the laser temperature is changed over ~50 K. As a rule of thumb the wavelength is tuned by 0.08 nm/°C for DFB lasers operating in the 1550 nm wavelength regime. Such lasers are commonly used in optical communications applications such as DWDM-systems to allow adjustment of the signal wavelength.

Widely tunable lasers

Sample Grating Distributed Bragg Reflector lasers (SG-DBR) have a much larger tunable range, by the use of vernier tunable Bragg mirrors and a phase section, a single mode output range of >50 nm can be selected.

Basic Tuning Mechanism

The most common Fabry-perot Laser is composed of uniform cleaved semiconductor chip, which is structured to provide gain for guided optical mode, with cleaves functioning as mirrors. Index grating is formed near the optical waveguide to provide a continuous reflection which gives both the mirror functionality as well as mode selection filter.

B. Equations

$$\lambda m/2 = n'L \quad (1)$$

Where, m is Mode number
λ is Wavelength
n' is Effective index
L is effective cavity length

$$\Delta\lambda/\lambda = \Delta n'/n' + \Delta L/L - \Delta m/m \quad (2)$$

Where, n' Tuned by net cavity index change
L Tuned by physical length change

Equation (1) gives the relationship between the lasing wavelength λ, cavity mode n', and the effective cavity length L.It is obvious that that, if one changes out of m, n', or L, the wavelength also changes. The relative change in wavelength derived from (1) is given in (2). As indicated the relative wavelength change is directly proportional to the relative change in either the length ,index or mode number.

Widely tunable lasers

Sample Grating Distributed Bragg Reflector lasers (SG-DBR) have a much larger tunable range, by the use of vernier tunable Bragg mirrors and a phase section, a single mode output range of >50 nm can be selected. Other technologies to achieve wide tuning ranges for DWDM-systems are:

External Cavity Lasers using a MEMS structure for tuning the cavity length.

DFB Laser Arrays based on several thermal tuned DFB lasers: Coarse tuning is achieved by selecting the correct laser bar. Fine tuning is then done thermally

Tunable VCSEL: One of the two mirror stacks is movable. To achieve sufficient output power out of a VCSEL structure, lasers in the 1550 nm domain are usually either optically pumped or have an additional optical amplifier built into the device.

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Applications of Tunable Lasers

Wavelength-tunable laser sources have many applications, some examples of which are:

In spectroscopy, a wavelength-tunable laser with narrow optical bandwidth can be used for recording transmission or absorption spectra with very high frequency resolution. In a

LIDAR system, a laser may be tuned to a wavelength which is specific to a certain substance to be monitored.

Various methods of laser cooling require a laser wavelength to be adjusted very precisely at or near some atomic resonance.

Tuning to atomic resonances is also used in laser isotope separation. The laser is then tuned to a particular isotope in order to ionize these atoms and subsequently deflect them with an electric field.

A tunable laser can be used for device characterization, e.g. of photonic integrated circuits.

In optical fiber communications with wavelength division multiplexing, a tunable laser can serve as a spare in the case that one of the fixed-wavelength lasers for the particular channels fails. Even though the cost for a tunable laser is higher, its use can be economical as a single spare laser can work on any transmission channel where it is needed.

In optical frequency metrology, it is often necessary to stabilize the wavelength of a laser to a certain reference standard (e.g. an absorption cell or an optical reference cavity). This can be accomplished e.g. with an electronic feedback system, which automatically adjusts the laser wavelength.

Some interferometers and fiber-optic sensors profit from a wavelength-tunable laser source, e.g. if this makes it possible to remove an ambiguity or to avoid mechanical scanning of an optical path length.

Advantages –

Current WDM networks are static since unique laser required for each wavelength

Provisioning is a local, manual process.

Expensive, takes weeks.

Tunable devices enable dynamic WDM networks

Flexible, remote service provisioning under software control.

Cost savings to carriers by reducing inventory, provisioning and the wavelength contention costs.

New revenue generating services to carriers for rapidly provisioned services.

Disadvantages-

Not suitable for small, static networks.

Manufacturing and installing cost is too high.

