REALIZATION OF WAVELENGTH CONVERSION AND DENSE WAVELENGT DIVISON MULTIPLEXING AT 40 Gb/S

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CERTIFICATE

This is to certify that the dissertation titled **"Realization of wavelength conversion and dense wavelength division multiplexing at 40Gb/s"** is the bonafide work of **Rajendra Singh Shahi (2K09/MOC/12)** under our guidance and supervision in partial fulfillment of requirement towards the degree of Master of Technology in Microwave and Optical Communication Engineering from Delhi Technological University, New Delhi.

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ABSTRRACT

Large bandwidth along with high transmission rate is require for today’s communication system. At present, optical fiber is the only medium for it with low loss communication links. With growing transmission rates, electronic regeneration become more and more expensive. So to overcome this problem of elctronic regenration, switching to optical domain is the best way to cater the high speed processing demand of the user. This can be accomplished by use of optical amplifier which are bit transparent and have an ability to amplify the signals at different wavelength simultaneously. These properties of optical amplifier are used to carry out the parallel logic and arithmetic operation which can remove the large power consumption and complexity of elctro-optic conversion. Semiconductor optical amplifier is one of the optical amplifier which is most suitable for high speed communication because of its distinct inherent characteristics like insensitivity to input signal modulation characteristics, polarization independent property, high saturation output power, low nonlinearties etc. So high speed optical processing need was felt to cater the ever increasing high speed demand of the user in the high speed traffic network.

The work was done for wavelength conversion by using nonlinear properties of semiconductor optical amplifier, the cross phase modulation (XPM), four wave mixing (FWM) its at rate of 20Gb/s but the work done could not be done beyond 20Gb/s with high conversion efficiency because of their nonlinear behaviour due to insensitiveness of polarization property. In the present work, the cross gain modulation (XGM),another nonlinear properties of semiconductor optical amplifier is used to convert the 1550 nm wavelength to 1549nmwavelength signal because of its high conversion efficiency and polarization independent property. In this thesis, the wavelength conversion has been done by using XGM at a rate of 40Gb/s by choosing the optimum value of .6ns carrier lifetime and 40mA current biasing where the nonlinearty are less and power content of signal is high i.e. 26dbm in the parametric range of [193.102-193.728THz] further, in the thesis, cross gain modulation (XGM) is used to realize the dense wavelength division multiplexing (DWDM) system at a rate of 40Gb/s with same carrier life time and current biasing parameter.

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CHAPTER 1

INTRODUCTION

In the field of telecommunication the system utilizing wavelength division multiplexing (WDM) are being rapidly adopted. Because it provide cost-effective additional capacity on fiber routes overloaded by the increase in data traffic. And the transition from electrical to optical switching in telecommunication networks is inevitable in present day scenario in order to meet fast rising demands of bandwidth. This leads to the requirement of all optical signal processing in optical networks. All optical signal processing especially dense wavelength division multiplexing (DWDM) requires wavelength conversion for switching the data from one wavelength to other. There is currently much research interest in this topic, and many studies have indicated that wavelength conversion is an essential technology for such networks. The ability to convert data from one wavelength channel to another makes such systems reconfigurable and helps to reduce the blocking probability in a wavelength routed network. Wavelength conversion can be achieved by detecting an optical data signal electrically and then modulating a laser at a different wavelength. To avoid this additional optical-to electrical conversion (and vice versa) wavelength conversion by all-optical means is preferable, especially as the bit rates increase to 10 Gb/s and beyond.

Many techniques have been explored by fiber optic engineers to achieve all-optical wavelength conversion. For example, the weak optical nonlinearities of silica can be used by taking advantage of the low propagation loss and small core size of single mode optical fiber, which allow long interaction lengths and high power densities to be achieved, respectively. Although the non linearities are very fast and the devices have demonstrated a wide range of functionality, optical fiber- based components are not favored because of the need for lengths typically around 1-10 km.

Even though recent advances in fiber technology have reduced the lengths of fiber-based wavelength conversion devices by an order of magnitude, the inability to integrate these silica fiber-based devices with the semiconductor opto-electronic components used in fiber transmission systems will remain an obstacle to widespread adoption. Semiconductor-based all-optical wavelength conversion devices are compact and readily lend themselves to integration and mass production using similar fabric promising.

1.1 Why all optical networks

The increasing demand of speed of data transfer in a network require high rate signal processing and high bandwidth. These are the requirement of all the telephone companies and other information service provider for upgrading the capacity and speed of the network . And for this purpose we have to use optical fiber as the transmitting medium and light will move instate of electron which are in electronic signal processing. So we have to use the component which can process the signal optically without entering into electrical signal in between the processing unit.

Since the mid 1990s, wavelength division multiplexing(WDM) has increasingly replaced time division multiplexing(TDM) as the technique to enhance the capacity of optical networks. Historically, WDM was primarily deployed in the point to point, long haul transmission of voice and data. However, as capacity demands increase in access metropolitan and LAN environments, network planners are evaluating the use of multiple wavelength optical technology throughout the network, thus developing a range of network configurations based on wavelength routing and including flexible network elements. To increase the speed of the network, the adoption of optical nodes is needed resulting in all optical network. This idea implies a careful management of the optical spectrum as a precious resource, limited by the pass band of optical network components.

In all optical network, signal remain in the optical domain from the source to the destination, thereby eliminating the well known electro-optic bottleneck. While this approach allow higher information transfer rates significantly beyond the rate possible in an electronic network.

1.2 Optical network at present

The current system do not operate solely in the optical domain, as switching needs to be performed in electronic domain as well. This involves conversion of the optical data to electronic data in order for the switching to take place and than conversion back to optical data after the switching operation. Commercial systems are currently restricted by the maximum speed at which the electronic can operate ,which is 10Gb/s[2].

As the overall data transmission obtainable in the optical domain far exceeds this maximum rate, electronic bottleneck may occur in future system at the multiplexer, electronic to optical converter and optical to electronic converter at the de-multiplexer. This would have the effect of limiting the maximum transmission rate of the system. In order to avoid this bottlenecks, at some point it is necessary for high speed telecommunication networks to operate solely in the optical domain [5]. In order for this to be realized, techniques to perform this all optical switching need to be developed.

In recent years, we have witnessed the introduction of many new technology for optical transmission, such as wavelength division multiplexing (WDM), Erbium doped fiber amplifier, Raman amplifier. These technologies help to expand the capacity of global telecommunication network dramatically. The underlying driving force for this vast expansion is an ever-present human ambition to move forward, for example, from a mere text-based email system to the word wide web (www), From voice communication (including fixed line and wireless communication) to voice over internet protocol to on line video conferencing ,from on line cheating to online gaming. All these developments requires more and more network capacity with controlled performance i.e. no jitter. The direct consequence of this hunger for bandwidth is that the single wavelength capacity in many back-bone networks has progressed up to 10Gb/s and work is on progress for above than it. To cater the ever increasing bandwidth requirement, researchers are constantly pushing the transmission limit. Semiconductor optical amplifier (SOA) has received extensive study as a potential device to implement all optical signal processing with such a high speed data rates[7]. The semiconductor optical amplifier (SOA) is a single pass device, which is similar to a semiconductor laser operating below threshold which is thoroughly discussed in later chapter. Several techniques can be implemented using the SOA, namely cross gain modulation, cross phase modulation and four wave mixing. These technique take advantage of modulation either the gain or phase of the device in order to perform all optical signal processing[1]. So we can say that optical network is the only key to next generation cyber infrastructure.

1.3 Problem on implementing all optical network

As we progress to high speed optical switching, the algorithm implementation complexity of selecting a wavelength for the route increases. So far, three algorithms[10] have been designed to implement the routing as per defined optical network which are given below as

1. Fixed path routing
2. Alternative path routing
3. Dynamic path routing

The semiconductor optical amplifier are most suitable to use in high speed optical processing because of its nonlinear properties i.e. cross gain modulation.

1.4 Need of work done

All optical network require an optimize infrastructure high speed optical processing issue because of high traffics data on a network. So in resolving this routing problem in high traffics optical data networks the researchers have suggested and demonstrated some method and techniques based on nonlinear properties of SOA i.e. cross phase modulation (XPM), cross gain modulation (XGM) and four wave mixing at a rate of 10Gb/s. but still the bottleneck of high speed data routing was not yet removed because of high speed switching and routing demand in processing the data. So here in this thesis the wavelength conversion of 1550nm to 1549 has been done at a rate of 40Gb/s using XGM which can cater the high speed routing demand of the optical network. This wavelength conversion technique through XGM can also be used in designing a dense wavelength multiplexing (DWDM) system at a rate of 40Gb/s which can resolve the multiplexing problem at high speed optical networks. This 40Gb/s wavelength conversion is done by choosing the optimize value of carrier life time and current biasing of the SOA so that the minimum non-linearities and maximum power content in the signal can be optioned. These above operation has been done by using XGM of an SOA because it has the advantages of simple in implementation, bit rate transparency and polarization insensitiveness to the input signal.
The XGM SOA converter is polarization independent if SOA with a polarization independent gain are employed. Such amplifiers with high fiber-to-fiber gain are now fabricated in many laboratories.

1.5 Objective of the thesis

The objective of the thesis is:

- To convert to convert the wavelength of the data signal from 1550nm to 1549nm at a rate 40Gb/s using SOA nonlinear properties known as XGM by using the optimum value of the parameters such as carrier lifetime and current biasing of SOA.

- To develop a 1×4 DWDM system which is a de-multiplexer using XGM technique of SOA at a rate 40Gb/s using the parameter of designed wavelength converter.

CHAPTER 2

OPTICAL AMPLIFIERS: A REVIEW

2.1 Introduction

In order to transmit signals over long distances (>100 km) it is necessary to compensate for attenuation losses within the fiber. Initially this was accomplished with an optoelectronic module consisting of an optical receiver, a regeneration system, equalization system, and an optical transmitter to send the data. Although function of this arrangement is limited by the optical to electrical and electrical to optical conversions. Several types of optical amplifiers have since been demonstrated to replace the opto-electronic regeneration systems. These systems eliminate the need for electro-optical (E-O) and optical electronic (O-E) conversions. This is one of the main reasons for the success of today's optical communications systems.

Information revolution implies that multimedia network need high bandwidth real time communication services. At present, optical fiber is the only transmission medium offering such large bandwidth with low loss communication links. With growing transmission rates, electronic regeneration becomes more and more expensive. Optical amplifiers have really revolutionized the field of fiber optical communication. Optical amplifier are in general bit rate transparent and can amplify signal at different wavelength simultaneously which has been exploring the network application which cater the demands of high speed routing and processing application. Before the advent of optical amplifier, regenerators were used to refresh or strengthen the weakened the weak signals. Regenerators convert optical signal to electrical, eliminate the noise from electrical signal and send back to the optical signal for continuing transmission in optical communication network. Regeneration however can typically only amplify one channel or a single wavelength. Optical amplifier are an improvement to regenerators because optical amplifier can amplify light signal of multiple wavelength simultaneously. Optical amplifier provide a valuable tool for optical communication system because of their ability to amplify ,regenerate or otherwise control optical energy to be communicated to next destination. Optical amplifier can also be used with multiple wavelength while regenerator are often specific to particular wavelength. Apart from this it has following advantages that make it more prominent for its usage.

- Significant equipment cost reductions
- Improvement ability to upgrade
- Improvement reliability brought about by the simplification of repeaters
- Higher bit rate achievable

Using a power optical amplifier at the transmit end and a preamplifier at the receiving end of a fiber system, it is now possible to achieve repeater less transmission distance of 300km at data rate of 2.4Gbit/s[10] furthermore, bandwidths are currently limited to around 30nm per amplifier, which reduces considerably as more amplifier are placed in series.

2.2 Principle and theory

The pump laser source is mixed with the signal traffic using an optical coupler. The combined signal are fed into the Er- doped fiber where the photon from the 1480nm pump laser signal are absorbed by rear earth element, Erbium incorporated in the fiber in minute quantities.

The erbium ion are raised to a higher level of energy as shown in fig.2.2. however ,the ions that reach this higher level rapidly decay to lower metastable state. The energy difference between the higher level and metastable level is exactly equal to the wavelength of 1550nm signal(that is why erbium used). The arrival of a 1550nm signal photon triggers the release of an erbium ion temporarily held in the metastable state which than drop down the zero energy, or ground state where it originated. In doing so the ion releases the energy in the form of a photon at the same wavelength and pase as the 1550nm signal frequency photon. This mechanism provide the amplification

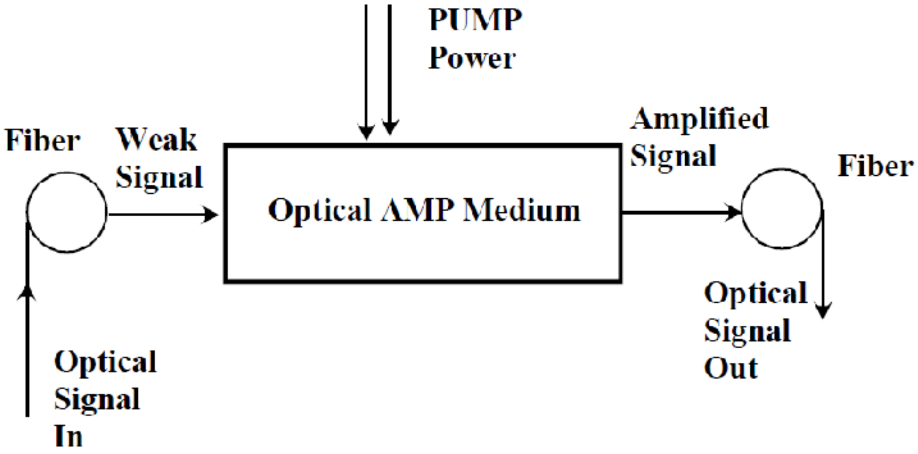

Fig2.1

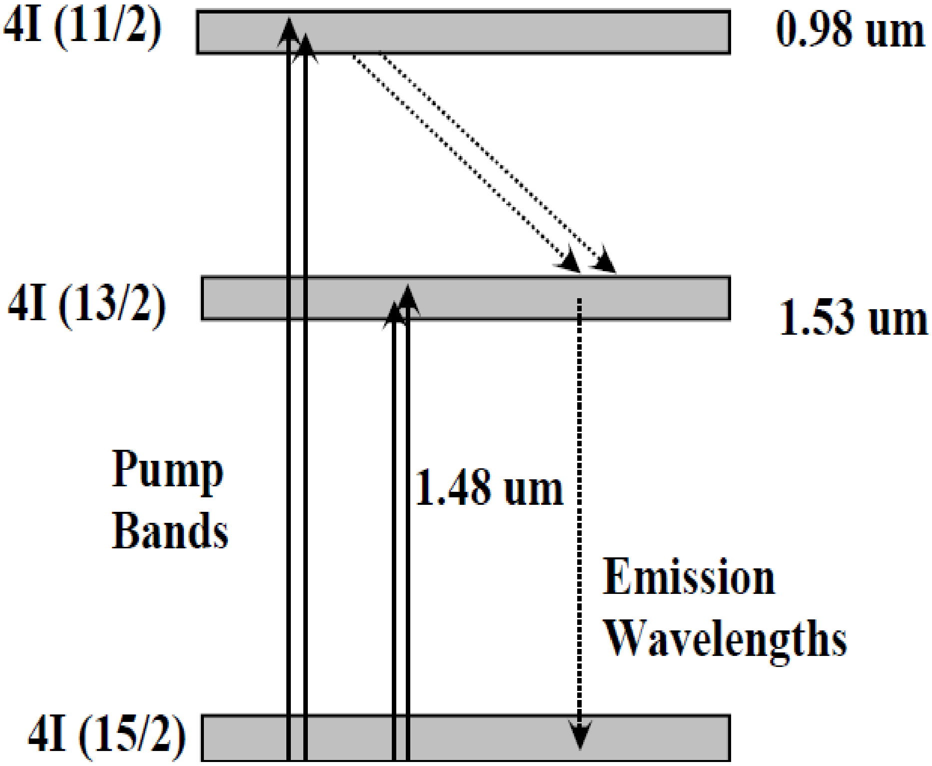

Fig 2.2 decay of ion in a pumped- Er fiber

2.3 Types of optical amplifiers

optical amplifier can be classified on the basis of device characteristics i.e. whether it is based on linear characteristic(semiconductor optical amplifier and rare earth doped fiber amplifier) or nolinear characteristics (Raman amplifier and Brilliouin amplifiers). Optical amplifier are also classified on the basis of structure i.e. whether semiconductor based or fiber based.

2.3.1 Semiconductor optical amplifiers

Semiconductor optical amplifier (SOA) uses the principle of stimulated emission to amplify an optical information signal. Optical input signal carrying original data enter to semiconductor's active region through small region coupling interface. The coupling is required because the mode field diameter of single mode beam is normally around 9mm, while size of the active region is less. Injection current delivers the external energy to the pump elements at the conduction band. The input signal stimulated the transition of electron down to the valence band & emission of photon with same energy &same wavelength as the input signal, so amplified optical signal is obtained. SOA is of two type fabry perot amplifier (FPA)& travelling wave amplifier. Fabry perot is same as

SOA. Typical schematic of SOA is shown in fig 2.3 where the light enter the active region is reflected several times from cleaved face &amplified as it leaves the cavity.