Purpose of Tunable Laser is achieved by using multiple lasers with very less spacing between their wavelengths.

DETECTORS FOR CWDM

The basic function of the optical receiver is to detect light and convert it to usable electrical signals. P-intrinsic-n photodiodes (PINs) and avalanche photodiodes (APDs) are the two most commonly used detectors in optical communication systems. Photodetectors can be considered current sources when modeling the behavior of the devices, with PIN photodetectors having a linear relationship between the amount of light input and the output current. This parameter is defined as the responsivity. APDs on the other hand are slightly different in that they have a nonlinear relationship between the input light and the current output. The implication is that APD receivers have higher sensitivity than PIN receivers in high bit-rate telecommunication links.

PIN DIODES

A PIN diode is a semiconductor device normally grown with a two-step MOVPE/MBE epitaxy process where for operation an electrical field is applied to the p- and n-doped diode structure with reverse bias to act like a capacitor The incident light gets absorbed and generates carriers proportional to the intensity. The two main parameters characterizing the performance of a PIN diode are responsivity and capacitance. The responsivity describes the conversion efficiency of the diode, that is, the amount photocurrent produced as a function incident optical power. This value can be in the order of 0.5 to 0.9 A/W, Amperes per Watt. GaAs/InP photodetectors that are most commonly used in CWDM system have a broad spectral response from 900 to 1650 nm. The ability of optical receivers to have similar performance over a wide range of input wavelengths allows system designers to use any receiver with any transmitter (with wavelength in the CWDM band). Capacitance influences the bit rate in which the PIN is capable of operating. The larger the active area, the greater the capacitance; with larger capacitance comes a lower operating bit rate. PIN diodes have been demonstrated at bit-rates up to 100 Gb/s, but are also available at other lower speeds.

APD DIODES

APD diodes utilize the avalanche effect inside a high electrical field where the incident light generates free carriers, which generate more carriers within the electrical field, thus resulting in a higher sensitivity than comparable PIN diodes. The APDs are an ideal choice for nonamplified CWDM due to high sensitivity and therefore the increased link budget. The maximum bit-rate of commercially available APDs is 10 Gb/s and, although lower than for PIN diodes, sufficient for all CWDM applications. Some practical issues are the low maximum input optical power of around 0 dBm and the relatively high reverse bias DC voltage of approximately 20 to 100 V needed to operate the APD.

Wavelength Division Multiplexing is one of the best method of multiplexing as it uses optical power very efficiently. In this technique a number of wavelengths are combined together and transmitted on single fiber.

In WDM system each laser must emit light at different wavelengths, with all laser wavelengths light are multiplexed together onto a single fiber. After being transmitted through a high bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing total optical power to each output port and then requiring that each receiver selectivity recover only one wavelength.

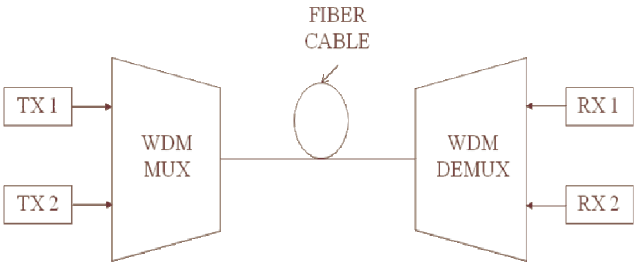

Figure 4: WDM System

A CWDM system multiplexes four channels together. The channels will be centered around wavelengths in the third window. The proposed wavelengths are 1510 nm, 1530 nm, 1550 nm and 1570 nm. These wavelengths are separated by a distance of 20nm. Fabry-Perot lasers are being used as optical sources. Instead of using an optical add-drop multiplexer a four laser diode combiner is being used. A standard p-i-n photo diode is being used as an optical detector on the receiver side. A trans-impedance amplifier is being used to convert the diode current into appropriate voltages. Four different types of data will be sent on the four channels simultaneously. It will be demonstrated that this technology increases the capacity of the fiber cable significantly. Additionally other parameters such as cost, power dissipation and speed of operation will be monitored.

4.1 RECEIVER MODULE DESIGN

The receiver module consists of three basic parts –
Photo detector diode used to convert the light signals into current pulses.
Trans-impedance amplifier used to convert the current into voltage.
Another amplifier to boost the signal level to the required format.

Figure 5: Block Diagram of Receiver Module

4.2 PHOTO DETECTOR MODULE

A PIN photodiode is used to receive the light. The material used is InGaAs. It has a high responsivity and has a minimum dark current. Its o/p capacitance is 0.7pF. It can support data rates up to 1.5Gbps. It has low dark current. Its rise time is <1ns. Its spectral range is from 1250nm to 1600nm. Photodiodes are semiconductor devices responsive to high energy particles and photons. Photodiodes operate by absorption of photons or charged particles and generate a flow of current in an external circuit, proportional to the incident power.

For applications within the wavelength range of 1.3µm - 1.55µm, photodiodes made on InGaAs/InP material are widely used due to the superior speed, responsivity and low noise characteristics.

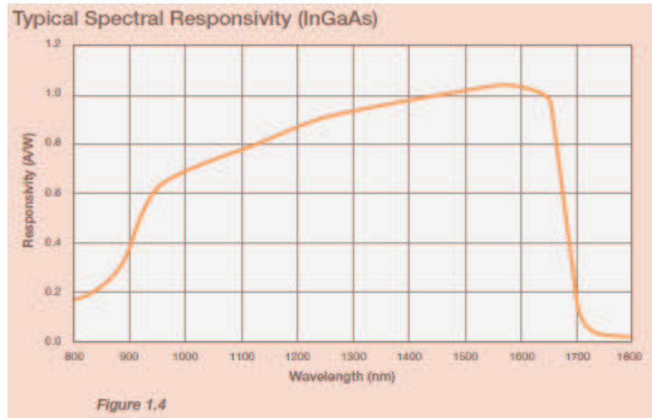

Figure 6: spectral response of InGaAs photodiode

4.3 PHOTO DETECTOR PARAMETERS

While using a photo-detector in a receiver circuit some of its electrical parameters should be considered during the designing process. Figure below shows an equivalent model of photo-detector.

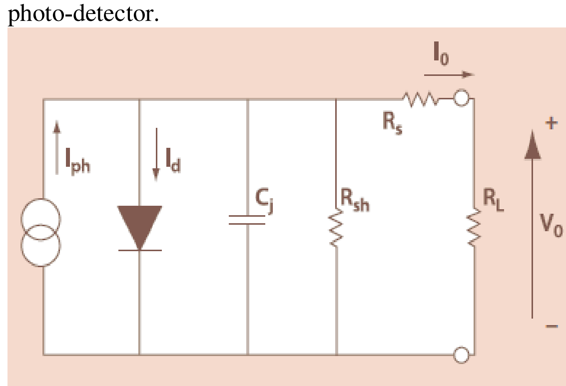

Figure7: equivalent model of photo-detector

A photo detector can be represented as a current source in parallel with an ideal diode. In addition, a junction capacitance Cj and a shunt resistance Rsh are in parallel with the other components. Series resistance Rs is connected in series with all components.
Important parameters are-
Shunt and series R.
Junction C.

Rise time/freq response.
Responsivity.
Shunt Resistance (Rsh)
Shunt resistance is the slope of the current-voltage curve of the photodiode at the origin, i.e. V=0. Although an ideal photodiode should have a shunt resistance of infinite, actual values range from 10s to 1000s of Mega ohms. Shunt resistance is used to determine the noise current. For best photodiode performance the highest shunt resistance is desired.
Series Resistance(Rs)
Series resistance of a photodiode arises from the resistance of the contacts and the resistance of the un-depleted semiconductors.
Its given by-

$$R_s = \frac{(W_s - W_d)\rho}{A} + R_c$$

Used to determine rise time. Junction Capacitance(Cj)
The boundaries of the depletion region act as the plates of a parallel plate capacitor. The capacitance is directly proportional to the diffused area and inversely proportional to the width of the depletion region. It is dependent on the reverse bias as follows:

$$C_J = \frac{\epsilon \ \epsilon_o A}{\sqrt{2\epsilon \ \epsilon_o \mu \rho \ (V_A + V_{bi})}}$$

Used to determine the speed of the response of the photodiode.
RiseTime/Freq Response
The rise time and fall time of a photodiode is defined as the time for the signal to rise or fall from 10% to 90% or 90% to 10% of the final value respectively.