Fig.2.3 semiconductor optical amplifier

Travelling wave amplifier (TWA) is also other type of SOA. Here TWA is an active medium without reflective facets so that input signal is amplified by a signal passage through active region. Practical active region without reflective facets was made by covering the facets of semiconductor material by antireflection coating, tilting the active region with respect to the facets and using buffering material between active region & facet to also reduce reflectance R as small as 10^{-3}. SOA are used in two ways:

1) System application
2) Functional application

2.3.1.1 Uses semiconductor optical amplifiers

a) Semiconductor optical amplifiers (SOAs) as Power Boosters

There is a growing need to manage the increase in loss budgets associated with optical networks comprising optical nodes which facilitate and promote dynamic wavelength routing. These nodes are complex at the optical level and in order to provide the necessary functionality, introduce a loss overhead which has ramifications in respect of system designs. There is also an evolutionary move to deploy tunable laser sources in network architectures for maximum flexibility and utilization of the wavelength resource. In general, the output power levels of tunable lasers are modest, especially since external modulation is required at data rates up to and beyond 10Gbit/s introducing additional insertion losses, resulting in the need to boost the signal prior to transmission. In addition, the ability to perform a limited amount of channel power equalization on each wavelength in a WDM multiplex is of benefit. SOA provide a low cost route to providing amplification in such scenarios where it is advantageous to embed the amplification within the node design or on transmitter line cards. Longer term they permit higher degrees of integration to be invoked which then translates into smaller footprint, more cost effective solutions. In this respect SOAs have a clear advantage over alternative solutions such as EDFAs [15].

b) Semiconductor optical amplifiers linear operating regime:

In amplification, the linear region is the preferred operating regime since an exact, amplified replica of the input is required. Operating an SOA outside this region causes distortion since at high output powers, the gain saturates and compresses. The resulting gain modulation causes patterning in the time domain, because the gain recovery time of an SOA is typically of the same order as the data modulation speeds. Thus one of the key operating issues to ensure linear functionality is the management of the input power levels in order to control the degree into which the device is driven into saturation. In order to provide some level of channel equalization, the gain of the SOA can be controlled by changing the bias current applied. However if the bias current is lowered to lower the gain, the saturation output power and hence the linear region also reduces which in turn limits the dynamic range of the variation in gain for a certain output power. The wavelength dependence of SOA characteristics translates into trade-offs in parameters with respect to wavelength. This also applies to the output saturation power and this variation must be taken into consideration in any designs operating over a specified wavelength range. It must be noted that all SOA parameters are quoted as a min or max values (as appropriate) across that specified wavelength band. These parameters can be optimized for any particular application by accurate movement of the gain peak. In booster applications, the output power is the primary design parameter of interest.

c)Chirp in gain compression:

operation of an SOA in gain compression not only results in patterning but also produces chirp (frequency variations) of the amplified optical signal. The level of chirp produced is proportional to the amount of gain compression the signal is subject to, the net effect of additional chirp being to increase the power penalty (and hence attainable transmission distance) of the link due to resulting increase in dispersion. Unlike directly modulated lasers the chirp induced is of opposite sign; lasing occurs through current injection to increase the output power whilst the SOA imparts gain through carrier depletion.

d) Noise figure (NF):

The amplification process is always accompanied by spontaneous emission, where photons of random phase and polarization are added to the signal. The noise performance of an optical amplifier is characterized by the NF, defined as the amount of degradation in the signal to noise ratio caused by the amplification process [16]. In transmitter booster applications, the NF will play a role but is not as critical as in pre-amplifier applications. In optical nodes the NF is crucial in defining overall system performance.

e) Polarization dependent gain:

In any optical communication system the state of polarisation at any in-line component is unknown, since installed optical fibre does not preserve the state of polarization. Thus, typically, the SOA has to be polarization insensitive. Through chip design know-how, very low polarization dependent gain <0.5dB is available[16]. In transmitter applications, there is a well defined polarization state emanating from the laser and PDG is not a critical issue as long as the SOA provides the output power for the required gain. In mid-span optical node uses, the PDG is important since a random polarization enters into the node.

f) Wide optical bandwidth

SOA's exhibit a ~80nm optical gain bandwidth at the 3dB drop from the peak gain. Access to a wider bandwidth is possible if the minimum system gain required (at the extremities) is lower[15]. Centring the gain peak very accurately during the material growth stage means that the SOA can meet the amplifier needs for all of the low loss transmission window of optical fibers. In DWDM applications, the SOA provides the required bandwidth easily.

g) Multi-wavelength operation:

The SOA can operate in single and multi-channel environments. For further details of the performance of the SOA as a power booster in multi-channel scenarios see[16].

h) Data rate transparent:

The SOA is able to amplify at data rates ranging from Mbit/s up to and beyond 40Gbit/s. In this respect it is a future proof technology compatible with any upgrade scenario since it is also protocol independent.

i) Small form factor, amenable to integration:

The SOA is housed within a standard 14-pin butterfly package, the subject of a multi source agreement (MSA) with other leading SOA suppliers which guarantees system providers with common optical/mechanical specifications. The size of the package represents a significant improvement on competing optical amplifier solutions. Longer term, Kamelian's know-how in on-chip mode expansion technology promotes a manufacturable solution to the integration of the SOA with other components to yield low cost, highly functional modules.

2.3.2Fiber amplifiers

Fiber amplifier acts as power amplifier, repeater, and a preamplifier. The gain medium comprises a length of single mode fiber connected to WDM coupler, which provides low insertion loss at both, signal and pump wavelength excitation occur through optical pumping laser combined with optical input signal within the couplers shown in fig 2.4. Stimulated emission process occurred inside the fiber gain medium. The amplified optical signal is emitted from other end of fiber made from heavily doped ions depending on the type i.e. Rare-earth doped fiber amplifier, Raman fiber amplifier & Brillouin fiber amplifier.

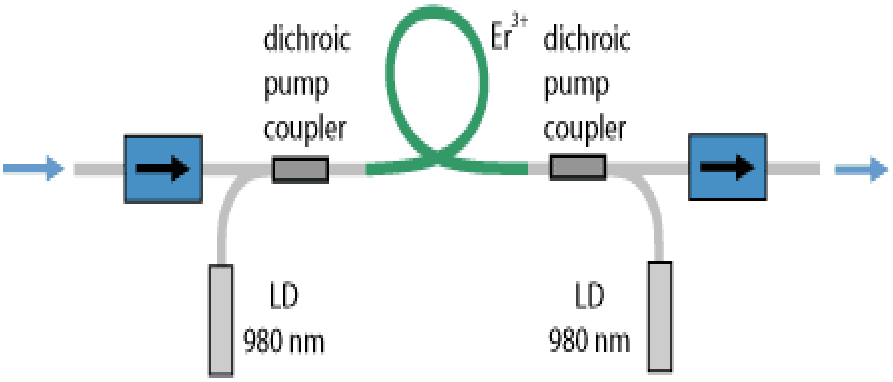

Fig.2.4 schematic of basic fiber amplifier

2.3.2.1 Doped fiber amplifiers

Doped fiber amplifiers (DFAs) are optical amplifiers that use a doped optical fiber as a gain medium to amplify an optical signal. They are related to fiber lasers. The signal to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where the core of a silica fiber is doped with trivalent Erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1480 nm, and exhibits gain in the 1550 nm region.

Amplification is achieved by stimulated emission of photons from dopant ions in the doped fiber. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through nonradiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fiber, the wavelength and power of the pump laser.

Although the electronic transitions of an isolated ion are very well defined, broadening of the energy levels occurs when the ions are incorporated into the glass of the optical fiber and thus the amplification window is also broadened. This broadening is both homogeneous (all ions exhibit the same broadened spectrum) and inhomogeneous (different ions in different glass locations exhibit different spectra). Homogeneous broadening arises from the interactions with phonons of the glass, while inhomogeneous broadening is caused by differences in the glass sites where different ions are hosted. Different sites expose ions to different local electric fields, which shifts the energy levels via the Stark effect. In addition, the Stark effect also removes the degeneracy of energy states having the same total angular momentum (specified by the quantum number J). Thus, for example, the trivalent Erbium ion (Er^{+3}) has a ground state with J = 15/2, and in the presence of an electric field splits into J + 1/2 = 8 sublevels with slightly different energies. The first excited state has J = 13/2 and therefore a Stark manifold with 7 sublevels. Transitions from the J = 13/2 excited state to the J= 15/2 ground state are responsible for the gain at 1.5 µm wavelength. The gain spectrum of the EDFA has several peaks that are smeared by the above broadening mechanisms. The net result is a very broad spectrum (30 nm in silica, typically). The broad gain-bandwidth of fiber amplifiers make them particularly useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.

a)Basic principle of EDFA

The most common example of doped fiber amplifier (DFA)is the Erbium Doped Fiber Amplifier (EDFA), where the core of a silica fiber is doped with trivalent Erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1480 nm, and exhibits gain in the 1550 nm region. A relatively high-powered beam of light is mixed with the input signal using a wavelength selective coupler. The input signal and the excitation light must of course be at significantly different wavelengths. The mixed light is guided into a section of fiber with erbium ions included in the core. This high-powered light beam excites the erbium ions to their higher-energy state. When the photons belonging to the signal at a different wavelength from the pump light meet the excited erbium atoms, the erbium atoms give up some of their energy to the signal and return to their lower-energy state. A significant point is that the erbium gives up its energy in the form of additional photons which are exactly in the same phase and direction as the signal being amplified. So the signal is amplified along its direction of travel only. This is not unusual - when an atom “lases” it always gives up its energy in the same direction and phase as the incoming light. That is just the way lasers work. Thus all of the additional signal power is guided in the same fiber mode as the incoming signal. There is usually an isolator placed at the output to prevent reflections returning from the attached fiber. Such reflections disrupt amplifier operation and in the extreme case can cause the amplifier to become a laser.

b)Noise

The principal source of noise in DFAs is Amplified Spontaneous Emission (ASE), which has a spectrum approximately the same as the gain spectrum of the amplifier. Noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 dB.

As well as decaying via stimulated emission, electrons in the upper energy level can also decay by spontaneous emission, which occurs at random, depending upon the glass structure and inversion level. Photons re emitted spontaneously in all directions, but a proportion of those will be emitted in a direction that falls within the numerical aperture of the fiber and are thus captured and guided by the fiber. Those photons captured may then interact with other dopant ions, and are thus amplified by stimulated emission. The initial spontaneous emission is therefore amplified in the same manner as the signals, hence the term Amplified Spontaneous Emission. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance. Counter-propagating ASE can, however, lead to degradation of the amplifier's performance since the ASE can deplete the inversion level and thereby reduce the gain of the amplifier.

c) Gain saturation

Gain is achieved in a EDFA due to population inversion of the dopant ions. The inversion level of a EDFA is set, primarily, by the power of the pump wavelength and the power at the amplified wavelengths**.** As the signal power increases, or the pump power decreases, the inversion level will reduce and thereby the gain of the amplifier will be reduced. This effect is known as gain saturation – as the signal level increases, the amplifier saturates and cannot produce any more output power, and therefore the gain reduces. Saturation is also commonly known as gain compression.

To achieve optimum noise performance EDFAs are operated under a significant amount of gain compression (10 dB typically), since that reduces the rate of spontaneous emission, thereby reducing ASE. Another advantage of operating the EDFA in the gain saturation region is that small fluctuations in the input signal power are reduced in the output amplified signal: smaller input signal powers experience larger (less saturated) gain, while larger input powers see less gain.

The leading edge of the pulse is amplified, until the saturation energy of the gain medium is reached. In some condition, the width (FWHM) of the pulse is reduced.

d)Inhomogeneous broadening effects

Due to the inhomogeneous portion of the linewidth broadening of the dopant ions, the gain spectrum has an inhomogeneous component and gain saturation occurs, to a small extent, in an inhomogeneous manner. This effect is known as Spectral hole burning because a high power signal at one wavelength can 'burn' a hole in the gain for wavelengths close to that signal by saturation of the inhomogeneously broadened ions. Spectral holes vary in width depending on the characteristics of the optical fiber in question and the power of the burning signal, but are typically less than 1 nm at the short wavelength end of the C-band, and a few nm at the long wavelength end of the C-band. The depth of the holes are very small, though, making it difficult to observe in practice.

e)Polarization effects

Although the DFA is essentially a polarization independent amplifier, a small proportion of the dopant ions interact preferentially with certain polarizations and a small dependence on the polarization of the input signal may occur (typically < 0.5 dB). This is called Polarization Dependent Gain (PDG). The absorption and emission cross connections of the ions can be modeled as ellipsoids with the major axes aligned at random in all directions in different glass sites. The random distribution of the orientation of the ellipsoids in a glass produces a macroscopically isotropic medium, but a strong pump laser induces an anisotropic distribution by selectively exciting those ions that are more aligned with the optical field vector of the pump. Also, those excited ions aligned with the signal field produce more stimulated emission. The change in gain is thus dependent on the alignment of the polarizations of the pump and signal lasers – i.e. whether the two lasers are interacting with the same sub-set of dopant ions or not. In an ideal doped fiber without birefringence, the PDG would be inconveniently large. Fortunately, in optical fibers small amounts of birefringence are always present and, furthermore, the fast and slow axes vary randomly along the fiber length. A typical DFA has several tens of meters, long enough to already show this randomness of the birefringence axes. These two combined effects (which in transmission fibers give rise to Polarization Mode Dispersion) produce a misalignment of the relative polarizations of the signal and pump lasers along the fiber, thus tending to average out the PDG. The result is that PDG is very difficult to observe in a single amplifier (but is noticeable in links with several cascaded amplifiers).

f)Erbium-doped fiber amplifiers

The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber.

Two bands have developed in the third transmission window – the Conventional, or C-band, from approximately 1525 nm – 1565 nm, and the Long, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands.

The principle difference between C- and L-band amplifiers is that a longer length of doped fiber is used in L-band amplifiers. The longer length of fiber allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain.

EDFAs have two commonly-used pumping bands – 980 nm and 1480 nm. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stablesed laser sources are typically needed. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980 nm and 1480 nm pumping is generally utillised in amplifiers.

The EDFA was first demonstrated several years later [2] by a group including David N. Payne, R. Mears, and L. Reekie, from the University of Southampton and a group from AT&T Bell Laboratories.

g)Doped fiber amplifiers for other wavelength ranges

Thulium doped fiber amplifiers have been used in the S-band (1450–1490 nm) and Praseodymium doped amplifiers in the 1300 nm region. However, those regions have not seen any significant commercial use so far and so those amplifiers have not been the subject of as much development as the EDFA. However, Ytterbium doped fiber lasers and amplifiers, operating near 1 micrometre wavelength, have many applications in industrial processing of materials, as these devices can be made with extremely high output power (tens of kilowatts).

2.3.2.2 Raman amplifier

A Raman amplifier is an optical amplifier based on Raman gain, which results from the effect of stimulated Raman scattering. The Raman-active medium is often an optical fiber, although it can also be a bulk crystal, a waveguide in a photonic integrated circuit, or a cell with a gas or liquid medium. An input signal can be amplified while co- or counterpropagating with a pump beam, the wavelength of which is typically a few tens of nanometers shorter. For silica fibers, maximum gain is obtained for a frequency offset of ≈ 10–15 THz between pump and signal, depending on the composition of the fiber core.
For application in telecom systems, fiber Raman amplifiers compete with erbium-doped fiber amplifiers. Compared with those, their typical features are:

i. Raman amplifiers can be operated in very different wavelength regions, provided that a suitable pump source is available.

ii. The gain spectrum can be tailored by using different pump wavelengths simultaneously.

iii. A Raman amplifier requires high pump power (possibly raising laser safety issues) and high pump brightness, but it can also generate high output powers.

iv. A greater length of fiber is required. However, the transmission fiber in a telecom system may be used, so that no additional fiber is required.

v. Raman fiber amplifiers can have a lower noise figure. On the other hand, they more directly couple pump noise to the signal than laser amplifiers do.
vi. They also have a fast reaction to changes of the pump power, particularly for co-propagating pump, and very different saturation characteristics.

vii. If the pump wavelength is polarized, the Raman gain is polarization-dependent. This effect is often unwanted, but can be suppressed e.g. by using two polarization-coupled pump diodes or a pump depolarizer.

A telecom Raman amplifier is pumped with continuous-wave light from a diode laser. Efficient amplification of ultra-short pulses is also possible using co-propagating pump pulses. However, the phenomenon of group velocity mismatch then severely limits the useful interaction length, particularly for pulse durations below 1 ps.

Fibers used for Raman amplifiers are not doped with rare earth ions. In principle, any ordinary single-mode fiber could be used, and in practice the transmission fibers themselves are often suitable. However, there are special fibers with increased Raman gain, resulting from certain dopants (e.g. germania) for enhanced Raman cross sections, or simply from a small effective mode area. Such fibers are used for lumped Raman amplifiers, where a shorter piece of fiber is dedicated to amplification only.