Optical Sources
The most commonly-used optical transmitters are semiconductor devices such as light-emitting diodes (LEDs) and laser diodes. The difference between LEDs and laser diodes is that LEDs produce incoherent light, while laser diodes produce coherent light. For use in optical communications, semiconductor optical transmitters must be designed to be compact, efficient, and reliable, while operating in an optimal wavelength range, and directly modulated at high frequencies.

Following are the optical sources which are commonly used in the WDM systems.
Light Emitting Diodes (LEDs)
For optical communication systems requiring bit rates less than approximately 100-200 Mbps together with multimode fiber- coupled optical power in the tens of microwatts, semiconductor light-emitting diode (LEDS) are usually the best light source choice. These LEDs require less complex drive circuitry than laser diodes since no

This parameter can be also expressed as frequency response, which is the frequency at which the photodiode output decreased by 3dB. It is roughly approximated by:

$$t_r = \frac{0.35}{f_{3dB}}$$

Responsivity
The responsivity of a photodiode is a measure of the sensitivity to light, and it is defined as the ratio of the photocurrent Ip to the incident light power P at a given wavelength:

$$R_\lambda = \frac{I_P}{P}$$

In another words, it is a measure of the effectiveness of the conversion of the light power into electrical current.
It varies with the wavelength of the incident light as well as applied reverse bias and temperature.

Why WDM is becoming more and more popular is because of capacity- upgrade of existing fiber networks (without adding fibers), transparency- each optical channel can carry any transmission format (different asynchronous bit rates, analog or digital), scalability buy and install equipment for additional demand as needed, wavelength routing and switching- wavelength is used as another dimension to time and space these reasons.
thermal or optical stabilization circuits are needed and they can be fabricated less expensively with higher yields.
Laser Diode
For optical fiber communication systems requiring bandwidths greater than approximately 200 MHz , the semiconductor injection laser diode is preffered over the LED. Laser diodes typically have response times less than 1 ns, have optical bandwidths of 2 nm or less than , and , in general , are capable of coupling several tens of mill watts of useful luminescent power into optical fibers with small cores and small mode-field diameters.
Tunable Laser
A tunable laser is a laser whose wavelength of operation can be altered in a controlled manner. While all laser gain media allow small shifts in output wavelength, only a few types of lasers allow continuous tuning over a significant wavelength range. There are many types and categories of tunable lasers. They exist in the gas, liquid, and solid state, Tunable lasers find applications in spectroscopy, photochemistry and optical communications.
Types of Tunability
Single line tuning

Since no real laser is truly monochromatic, all lasers can emit light over some range of frequencies, known as the linewidth of the laser transition. In most lasers, this linewidth is quite narrow (for example, the 1064 nm wavelength transition of an Nd: YAG laser has a linewidth of approximately 120 GHz, corresponding to a 0.45 nm wavelength range). Tuning of the laser output across this range can be achieved by placing wavelength-selective optical elements (such as an etalon) into the laser's optical cavity, to provide selection of a particular longitudinal mode of the cavity.

4.4 DESIGN STEPS

Circuit Diagram for receiver module

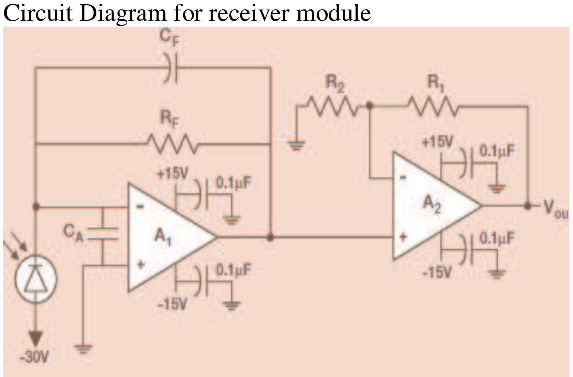

Figure 8: Receiver Module Circuit

Bandwidth of TIA- it should be approximately upto 0.7B where B is the maximum bandwidth of pin diode.

Calculation of input Capacitance of TIA-it involves adding the common mode and differential capacitances of TIA according to datasheet. For opa656 the value of C is (0.7pF +2.8 pF)=3.5pF.

Calculation of Rf –to do so use the following equation

$$f_{-3dB} = \sqrt{GBP / 2\pi R_F C_D}\ \text{Hz}$$

Here f-3dB=bandwidth of TIA

GBP=230M

Cd=Ctia+Cdiode=3.5pF+0.7pF=4.2pF

Next step involves calculation of Cf-use the following equation

$$1/(2\pi R_F C_F) = \sqrt{(GBP / (4\pi R_F C_D))}$$

Next step is calculating R1 and R2

Vout=Rf(1+R1/R2)Vin.

TRANSMITTER DESIGN

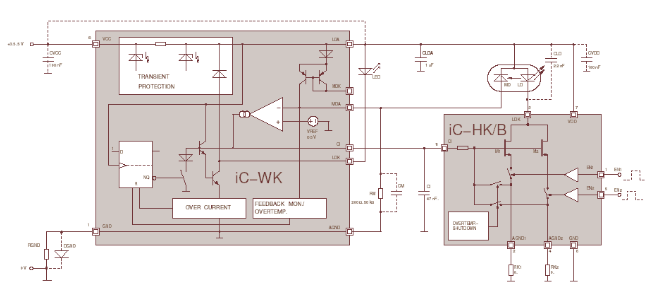

Figure 9: shows the combination of IcHK and IcWK used to drive the laser source.

The design steps used are as follows-

Current Required-

The current required by laser diodes used is about 15 mA.

It can withstand up to a maximum current of 85 mA.

Thus the transmitter should be designed so as to provide a current of not more than 100 mA.

Use of ICHK-

ICHK is a voltage controlled current source.

It is used to supply output current to the laser diode.

It enables spike free switching of laser with well defined current pulses ranging from dc to 155MHz.

The diode current is determined by resistors RK1 and RK2.

Since the diode current in this design ranges from 0 to 100mA RK can be omitted.

There are two channels present in this IC EN1 and EN2 are the inputs enabling them.

Since only one channel is used i/p pulse from TDM o/p is given to the EN1 pin while the EN2 pin is disabled.

Another important factor determining the current at o/p is the voltage at CI pin.

It has been found out that for a given value of RK=0 ohms the voltage required to produce a current of 100mA is about 1.75V.

A voltage divider circuit is used to provide the appropriate voltage at the pin.

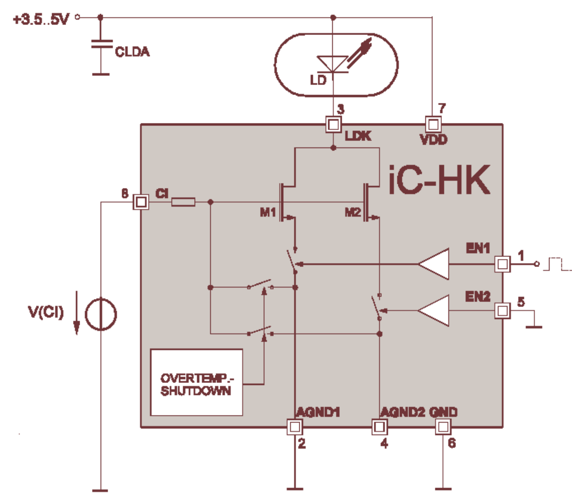

Figure 10: shows the ICHK in operation. As can be seen only one channel is enabled and RK=0 ohms. The voltage at pin CI is given by the voltage divider circuit.

Use of ICWK-

ICWK is a laser driver IC.

It is basically used in this circuit for soft start.

Laser power can be monitored using this IC. It also controls the voltage in such a way that the mean value of monitor current remains constant.

The frequency of operation should be greater than 100KHz.