2.3.2.3 Brillouin Fiber Amplifier

Brillouin scattering is an effect caused by the χ^3 nonlinearity of a medium, specifically by that part of the nonlinearity which is related to acoustic phonons [1]. An incident photon can be converted into a scattered photon of slightly lower energy, usually propagating in the backward direction, and a phonon. The coupling of optical fields and acoustic waves occurs via electrostriction. The effect can occur spontaneously even at low optical powers, then reflecting the thermally generated phonon field. For higher optical powers, there can be a stimulated effect, where the optical fields substantially contribute to the phonon population. Above a certain threshold power of a light beam in a medium, stimulated Brillouin scattering can reflect most of the power of an incident beam. This process involves a strong nonlinear optical gain for the back-reflected wave: an originally weak counter propagating wave at the suitable optical frequency can be strongly amplified. Here, the two counter-propagating waves generate a traveling refractive index grating; the higher the reflected power, the stronger the index grating and the higher the effective reflectivity.

2.3.2.3.1 Stimulated Brillouin scattering in Optical fibers

Stimulated Brillouin scattering (SBS) is frequently encountered when narrow-band optical signals (e.g. from a single-frequency laser) are amplified in a fiber amplifier, or just propagated through a passive fiber. While the material nonlinearity of e.g. silica is actually not very high, the typically small effective mode area and long propagation length strongly favor nonlinear effects. For silica fibers, the Brillouin frequency shift is of the order of 10–20 GHz, and the Brillouin gain has an intrinsic bandwidth of typically 50–100 MHz, which is determined by the strong acoustic absorption (short phonon lifetime). However, the Brillouin gain spectrum may be strongly “smeared out” by various effects, such as transverse variations of the acoustic phase velocity or longitudinal temperature variations. Accordingly, the peak gain may be strongly reduced, leading to a substantially higher SBS threshold.

The Brillouin threshold of optical fibers for narrow-band continuous-wave light typically corresponds to a Brillouin gain of the order of 90 dB. (With additional laser gain in an active fiber, the threshold can be lower). For trains of ultrashort pulses, the SBS threshold is determined not by a peak power, but rather by a power spectral density, as explained in a Spotlight article.

SBS introduces the most stringent power limit for the amplification and the passive propagation of narrow-band optical signals in fibers. In order to raise the Brillouin threshold, it is possible to increase the bandwidth of the light beyond the Brillouin gain bandwidth, reduce the fiber length, concatenate fibers with slightly different Brillouin shift, or (in high-power active fiber devices) exploit the longitudinally varying temperature. There are also attempts to reduce the overlap of guided optical and acoustic waves, or to introduce significant propagation losses for the acoustic wave. To some extent, SBS problems can be reduced via basic amplifier design modifications, concerning e.g. the doping concentration, effective mode area and pump propagation direction.

2.4 SOA-Basic parameter

In an SOA ,carriers (referred as electron) are injected into the active region from an external current source. These energized carrier occupy energy state in the conduction band (CB) of the active region material leaving holes in the valence band(VB). Three radiative mechanism generally occur in the semiconductor optical amplifier. These are shown in fig 2.5for a material with a energy band structure consisting of two discrete energy levels. In stimulated absorption an incident light photon of sufficient energy can stimulate a carrier from the VB to the CB. This is a loss process as the incident photon is extinguished.

If a photon of suitable energy is incident on the semiconductor, it can cause stimulated recombination of a CB carrier with a VB hole. The recombination carrier losses its energy in the form of a photon of light. This new stimulated photon will be identical in all respect to the inducing photon(identical phase ,frequency and direction i.e. a coherent interaction). Both the original photon and stimulated photon can give rise to more stimulated transitions. If the injected current is sufficient is sufficiently high than a population inversion is created when the carrier population in the CB exceed in that of VB. In this case the likelihood of stimulated absorption and so semiconductor will exhibit optical gain.

In the spontaneous emission process ,there is a non zero probability per unit time that a CB carrier will spontaneously recombine with a VB hole and t hereby emit a photon with random phase and direction. Spontaneous emitted photon photon have a wide range of frequencies. Spontaneously emitted photon have a wide range of frequencies. Spontaneously emitted photon are essential noise and also take part in reducing the carrier population available for optical gain. Spontaneous emission is a direct consequence of amplification process and can not be avoided. Hence a noiseless SOA can not be created. Stimulated process are proportional to the intensity of the inducing radiation whereas the spontaneous emission process is independent of it.

2.4.1 Small signal gain and gain bandwidth

Basically there are two gain definition for SOAs. The first definition is the intrinsic gain G of the SOA, which is simply the ration of output signal power at the output facet and input power at input facet. The second is fiber to fiber gain which includes the input and output coupling losses. All these gain are usually expressed in db. The gain spectrum of a particular SOA depend on its structure material and operational parameters. In most of application high gain and wide gain bandwidth is required. The small signal (small means that the signal has negligible influenceon the SOA gain coefficient) internal gain of a Fabry perot SOA at optical frequency ν is given by

$$G(\nu)=(1-R_1)(1-R_2)Gs/(1-\sqrt{(R_1R_2)}.Gs)^2+4\sqrt{(R_1R_2)}GsSin^2[\pi(v- v_o)/\Delta]$$

Where R_1 and R_2 are the input and output facet reflectivity and Δv is the cavity longitudinal mode spacing given by

Gs is the gain saturation

$\Delta v=c/2nLr$

v_o is the closest cavity resonance to v.

The gain bandwidth is defined as the full width at the half maximum (FWHM) of the gain spectrum. Amplifier of high bandwidth are preferred for optical communication system since the gain is nearly same over the entire bandwidth. A 3dB bandwidth is about 45nm for bulk SOA and it can exceed up to 60 dB for quantum well SOA.

CHAPTER 3

LITERATURE REVIEW

2.3 Introduction

ALL-OPTICAL wavelength converters are expected to become key components in the future broadband networks. Their most important use will be for avoidance of wavelength blocking in optical cross connects in wavelength division multiplexed (WDM) networks. Thereby the converters increase the flexibility and the capacity of the network for a fixed set of wavelengths. Equally important, the wavelength conversion function enables decentralized network management concerning the wavelength paths through the network and may facilitate easier protection switching . The potential of wavelength converters has already been demonstrated in a number of system experiments. A fine example is the 8 x10 Gb/s WDM link reported in [9].Efficient optical space switches can also be constructed using tunable wavelength converters together with an array of fixed output filters. This application of converters has for example been employed for internal routing in a complex 2.5 Gb/s optical ATM switch block experiment [10]. Clearly, wavelength conversion is a very useful function in advanced optical systems. The requirements to the converters will be system dependent, but preferably the converters should feature the following.

- ❖ Bit-rate transparency (up to at least 10 Gb/s)
- ❖ No extinction ratio degradation
- ❖ High signal-to-noise ratio at the output (to ensure cascadability)
- ❖ Moderate input power levels (-0 dBm)
- ❖ Large wavelength span for both input and output signals
- ❖ Possibility for same input and output wavelengths (no conversion)
- ❖ Low chirp
- ❖ Fast setup time of output wavelength
- ❖ Insensitivity to input signal polarization
- ❖ Simple implementation

Several techniques have been proposed to achieve wavelength conversion. The straight forward solution is an electro-optic converter consisting of a detector followed by a laser that retransmits the incoming signal on the new wavelength. Disadvantages of the electro-optic converter such as complexity and large power consumption have, however, directed the interest to all optical wavelength converteor's. They enable direct translation of the information on the incoming wavelength to new wavelength without entering the electrical domain. Examples of all optical wavelength converters are: Semiconductor optical amplifiers (SOA's) used in the cross gain modulation (XGM) mode or the cross phase modulation (XPM)mode ; SOA's using four wave mixing (FWM); bistable lasers incorporating saturable absorbers injection locked Y-lasers and DBR lasers relying on optical frequency or intensity modulation. Wavelength conversion based on four-wave mixing in optical fibers and quasi phase matching in Lithium Niobate waveguides has also been reported, but the semiconductor base converters generally appear to be most efficient seems to be well suited for system use.

Important parameters such as input power levels, maximum bit-rate and wavelength dependency will be discussed. An explanation of the large bandwidth of SOA converters is also given based on modeling. Finally, transmission of wavelength converted signals is addressed. Another wavelength conversion technique is based on fourwave mixing in SOA's as mentioned above. The scheme is attractive because of transparency to modulation format as well as high bit rate capabilities. Unfortunately the conversion efficiency for this scheme is not very high and it decreases swiftly with increasing conversion span. Consequently, it is difficult to retain a large signal to noise for the converted signal and to cascade more converters. SOA converters using the XGM and the XPM conversion scheme presently seems to be well suited for system use. But later, we will discuss the wavelength conversion mechanism based on XGM is Preferred because of following features:

- High conversion efficiency
- Polarization independence
- Insensitive to the wavelength of the input data
- Simple in implementation

presently seems to be well suited for system use. But later, we will discuss the wavelength conversion mechanism based on XGM is Preferred because of some features:

3.2 Necessity of wavelength conversion

Recently, the explosive growth of data traffic has led to a dramatic increase in demand for transmission bandwidth imposing an immediate requirement for broadband transport networks. The telecommunication networks widely employ wavelength division multiplexing (WDM) in single-mode optical fibers to interconnect discrete network locations and offer high capacity, high speed, and long reach transmission capabilities . Using WDM, the bandwidth of a fiber link can be divided into non-overlapping wavelength channels, each of which can operate at peak electronic processing rate . The ability to shift an optical channel from one wavelength to another can be required for WDM network. In that case, wavelength conversion is a key technology that may connect various optical networks without wavelength collisions.

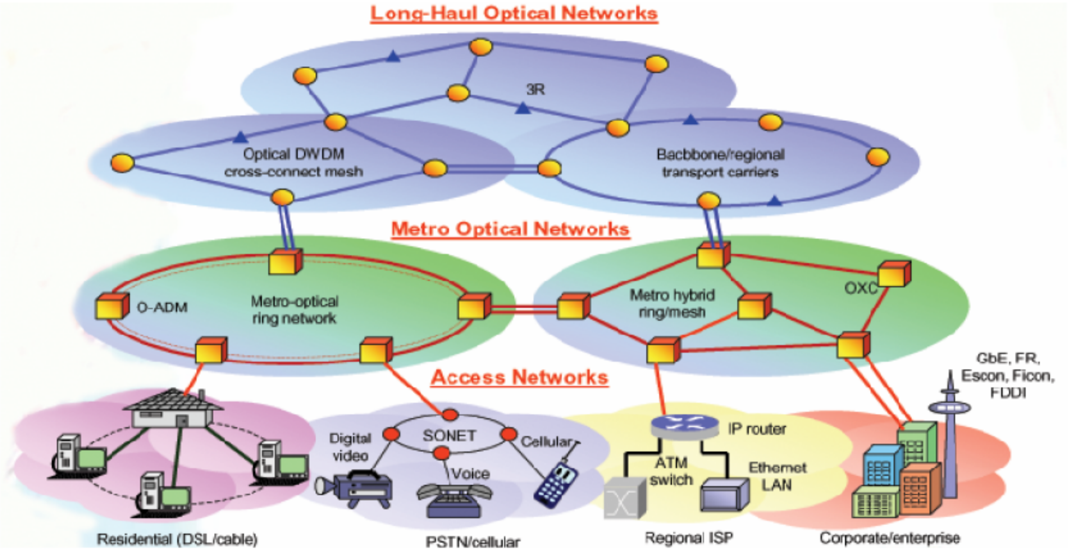

Fig. 3.1 network configuration

The network configurations according to data transmission distance are shown in Fig.3.1. The long-haul optical networks connect continents via the long-haul submarine cables at tens or hundreds of gigabits per second. Moreover, they connect adjacent countries in a continent via the long-haul terrestrial cables. Unlike long-haul submarine cables, long-haul terrestrial cables may need to make connections at intermediate points along their routes. Typically, these are cities large enough to generate significant traffic, but not large enough to be hubs. This is done with various forms of optical add-drop multiplexers (OADMs). They may be static, to direct signals in the same ways, or dynamic, to switch signals in different directions. They also may split off the contents of an entire fiber, or individual optical channels in a fiber carrying WDM traffic. The choice depends on the type of system and the amount of traffic. Normally, signals are added or dropped at the intermediate locations. In WDM systems, this may require conversion the wavelengths of some signals to wavelengths that are available in the through cable. Wavelength conversion also may be necessary at hubs, where signals are switched in different directions and reorganized. Sometimes the concept of wide area network (WAN) is introduced, which contains spans typically ranging from hundreds to several thousands of kilometers. It interconnects networks of national size and may range over a whole continent like Europe. The nodes also serve as entry points to the metropolitan area networks (MANs) and the transoceanic global area network (GAN). It is assumed that all signals will be fully regenerated at these entry points. The switching in the WAN will be mainly performed on wavelength and waveband level, due to the highly aggregated traffic. A waveband may consist of more than 10 wavelengths. For this kind of switching MEMS will be the technology of the choice, which also will be used for fast restoration in the meshed network. The metro optical network is a distribution system to serve large metropolitan areas, not a simple information pipeline between a pair of points as shown in Fig. 3.1. There are two distinct ways of accessing a metro optical network, through a hub and through an OADM. A hub is a point where most of the signals in a system are switched and organized. Hubs include local switching offices, and correspond to the terminal points on submarine cables. OADMs are points where some signals are picked up and others dropped. An OADM along the network diverts only part of the signals to the node. Also, the metro optical networks contain the optical cross-connect (OXC) switching; what is called a switching fabric. The OXC plays a role to direct signals among many possible users. Signals are directed from any of N possible inputs to any of M possible outputs. The OXC can transfer high-speed optical signals among input and output fibers. Wavelength conversion is an essential way to enhance the flexibility of the metro optical networks.

As another similar concept, the MAN, which connects the access to the WAN, is characterized by a fairly well defined distance scale often quoted as 20-200 km. It is rapidly growing in terms of capacity because the traffic within the MAN is greatly increased. The capacity is being provided by Dense WDM (DWDM) channels. As the spanned distance is less than that of a WAN, a larger number of wavelengths (100-1000) and high bit rates (2.5-40 Gb/s) are possible because nonlinear effects are less. An evolution of path assignment comes from introduction of optical burst switching (OBS) and optical packet switching (OPS).

The optical access networks give individual subscribers access to the global telecommunications network, as shown in Fig.3.1. The access network fans out from the access points of the metro optical network which acts as the highway of the optical metro/access network domain. It concentrates the traffic streams coming from the users and may also perform statistical multiplexing taking into account different quality of services (QoS) and service level agreements (SLAs). The Access Network also provides the appropriate interfaces for the different services at the user sites via various infrastructures, such as x – digital subscriber line (xDSL), cable TV, public switched telephone network (PSTN), regional internet service provider (ISP), and enterprise network.

3.3 SOA-based wavelength converters

As remarked in previous section, the wavelength converter is the most important device to avoid the unnecessary wavelength collision, to switch and reorganize signals in different directions, and to achieve the high flexibility in construction of OADM and OXC in WDM networks. Among the various kinds of wavelength converter, semiconductor optical amplifier (SOA)-based wavelength converters are worthy of notice in view of integration capability, compactness, and conversion efficiency. The SOA-based wavelength converters are representatively sorted into two types using the cross gain modulation (XGM) and the cross phase modulation (XPM).

The SOA-based wavelength converter (WC) using XGM makes use of the dependence of the gain of an SOA on its input power, as shown in Fig. 1. As the input power increased, the carriers in the gain region of the SOA get depleted, resulting in a reduction in the amplifier gain . The carrier dynamics within the SOA are very fast, happening on a pico-second time scale. Thus the gain responds in tune with the fluctuations in input power on a bit-by-bit basis. The XGM WC can handle bit rates as high as 10 Gb/s. Furthermore, it is turned out that the XGM WC can reach bit rates of 100 Gb/s with longer length of SOA. If a low-power probe signal at a different wavelength is sent into the SOA, it will experience a low gain when there is a high logic state in the input signal and a higher gain when there is a low logic state. This very same effect produces crosstalk when multiple signals at different wavelengths are amplified by a single SOA and makes the SOA unsuitable for amplifying WDM signals.

The XGM WC has the advantage that it is conceptually simple to assemble. It is polarization-insensitive because the gain of SOA is polarization-independent. However, there are several drawbacks, such as inversion of the pump input signal and the relatively large chirp of the probe output signal due to the large gain modulation. Additionally, the achievable extinction ratio (ER) is small (< 10 dB) since the gain does not really drop to zero when there is an input high logic state bit. The input signal power must be high (around 0dBm) so that the amplifier is saturated enough to produce a good variation in gain, as shown in Fig. 3.2(b). This high-powered signal and probe are counter-propagating. Moreover, as the carrier density within the SOA varies, it changes the refractive index as well, which in turn affects the phase of the probe and creates a large amount of pulse distortion. To sum up, the SOA-based WC using XGM, which is simply made up of a SOA, has the demerits that the wavelength-converted output signal is inverted with large chirp, low ER, and a lot of distortion.

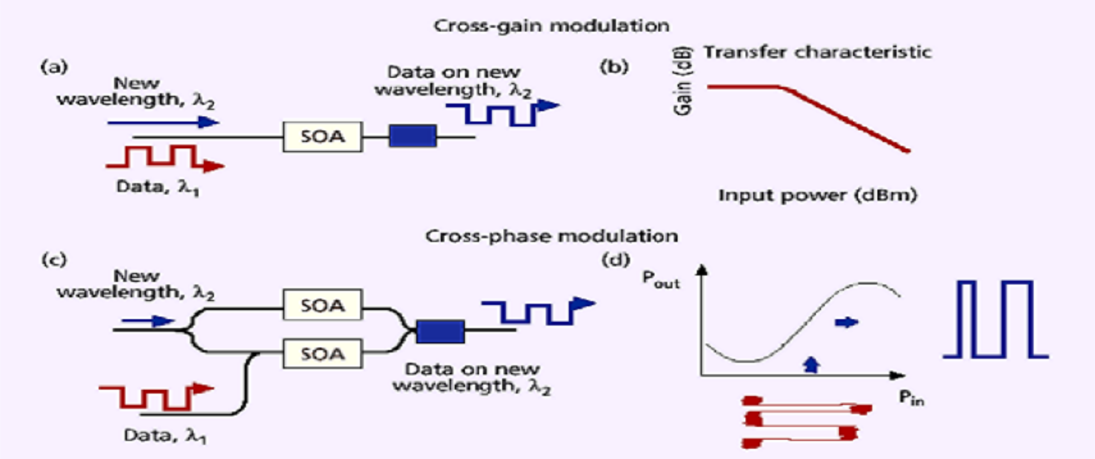

Fig. 3.2 Schematic diagrams and transfer characteristics of SOA-based WC using (a)(b) XGM and (c)(d) XPM.

The same phase-change effect that creates pulse distortion in XGM can be used to effect wavelength conversion. As the carrier density in the amplifier varies with the input signal, it produces a change in refractive index, which in turn modulates the phase of the probe. This phase modulation can be converted into intensity modulation by using an interferometer such as Mach-Zehnder interferometer (MZI). Fig. 3.2(c) shows one possible configuration of a SOA-MZI WC using XPM. Both arms of the MZI have exactly the same length and incorporate an SOA. The signal is sent in at one end and the probe at the other end. If no signal is present, then the probe signal comes out unmodulated. When the signal is present, it induces a phase change in each amplifier. The couplers in the MZI are designed with an asymmetric coupling ratio. This makes the phase change in each amplifier different. This results in an intensity-modulated probe signal at the output. The transfer characteristics curve is shown in Fig. 3.2(d). To sum up, the SOA-MZI WC using XPM, which is composed of two SOA's in the structure of MZI, has the advantages that non-inverted output signal is achieved with high ER. However, it has a critical drawback that input power dynamic range (IPDR) is too narrow to be 3~4 dB at 10 Gb/s.

3.4 Cross gain modulation in semiconductor optical amplifier

The rate of stimulation imission in an SOA is dependent on the optical input power. At high optical injection, the carrier concentration in the active region is depleted through stimulated emission to such extent that gain of the SOA is reduced. This effect is known as gain saturation and typically occurs for input power of the order of 100uW or more.

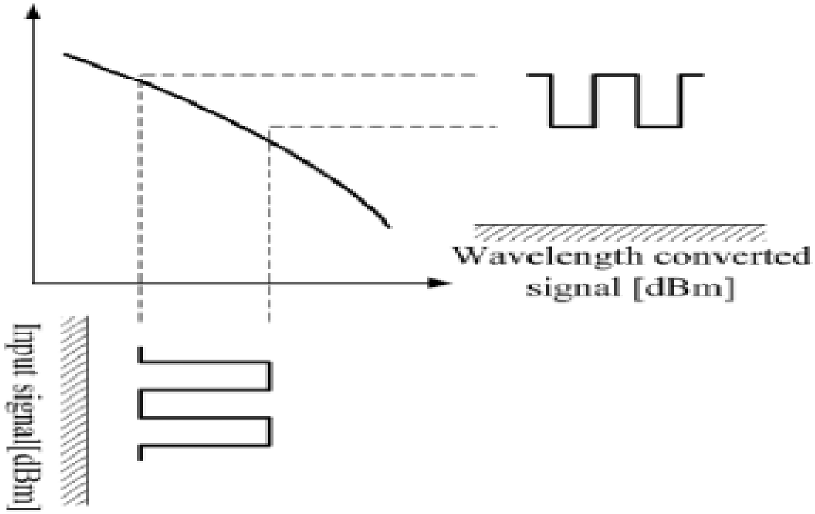

Fig 3.3 transfer curve of XGM

3.4.1 Basic principle and characteristics of XGM

The wavelength convertion technique is implemented by the use of gain saturation mechanism . The two optical signals enter a single SOA with one carrying amplitude modulated data and other signal is of constant power (CW). If the peak optical power in the modulated signal is near the saturation power of the SOA, the gain will be modulated in synchronism with the power excursions. When the data signal is at a high level (a binary1), the gain is depleted, and vice versa. This gain modulation is imposed on the unmodulated input beam. Thus, an inverted replica of the input data is created at the target wavelength.

However, a lot of research is under process for limiting the carrier life time around tength of picoseconds so that conversion rate could go beyond 10Gbps.

By using the high optical injection the carrier life time can be decreased up to 1/100th of nanoseconds along with the tradeoff of simultaneously arising non linearities. Under high optical injection the rate of stimulated emission in the SOA increases and this can reduce the effective life time to as low as 10ps that enables us to process the signal with 80Gbps and even more.

There are two propagation schemes by which the signal can be injected into the SOA for wavelength conversion mechanism which are given as:

1) Co-propagation scheme.
2) Counter propagation scheme.

These are shown in fig. 3.3

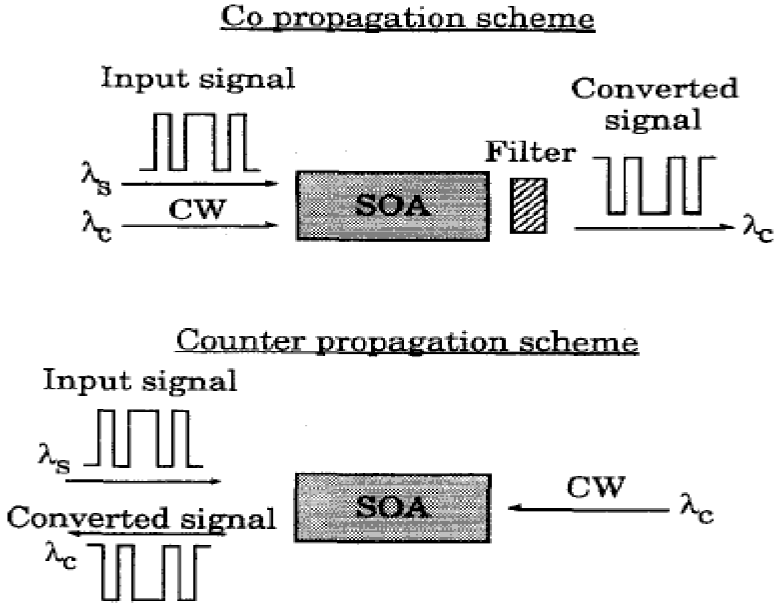

Fig. 3.3 propagation scheme.

In this thesis, co-propagation scheme is used in SOA-XGM because of its uniform increase in the modulation spectrum intensity over the entire frequency range which qualitatively agrees with our experimental result. At a rate of 10Gb/s, the inverted output will have some distortion as correspond to the input signal because of less lifetime of a carrier. When the rate of signal in wavelength conversion mechanism go beyond 40Gb/s then the signal excursion at a transition state will get affected and the waveform at the output end will be distorted more.

3.4.2 Application of XGM-SOA

XGM-SOA can be used in following applications:

1) Switching and routing
2) DWDM
3) Logic functions
4) Optical pattern matching networks
5) Add/drop multiplexer

3.4.2.1 switching and routing

Optical packet switching and routing promises to bring the flexibility and efficiency of internet to transparent optical networking with bit rate extending beyond the currently available with electronic router technologies. New optical signal processing have been demonstrated that enable the routing at bit rates from 10Gb/s to beyond 40Gb/s which is designed in this thesis. We review these signal processing technique and how all optical wavelength converter technique can be used to implement optical switching and routing application.

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3.4.2.2 Dense wavelength division multiplexing

Dense wavelength division multiplexing (DWDM) originally to optical signal multiplexed within the 1550nm band so as to leverage the capability and cost of EDFA which are effective for wavelength between approximately 1525-1565 nm (c band)or 1570 to 1610 nm L band.

Optical DWDM can cater the need of to days problem in efficient use of available bandwidth with coast effective mechanism. The huge bandwidth find in optical fiber is now satisfying the network demands. Due to the multiplicity on the connection on any single link, fault tolerance is of almost important in such DWDM network. Active research on providing fault tolerance in WDM networks in recent times underscores its significance.

In this thesis a small subsystem of DWDM system is designed with the rate of 40gb/s that can efficiently be used in network ultra fast integration, routing and switching application.

3.4.2.3 All-optical Composite Logic Gates

For many years, there have been prospects to realize all-optical computers using digital optical elements. As compared with electronic gates, optical elements lack the packing density because interaction length of electrons is much shorter than that of photons. Nevertheless, it is very practical to aim at simple optical-signal processing in telecommunication networks. The all-optical processing is especially attractive in the high-capacity core networks where we want to avoid inefficient opto-electronic conversion. All-optical logic devices required in OADM and OXC perform networking functions, such as addressing and header recognition, data encoding and encryption, pattern matching, etc.

In order to realize the devices, various configurations of optical logic gates have been reported that utilize the ultrafast non-linear properties of SOA's, including from single SOA structure using cross gain modulation (XGM) to interferometric structures, such as terahertz optical asymmetric demultiplexer (TOAD) and ultrafast nonlinear interferometer (UNI). These schemes have been shown to have some advantages, but they are difficult to control or construct and polarization states or random phase changes are critical for their output performance. Among them, SOA-MZI structure using XPM is the most promising candidate due to its attractive features of low energy requirement, simplicity, compactness by integration capability, and stability. In addition, it has the merits of high ER, regenerative capability, high speed operation, and low chirp.

So far, all-optical AND and XOR gates using SOA-MZI structure have been investigated, and all-optical NAND gate using SOA-MZI structure has not yet been reported. The all-optical AND gate is one of the fundamental logic gates because it is able to perform the bit-level functions such as address recognition, packet-header modification, and data-integrity verification [36]. The all-optical XOR gate is a key technology to implement primary systems for binary address and header recognition, binary addition and counting, decision and comparison, encoding and encryption, and pattern matching.

CHAPTER 4

DESIGN OF WAVELENGTH CONVERTER AT40GB/S

4.1 INTRODUCTION

All optical wavelength conversion is the key component in the future broadband network since they are reconfigurable and helps to reduce the blocking probability in a wavelength routed networks. As far as the wavelength conversion phenomenon are concerned, there are lots of technique through which this conversion can be done. Wavelength conversion using XGM is preferred because it has several advantages over the other techniques such as its simplicity, high conversion efficiency, polarization efficiency, polarization independence and insensitivity the wavelength of the input data (provide within the SOA gain bandwidth). Polarization independency property of XGM makes its presence more important in fiber based system as it is unable to maintain its polarization of signal. This polarization insensitivity property of XGM can be used in developing a DWDM system, routing subsystem, logic gate etc. here in this chapter a wavelength conversion system is designed at a rate of 40 Gb/s at the best power efficiency.

4.2 Principle and simulation setup of XGM SOA

The principle of XGM-SOA wavelength conversion is earlier demonstrated in chapter 3 whixh define how the gain of an SOA will saturated and what phenomena is taking place in its band structure.

Here as shown in fig.4.1 the two optical signal enter a single SOA with one carrying amplitude modulated data signal and the other having the constant power. If the peak optical power in the modulated signal is near the saturation power of SOA,the gain will be modulated in synchronism with the power excursions. When the data signal is at a high level the gain would get depleted and vice- versa. This gain modulation is imposed on the un-modulated input beam and thus, an inverted replica of the input data is created at the same target wavelength.

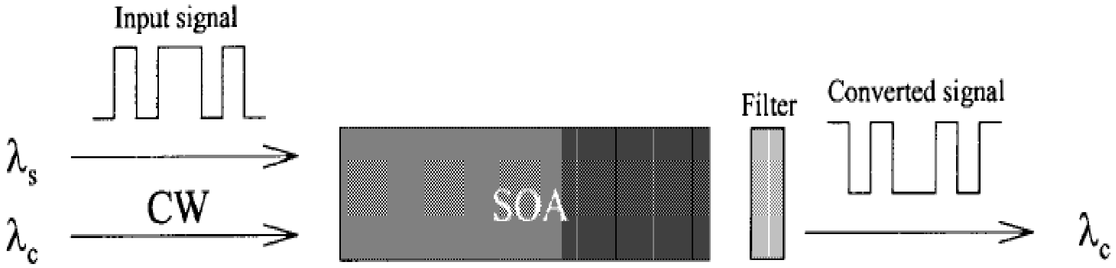


Fig.4.1 model schematic of XGM

Simulation-setup of XGM-SOA wavelength conversion is shown in which the signal of wavelength 1550nm is being generated through continuous wave loretzian laser and converted to 1549nm wavelength through cross gain modulation process.

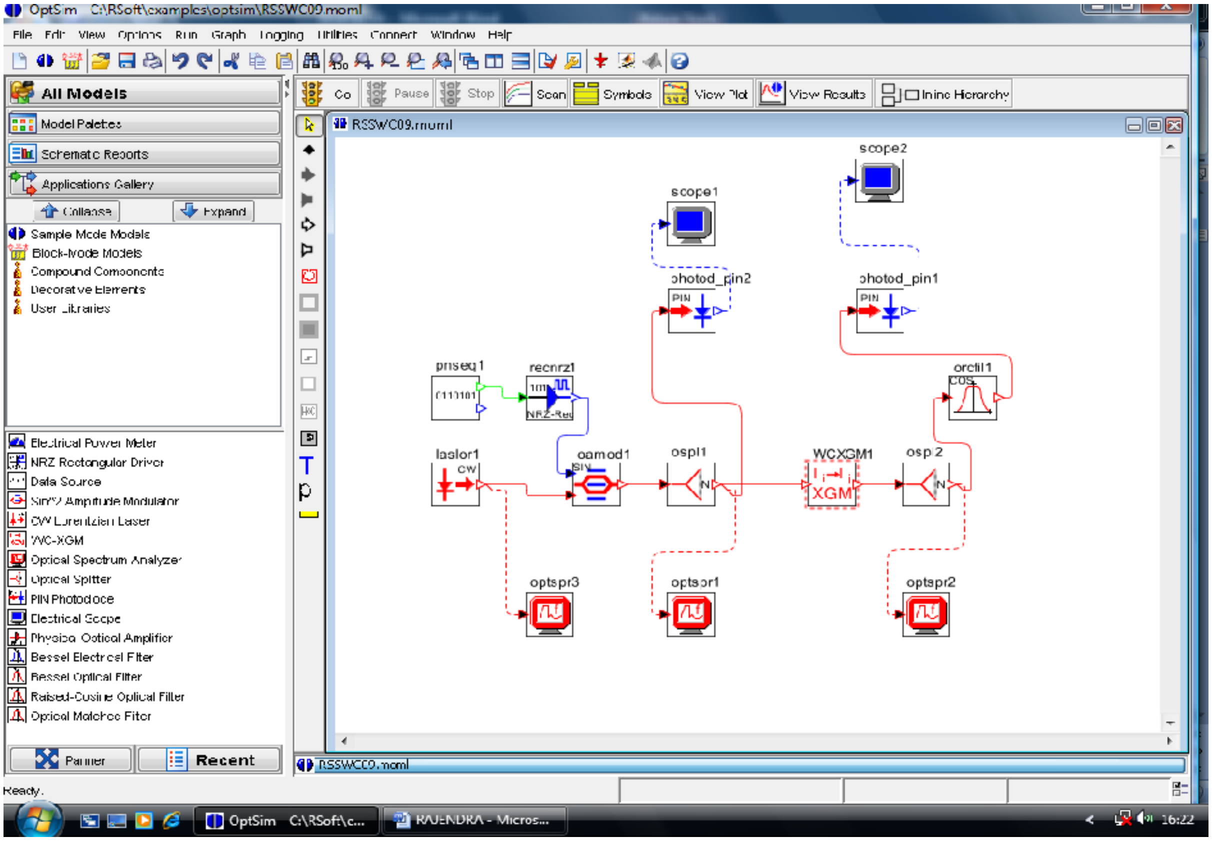


Fig4.2 Simulation set-up of Cross gain modulation based wavelength conversion

The efficiency of conversion is enhanced by proper filtering of input signal by $\sin^2$ Mach-Zehnder amplitude modulator having a chirp factor of 0.0(idealy) and extinction ratio of 25db, which modulates the input optical signal of lorenzian laser by generating the NRZ electrical signal. The $\sin^2$ Mach-Zenhder modulator which is used in simulation experiment is based on electro-optic effect in the $LiNbO_3$.