The typical monitor current (Imhi) is selected from the data sheet.

Monitor current is then calculated by

$$Im_{av} = Im_{hi} \times t_{hi} / T$$

Value of RM is calculated from the internal reference voltage using this equation.

$$RM = 500\ mV / Im_{av}$$

IC WK sets CI such that the monitor current matches target current.
The typical value of the current is 100mA.
The capacitor value depends on CI. If CI is less WK would readjust itself with every pulse. Hence for proper operation CI is calculated by-

$$CI \geq (100\ \mu A / f) / \Delta V(CI)$$

The typical value of CI is 100pF.
The typical value of CM is 47pF.

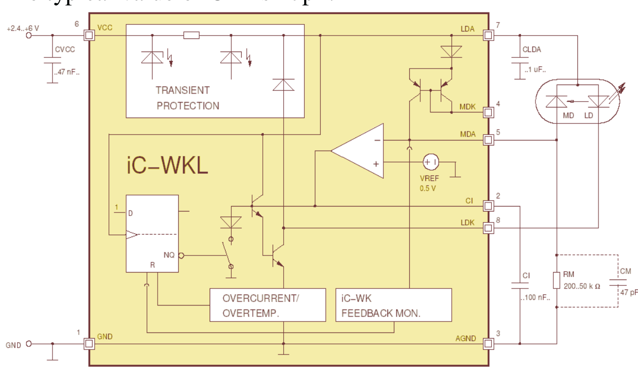

Figure 11:ic-WKL module

Lasers are usually labeled with a safety class number, which identifies how dangerous the laser is:
Class I/1 is inherently safe, usually because the light is contained in an enclosure, for example in cd players.
Class II/2 is safe during normal use; the blink reflex of the eye will prevent damage. Usually up to 1 mW power, for example laser pointers.
Class IIIa/3R lasers are usually up to 5 mW and involve a small risk of eye damage within the time of the blink reflex. Staring into such a beam for several seconds is likely to cause (minor) eye damage.
Class IIIb/3B can cause immediate severe eye damage upon exposure. Usually a laser up to 500 mW, such as those in cd and DVD burners comes under this category.
Class IV/4 lasers can burn skin, and in some cases, even scattered light can cause eye and/or skin damage. Many industrial and scientific lasers are in this class.
The indicated powers are for visible-light, continuous-wave lasers. For pulsed lasers and invisible wavelengths, other power limits apply. People working with class 3B and class 4 lasers can protect their eyes with safety goggles which are designed to absorb light of a particular wavelength. [5]

Dispersion

For modern glass optical fiber, the maximum transmission distance is limited not by attenuation but by dispersion, or spreading of optical pulses as they travel along the fiber. Dispersion in optical fibers is caused by a variety of factors. Intermodal dispersion, caused by the different axial speeds of different transverse modes, limits the performance of multi-mode fiber. Because single-mode fiber supports only one transverse mode, intermodal dispersion is eliminated.

Advantages of WDM

1. WDM system avoids new equipment costs.
2. It supports much more data rate using a single fiber cable.
3. Low operational cost. As WDM supports large number of inputs compare to SDH and PDH though installation cost is more operational cost is less, High capacity network Easy expansion.
4. WDM reduces costly mux/demux function, reuses existing optical fibers.
5. Alternative to new fiber installation, Maximizes capacity of leased fibers, Future proofing of new fiber routes.
WDM allows high flexibility in expanding bandwidth
6. Cost Reduction - integrating optics and eliminating mux stages.
7. Operation Efficiency - elimination of redundant protocol layers.

III. CONCLUSION

We have outlined need for tunable semiconductor laser. We discussed their tuning mechanism along with their various types. We have studied a high performance tunable laser array. It provides a wide wavelength rang of 40.6nm in the L-band that can be controlled by means of temperature. The power consumption is less than 2.5w. This result shows that high band TLA module can be used as widely wavelength tunable light source. In our lab setup, tunable laser was replaced by group multiple lasers with different wavelength having minimum wavelength gap between them.
Hence, CWDM system can be implemented with improved performance at lower cost.

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