The signal output of the sin^{2}MZ modulator is divided by optical splitter. With equal input output loss, one for having the response in term of eye diagram in electrical domain and other for wavelength conversion through XGM block, which is composes of SOA, having a confinement factor of 0.4 with 3.0db input and output insertion loss. The output wave which comes out by XGM by increasing the biasing current will have a saturation power of few miliwatts which is particularly required in wavelength division multiplexing (WDM) application to avoid crosstalk to arising from gain saturation effect

The saturation power of an SOA can be found out by eq 4.4.this 1549nm converted signal can directly be analyzed on optical signal spectrum analyzer through PIN diode ,having a quantum efficiency and responsivity of 0.7 and 0.8752 with the limitation of dark current 0.1nA that ensure the proper conversion with high efficiency. The Bessel filter used here is a one type of low pass filter that has central frequency of 3.75GHz with -3db bandwidth of 1 GHz which ensure reliable transfer of information by filtering the high frequency noise having a role factor 0<ά<1 that define the width of middle frequency.

The main disadvantage of this method are substantial phase distribution due to frequency chirping ,degradation due to spontaneous emission, and a relatively low extinction ratio.

$$P_o=(A/£)I_{ou} \qquad \text{………..(4.4)}$$

Where ,I_{ou}=hυ/ật

Where h: Planck's constant.
υ: signal optical frequency
ậ: differential model gain
t : spontaneous carrier lifetime
A: active region cross section area
£: optical confinement coefficient.

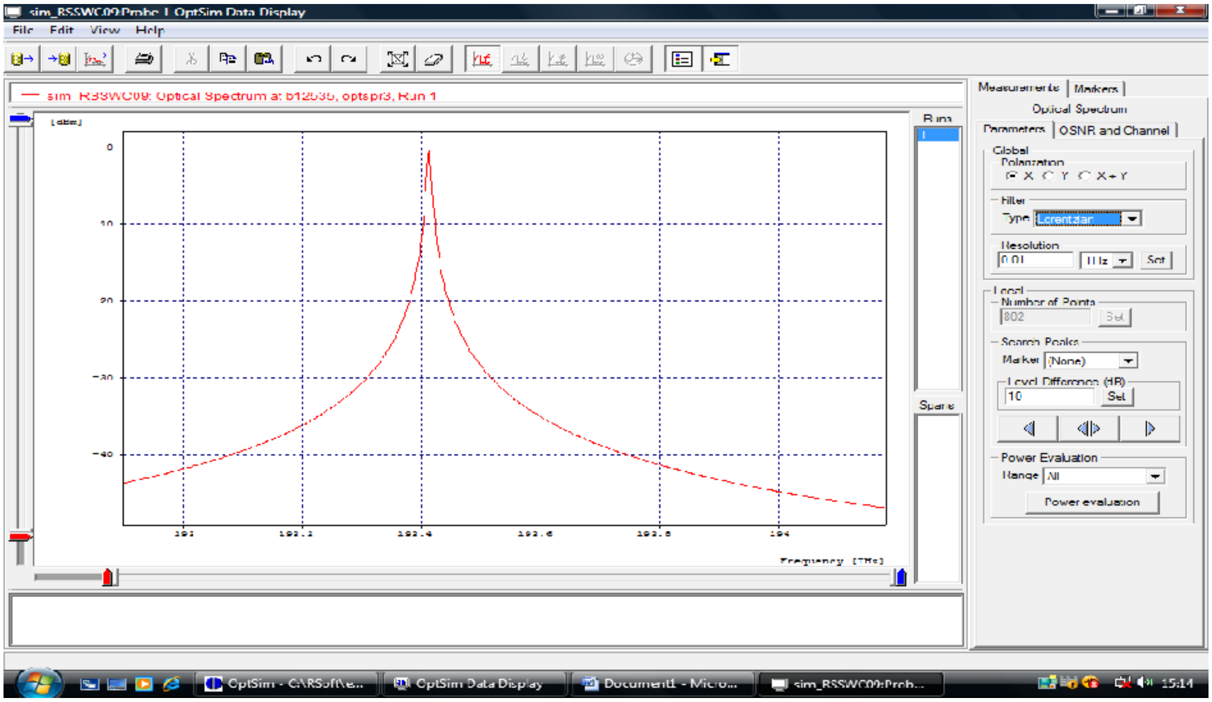
4.3 Frequency response of XGM-SOA

The frequency response of XGM-SOA is obtained by changing the carrier life time for a biasing current constant. This is done for different level of biasing current and carrier life time at which the signal of waveform 1550nm is to be converted to 1549nm with high power content so that receiver would be able to receive it efficiently rather employing the amplifier to boost it up at the receiving level. Power evaluation is not only the factor for choosing it for 40Gb/s conversion rate but the efficiency of conversion is given the highest priority i.e. without any extra wave noise intended one.

Table 4.1 power evaluation at different carrier life time

SOA (I bias)mA	Carrier lifetime(ns)	Power evaluation(db)
10	0.2	12.691227
	0.4	14.893914
	0.6	16.667427
	0.8	17.999187
	1.0	18.969349
20	0.2	15.05597
	0.4	18.822769
	0.6	21.131641
	0.8	22.456974
	1.0	23.264635
40mA	0.2	19.425360db
	0.4	24.224054db
	0.6	26.041746db

	0.8	26.898990db
	1.0	26.896999 db
80mA	0.2	25.833109db
	0.4	29.341633db
	0.6	30.283135db
	0.8	29.065924db
	1.0	29.349669db



sim_RSSWC09: Optical Spectrum at b12535, optspr3, Run 1

Polarization: ● X ○ Y ○ X+Y

Type: Lorentzian

Resolution: 0.01 THz

Number of Points: 802

Marker: (None)

Level Difference (dB): 10

Range: All

Fig. 4.3 original laser output pulse at 1550nm

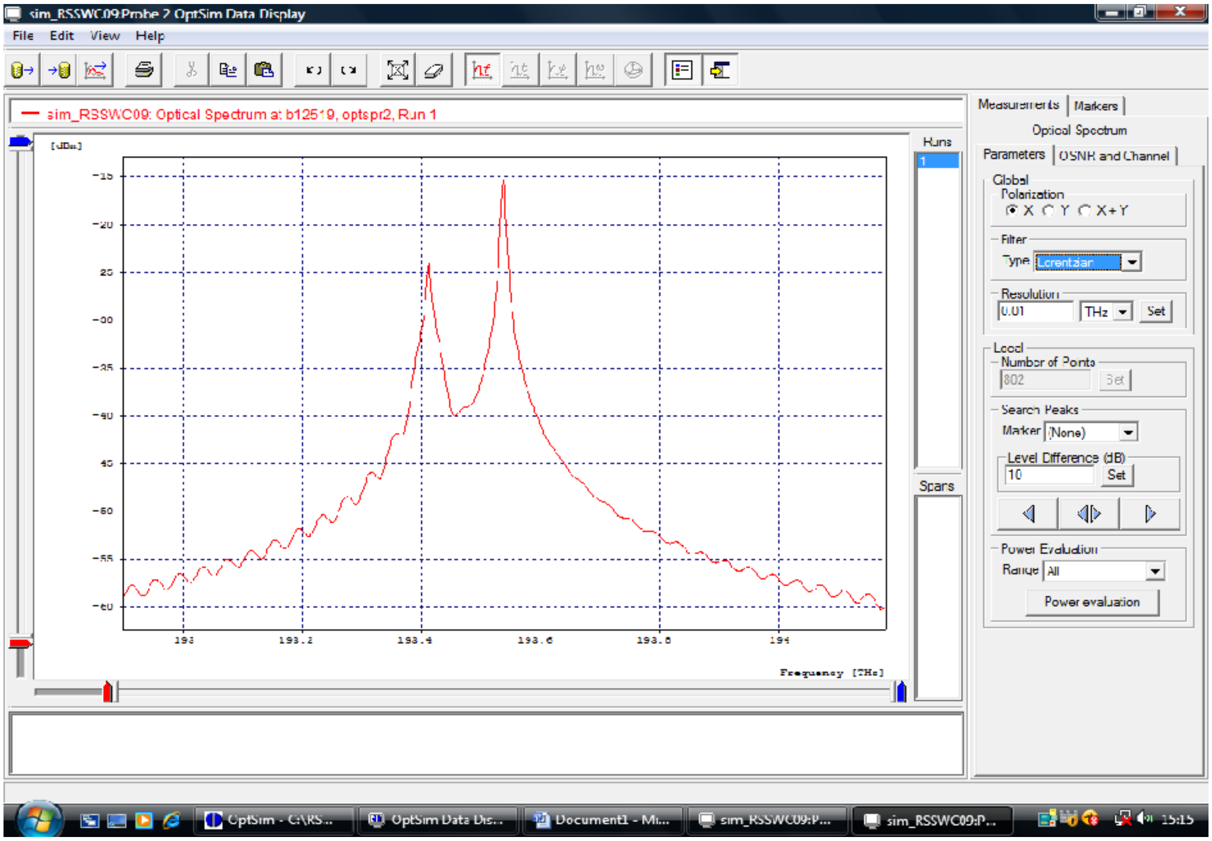
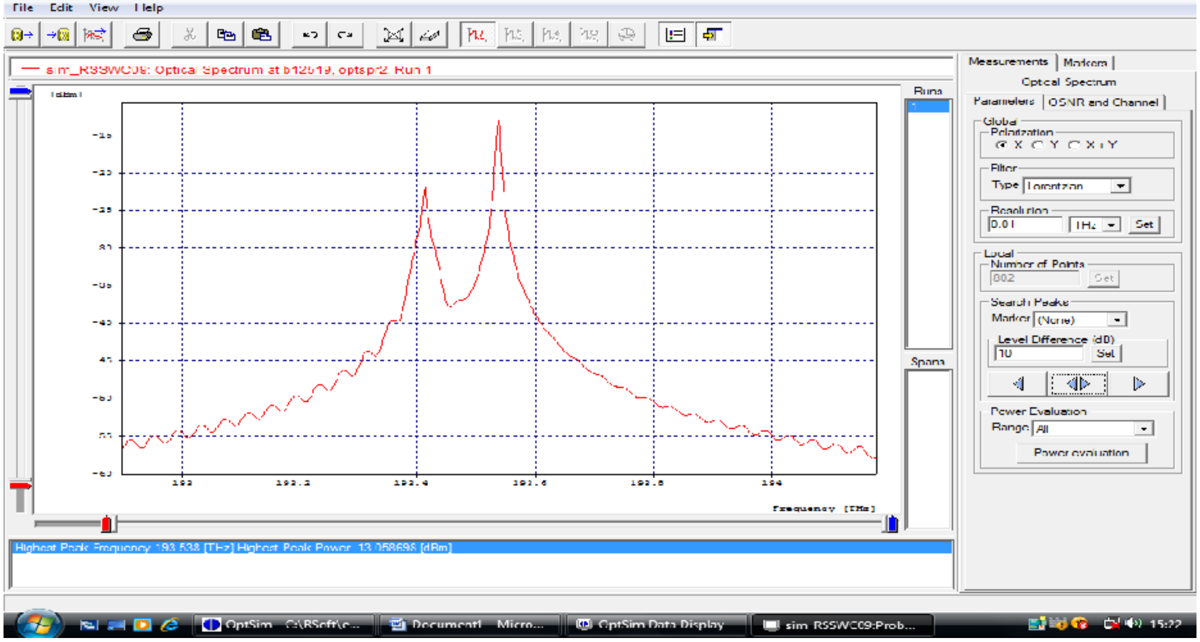


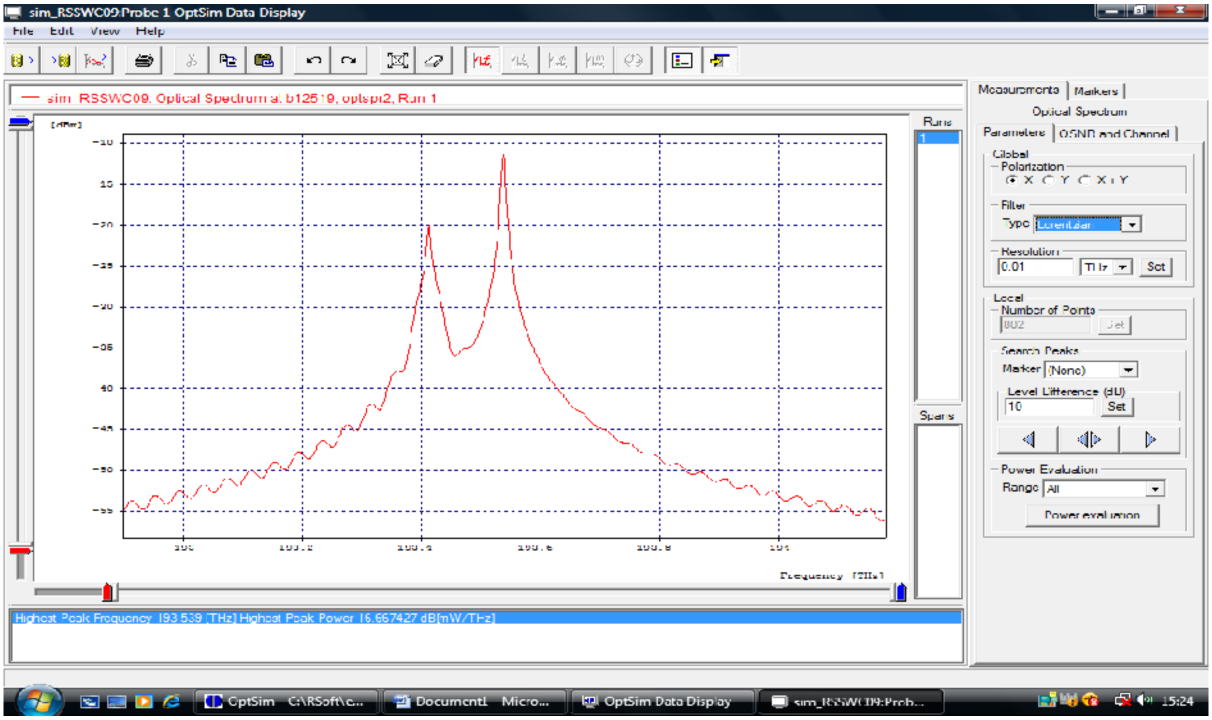
Fig.4.4wavelength converted signal at i=10mA,t=0.2ns



Highest Peak Frequency 193.538 [THz] Highest Peak Power 13.058698 [dBm]

Fig.4.5 wavelength conversion for I(BAIS)=10,t=0.4ns

[Type text]



sim_RSSWC09. Optical Spectrum at b12519, optspi2, Run 1

Global

Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz Set

Local

Number of Points 802 Set

Search Peaks

Marker (None)

Level Difference (dB) 10 Set

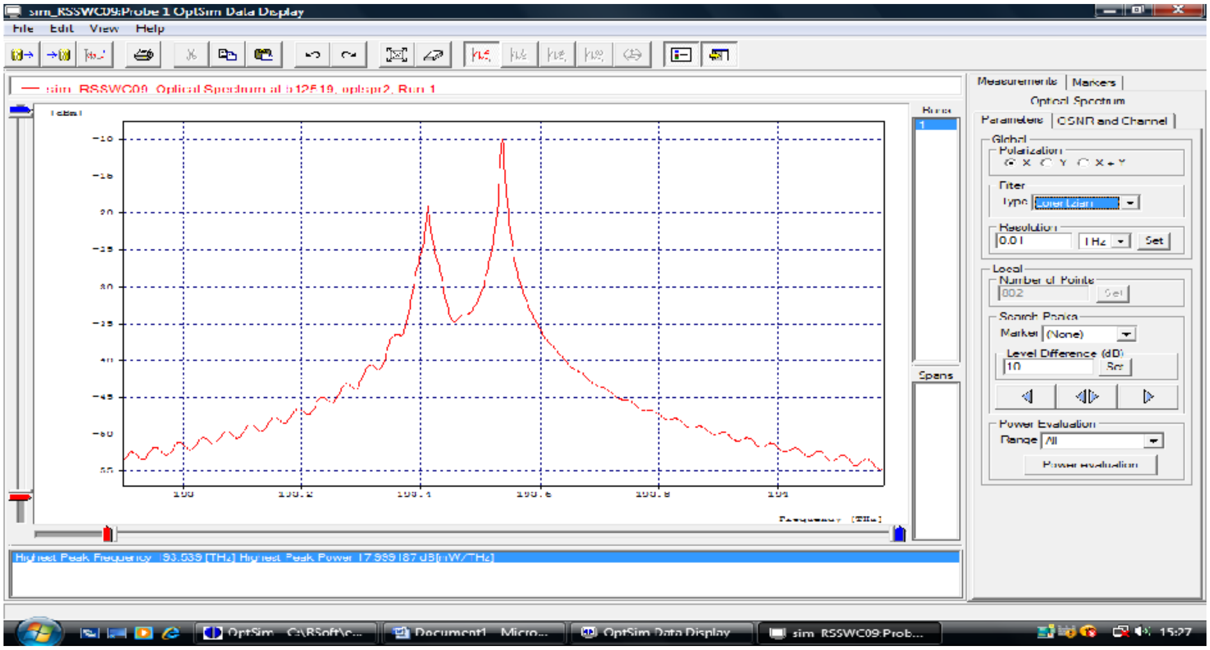
Power Evaluation

Range All

Power evaluation

```
Highest Peak Frequency 193.539 [THz] Highest Peak Power 16.667427 dB[mW/THz]
```

Fig.4.6 wavelength conversion at I(BAIS)=10mA,t=0.6ns



sim_RSSWC09. Optical Spectrum at b12519, optspi2, Run 1

Global

Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz Set

Local

Number of Points 802 Set

Search Peaks

Marker (None)

Level Difference (dB) 10 Set

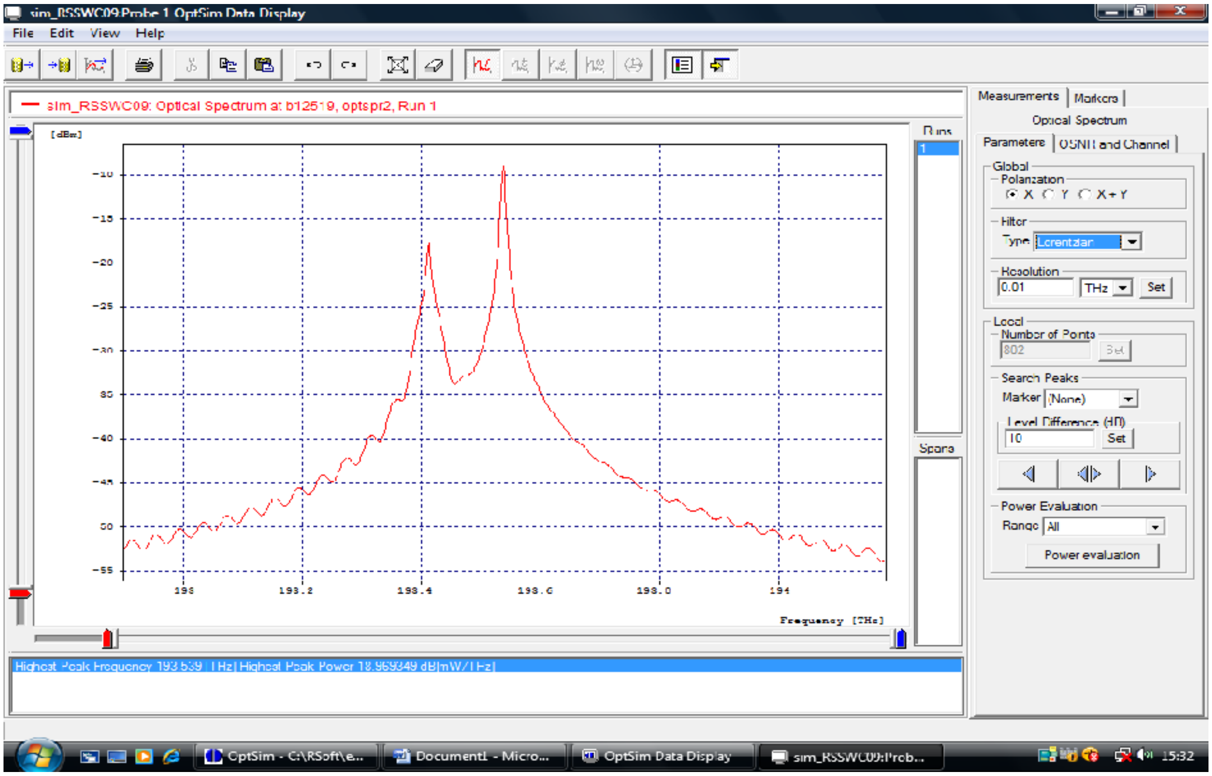
Power Evaluation

Range All

Power evaluation

```
Highest Peak Frequency 193.539 [THz] Highest Peak Power 17.989187 dB[mW/THz]
```

Fig.4.7 wavelength conversion at I(BAIS)=10mA,t=0.8ns



sim_RSSWC09: Optical Spectrum at b12519, optspr2, Run 1

Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz

Number of Points 802

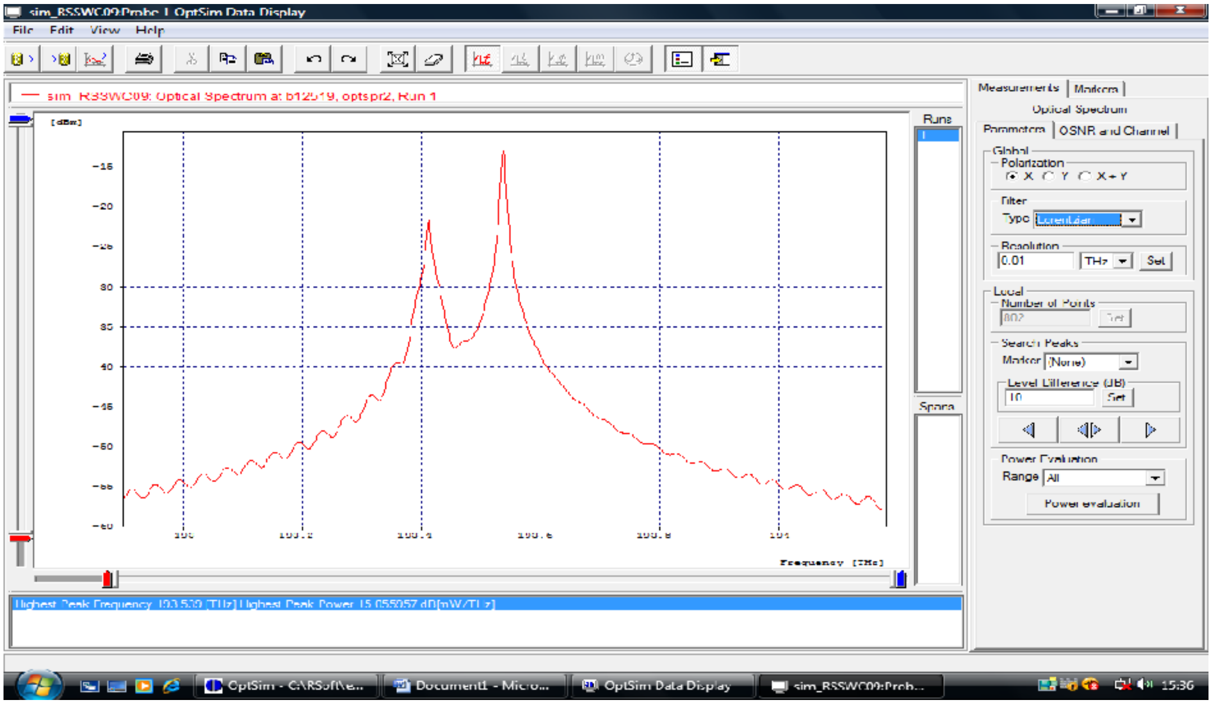
Marker (None)

Level Difference (dB) 10

Range All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 18.969349 dB[mW/THz]

Fig.4.8 wavelength conversion at I(BAIS)=10mA,t=1ns



sim_RSSWC09: Optical Spectrum at b12519, optspr2, Run 1

Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz

Number of Points 802

Marker (None)

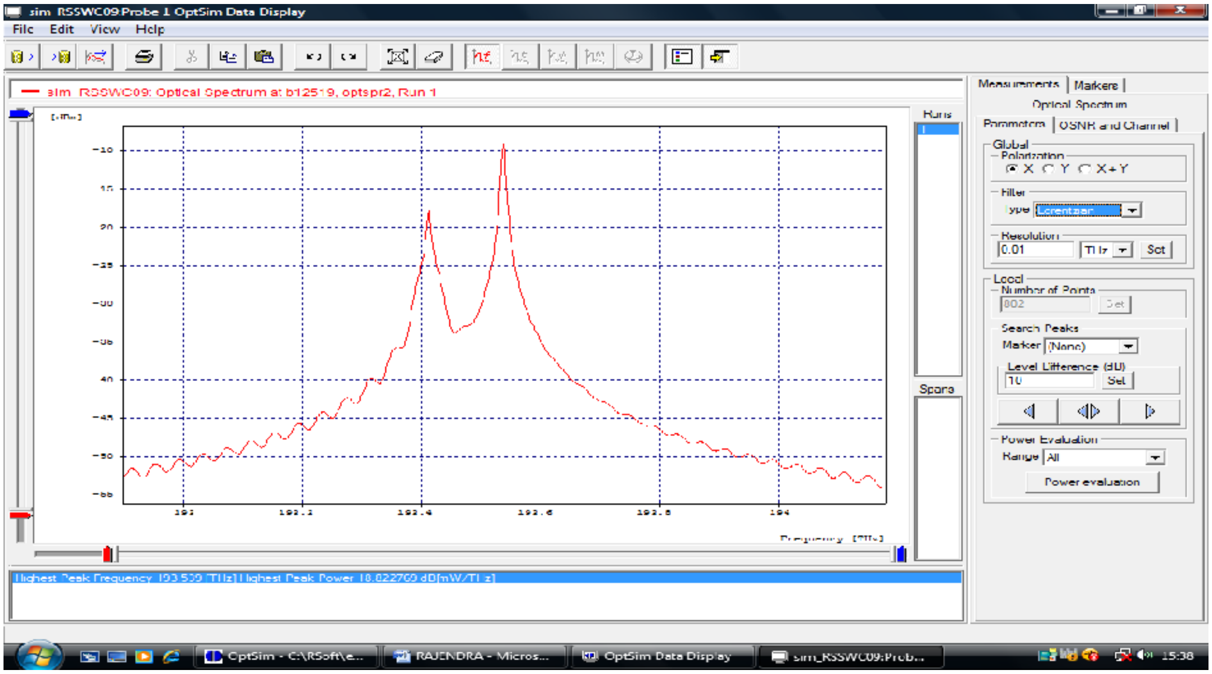
Level Difference (dB) 10

Range All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 15.055057 dB[mW/THz]

Fig.4.9 wavelength conversion at I(BAIS)=20mA,t=0.2ns

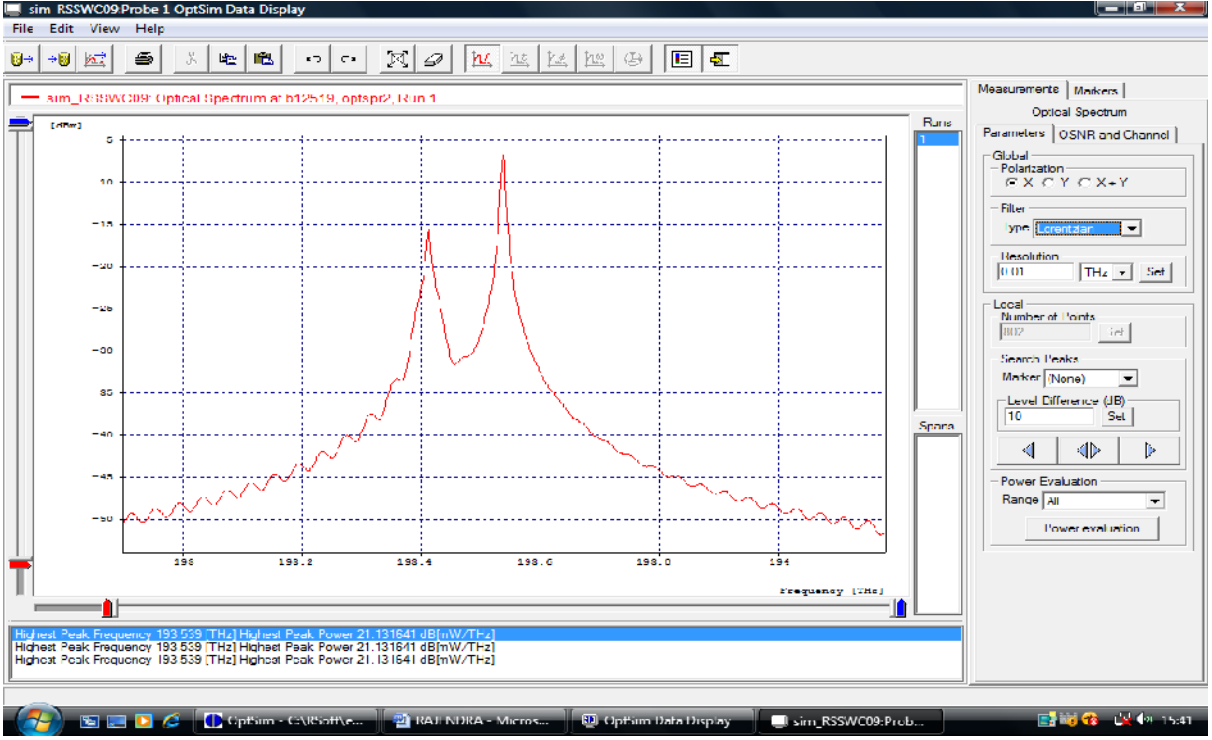
[Type text]



Polarization: ● X ○ Y ○ X+Y
Filter Type: Lorentzian
Resolution: 0.01 THz
Number of Points: 802
Marker: (None)
Level Difference (dB): 10
Range: All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 18.822769 dB[mW/THz]

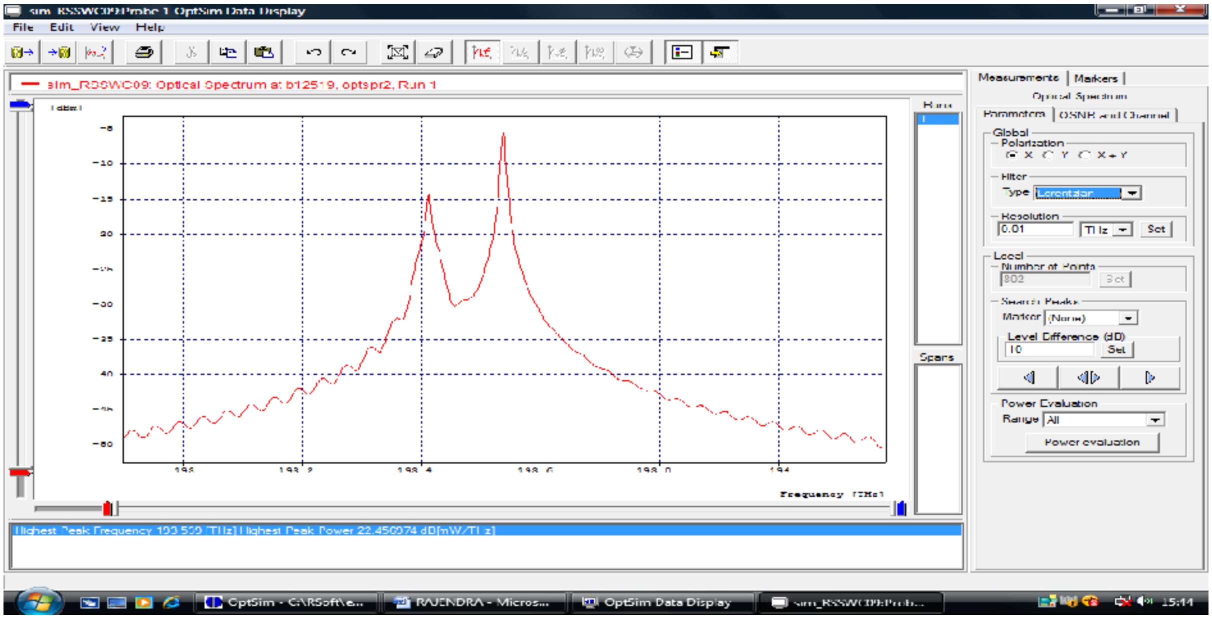
Fig. 9.10 wavelength conversion at I(BAIS)=20mA,t=0.4ns



Polarization: ● X ○ Y ○ X+Y
Filter Type: Lorentzian
Resolution: 0.01 THz
Number of Points: 802
Marker: (None)
Level Difference (dB): 10
Range: All

```
Highest Peak Frequency 193.539 [THz] Highest Peak Power 21.131641 dB[mW/THz]
Highest Peak Frequency 193.539 [THz] Highest Peak Power 21.131641 dB[mW/THz]
Highest Peak Frequency 193.539 [THz] Highest Peak Power 21.131641 dB[mW/THz]
```

Fig. 4.11 wavelength conversion at I(BAIS)=20mA,t=0.6ns



Filter Type: Lorentzian

Resolution: 0.01 THz

Number of Points: 802

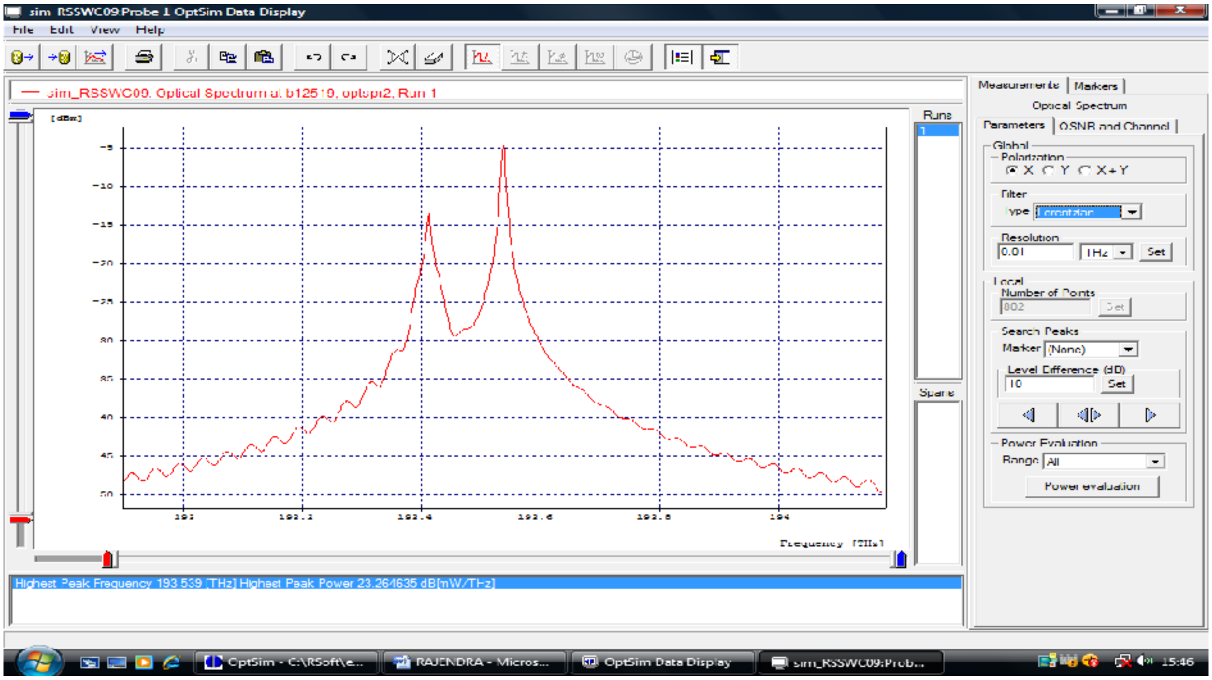
Marker: (None)

Level Difference (dB): 10

Range: All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 22.450974 dB[mW/THz]

Fig. 4.11 wavelength conversion at I(BAIS)=20mA,t=0.8ns



Filter Type: Lorentzian

Resolution: 0.01 THz

Number of Points: 802

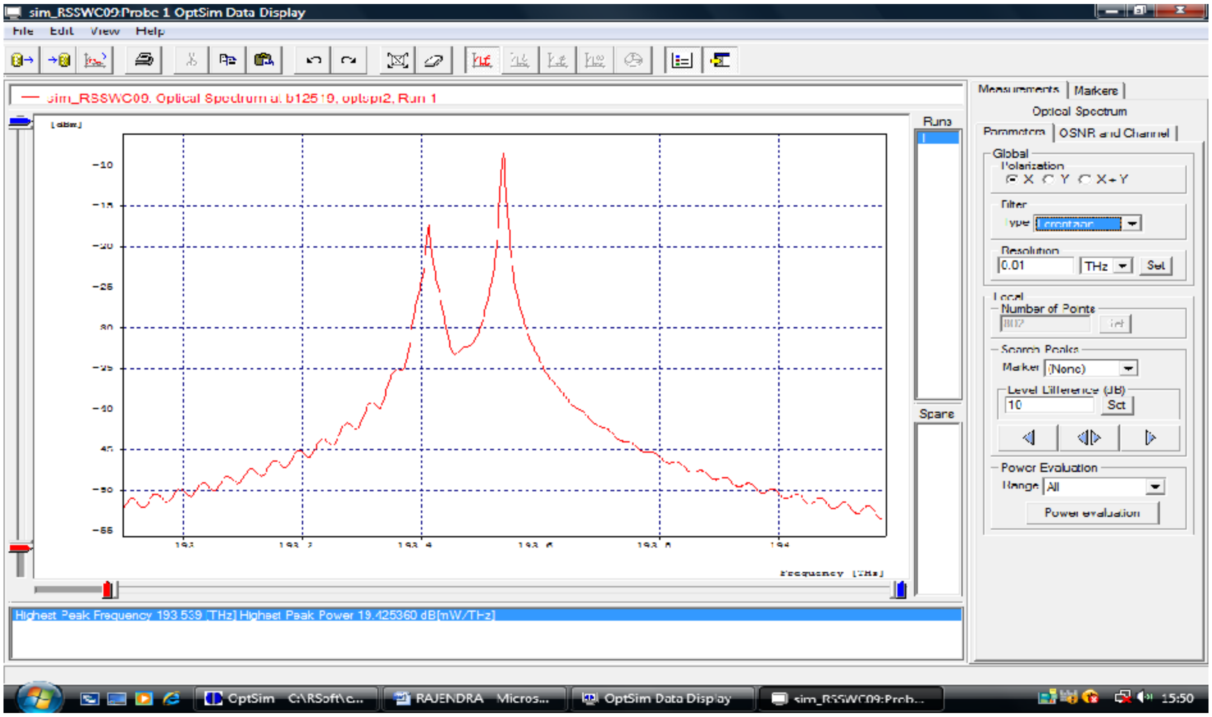
Marker: (None)

Level Difference (dB): 10

Range: All

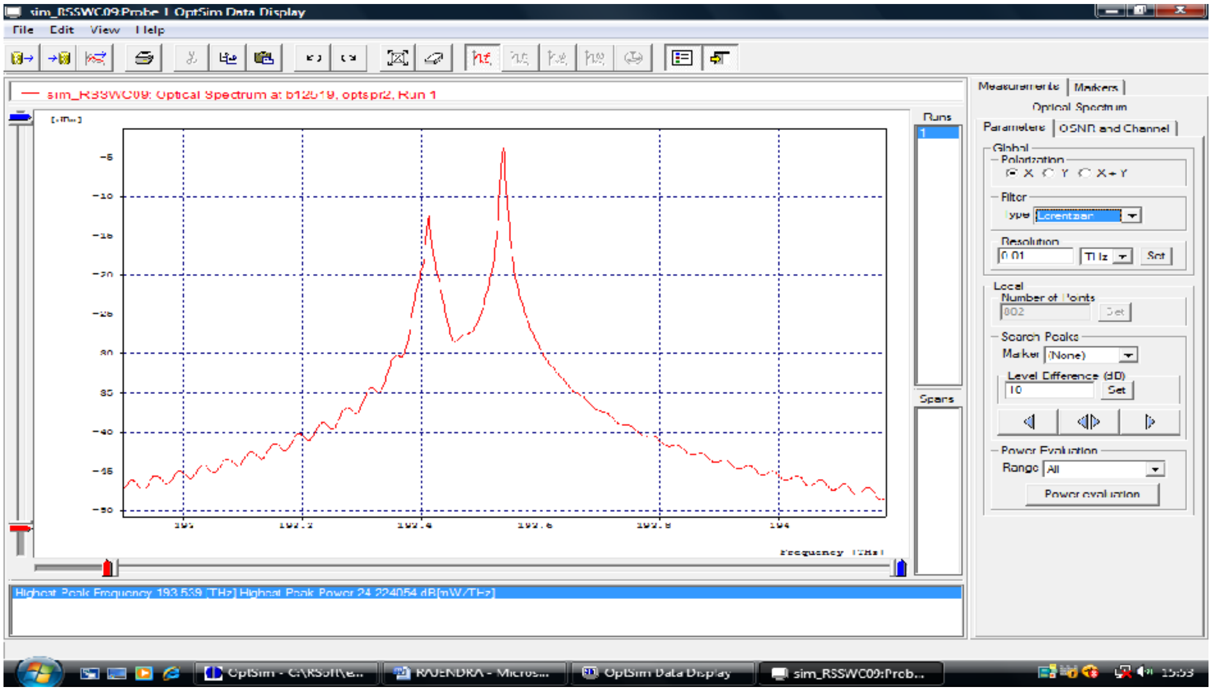
Highest Peak Frequency 193.539 [THz] Highest Peak Power 23.264635 dB[mW/THz]

Fig. 4.12 wavelength conversion at I(BAIS)=20mA,t=1ns



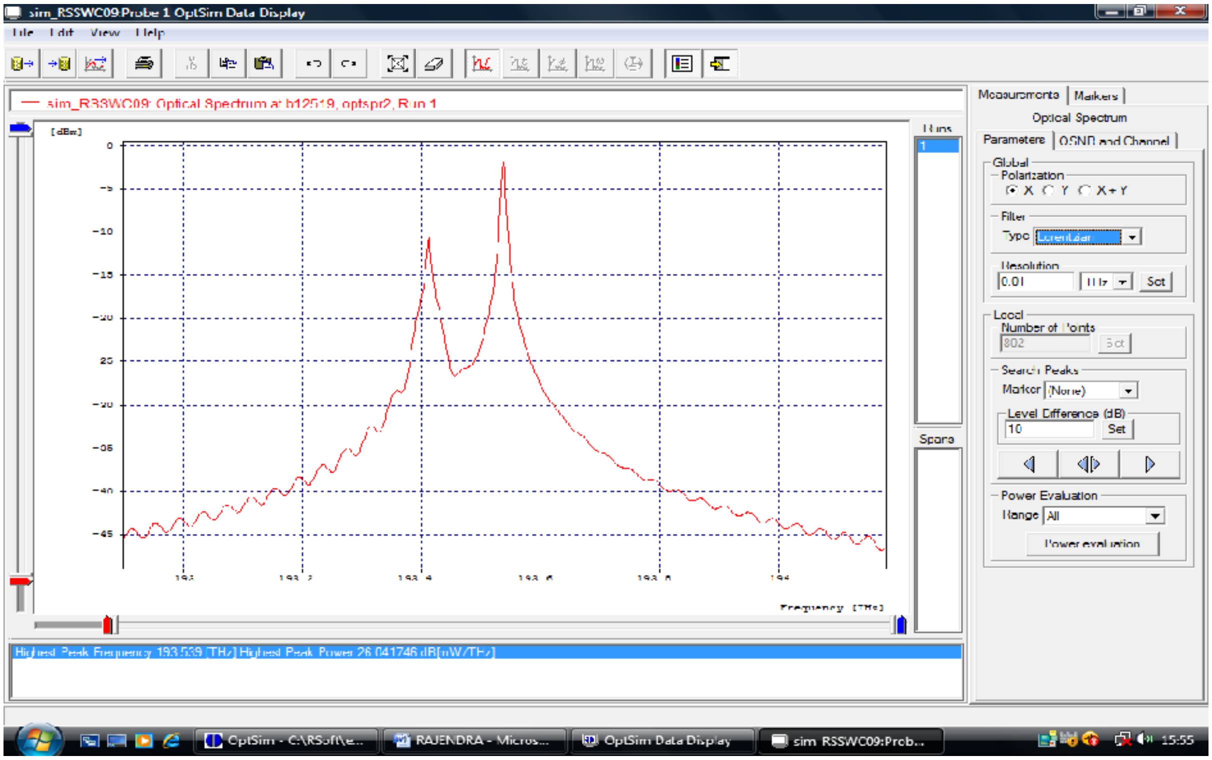
Highest Peak Frequency 193.539 [THz] Highest Peak Power 19.425360 dB[mW/THz]

Fig. 4.13 wavelength conversion at I(BAIS)=40mA,t=0.2ns



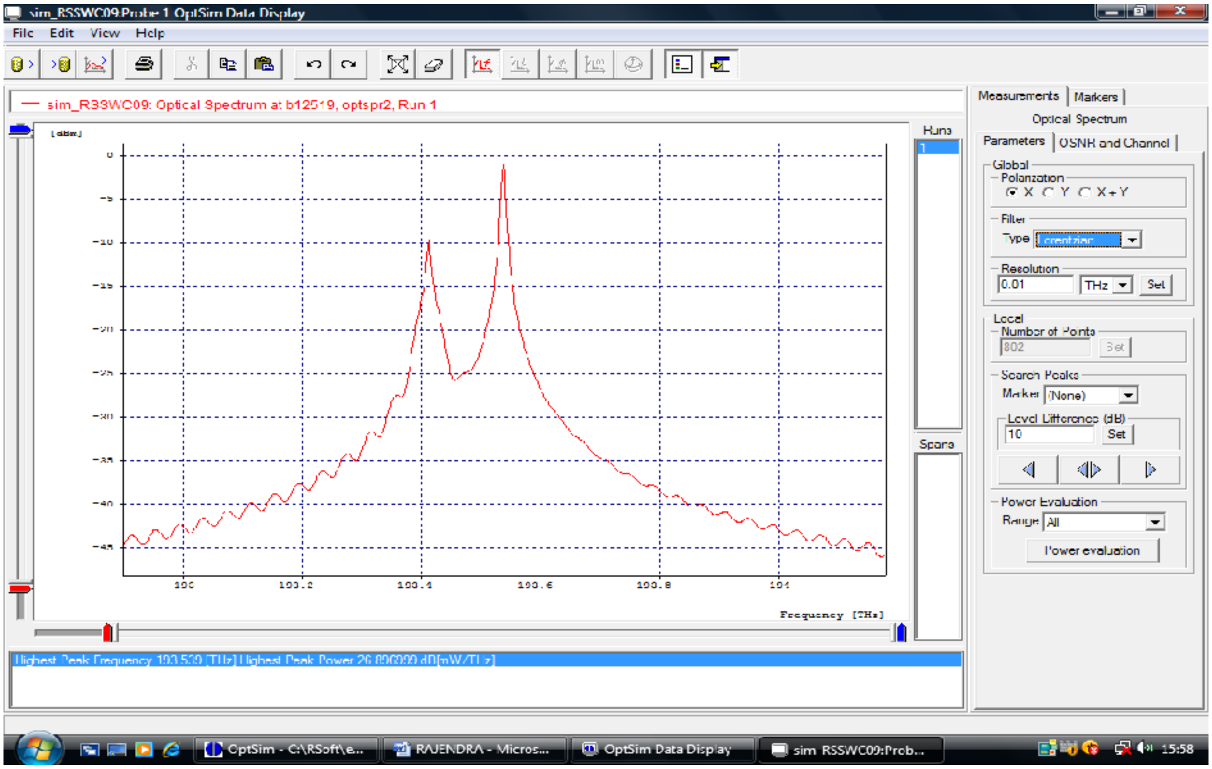
Highest Peak Frequency 193.539 [THz] Highest Peak Power 24.224054 dB[mW/THz]

Fig. 4.14 wavelength conversion at I(BAIS)=40mA,t=0.4ns



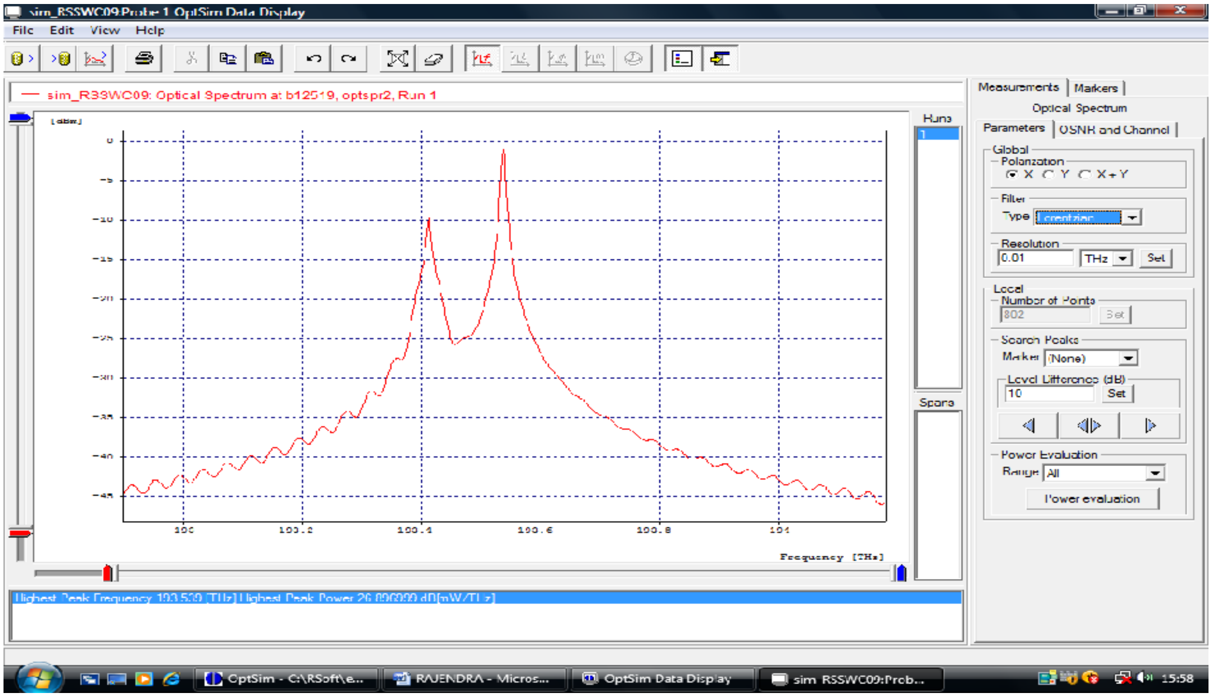
Highest Peak Frequency 193.539 (THz) Highest Peak Power 26.041746 dB[mW/THz]

Fig. 4.15 wavelength conversion at I(BAIS)=40mA,t=0.6ns



Highest Peak Frequency 193.539 [THz] Highest Peak Power 26.896090 dB[mW/THz]

Fig. 4.16 wavelength conversion at I(BAIS)=40mA,t=0.8ns



Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz

Number of Points 802

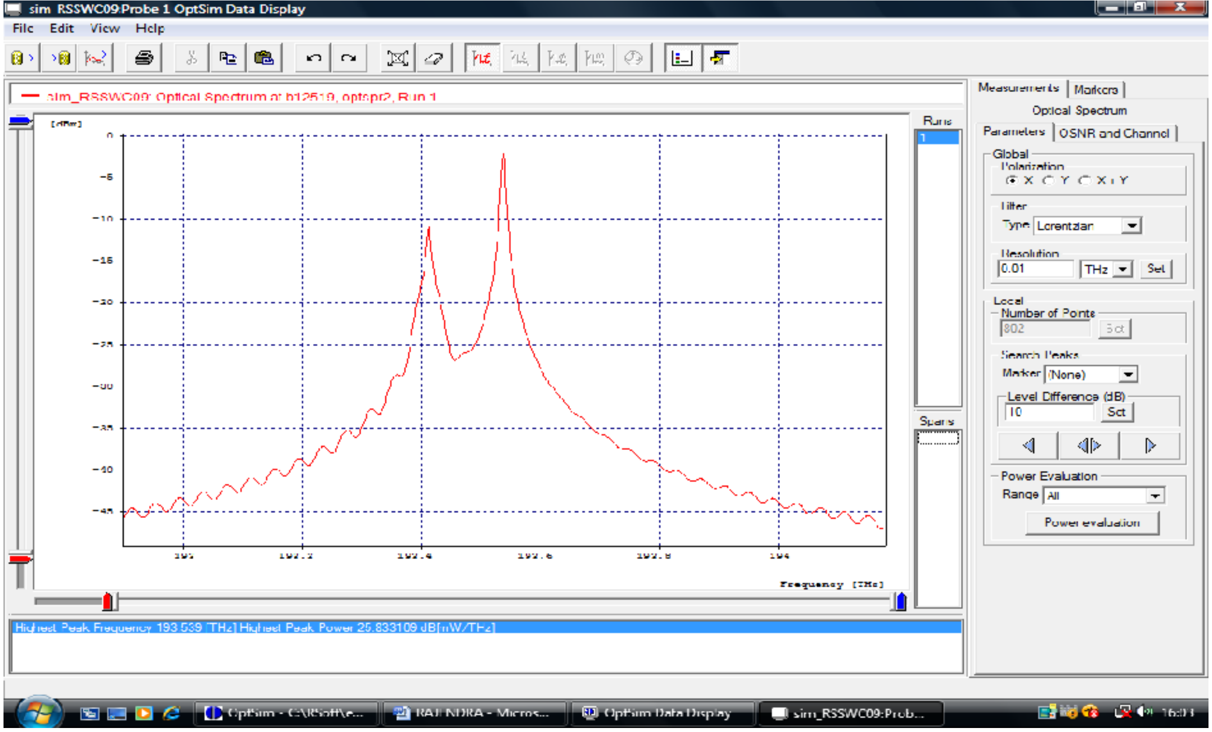
Marker (None)

Level Difference (dB) 10

Power Evaluation Range All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 26.896099 dB[mW/THz]

Fig. 4.17 wavelength conversion at I(BAIS)=40mA,t=1ns



Polarization ● X ○ Y ○ X+Y

Filter Type Lorentzian

Resolution 0.01 THz

Number of Points 802

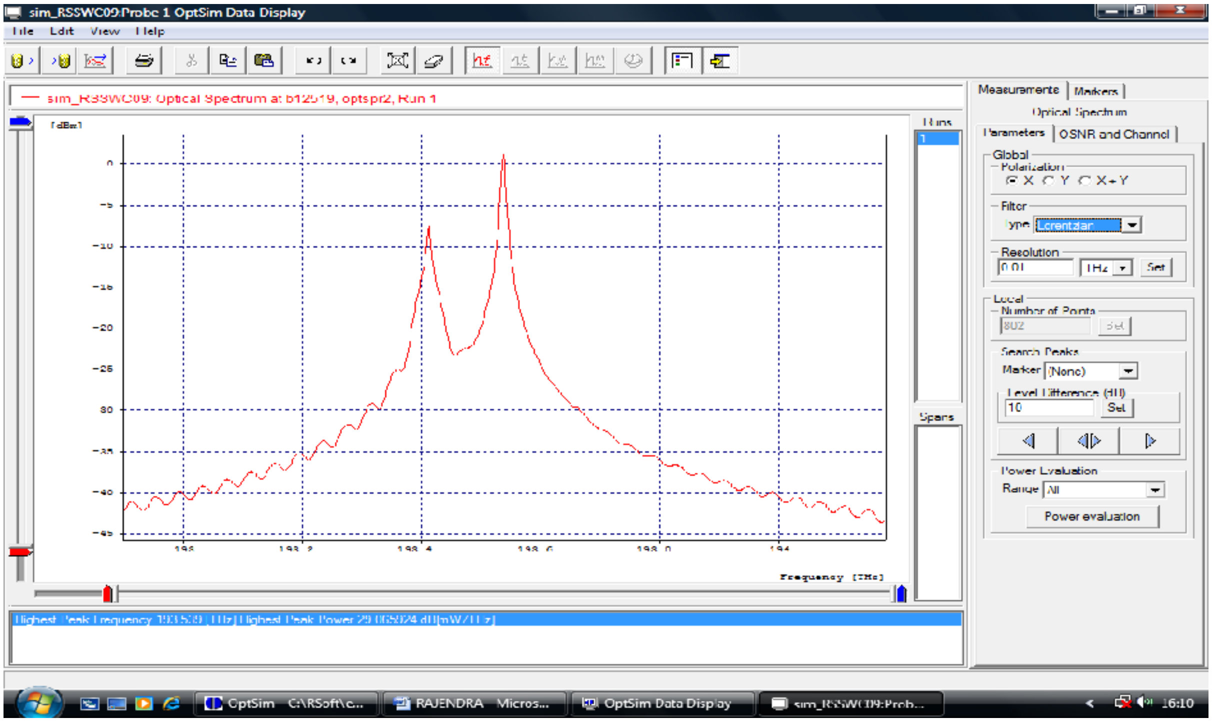
Marker (None)

Level Difference (dB) 10

Power Evaluation Range All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 25.833109 dB[mW/THz]

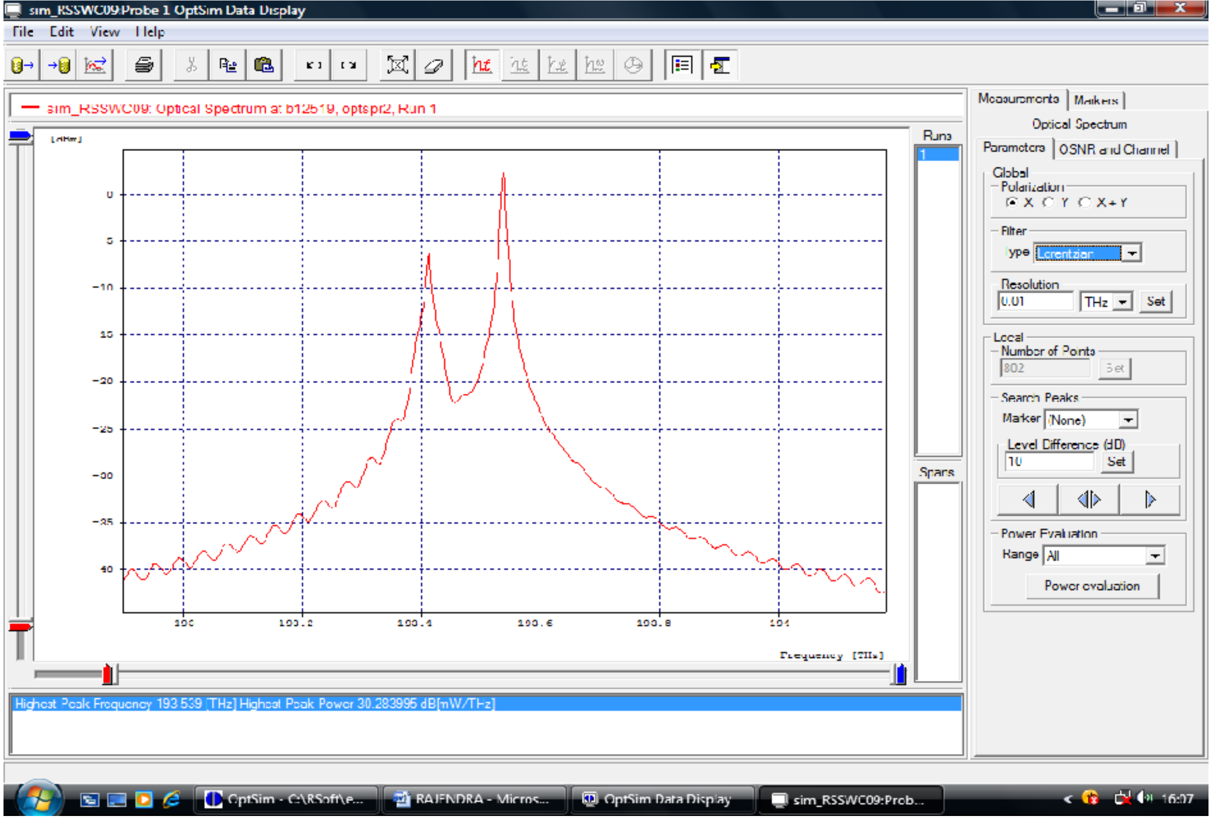
Fig. 4.18 wavelength conversion at I(BAIS)=80mA,t=0.2ns



Polarization: ● X ○ Y ○ X+Y
Type: Lorentzian
Resolution: 0.01 THz
Number of Points: 802
Marker: (None)
Level Difference (dB): 10
Range: All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 29.065024 dB[mW/THz]

Fig. 4.19 wavelength conversion at I(BAIS)=80mA,t=0.4ns

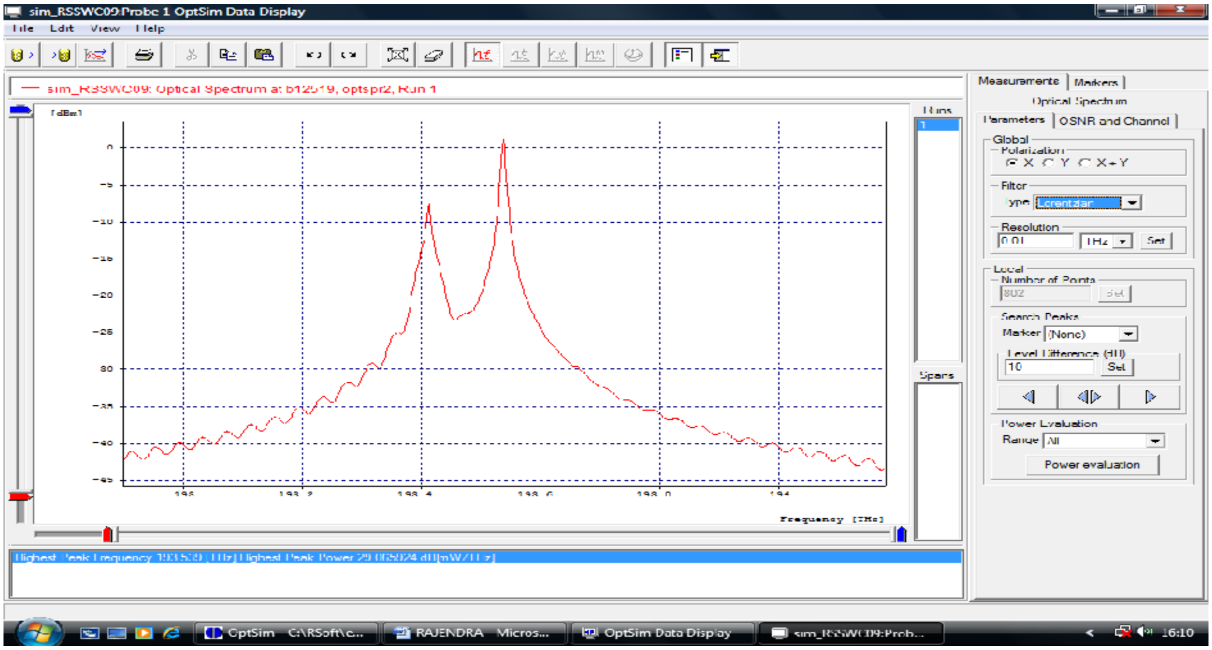


Polarization: ● X ○ Y ○ X+Y
Type: Lorentzian
Resolution: 0.01 THz
Number of Points: 802
Marker: (None)
Level Difference (dB): 10
Range: All

Highest Peak Frequency 193.539 [THz] Highest Peak Power 30.283995 dB[mW/THz]

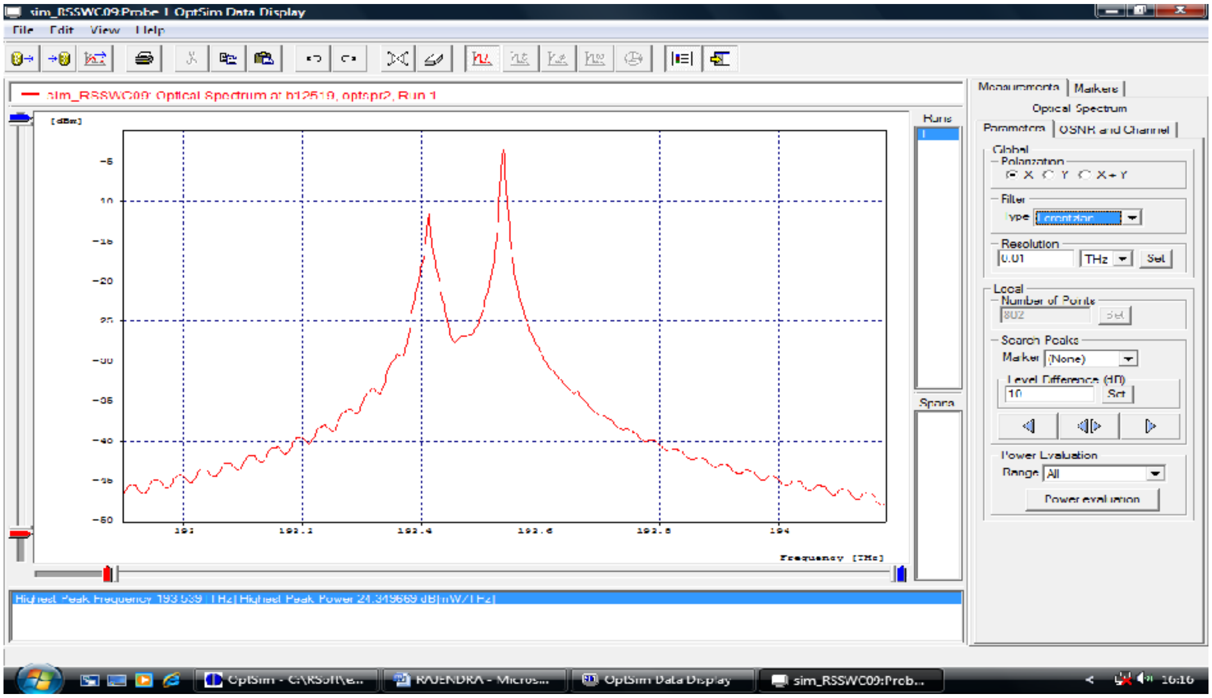
Fig. 4.20 wavelength conversion at I(BAIS)=80mA,t=.6ns

[Type text]



Highest Peak Frequency 193.539 [THz] Highest Peak Power 29.065024 dB[mW/THz]

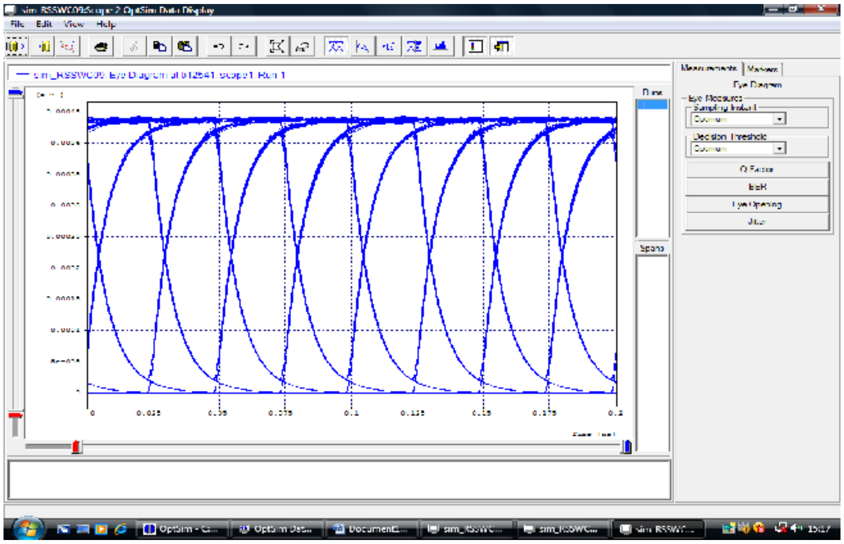
Fig. 4.21 wavelength conversion at I(BAIS)=80mA,t=0.8ns



Highest Peak Frequency 193.539 [THz] Highest Peak Power 24.349669 dB[mW/THz]

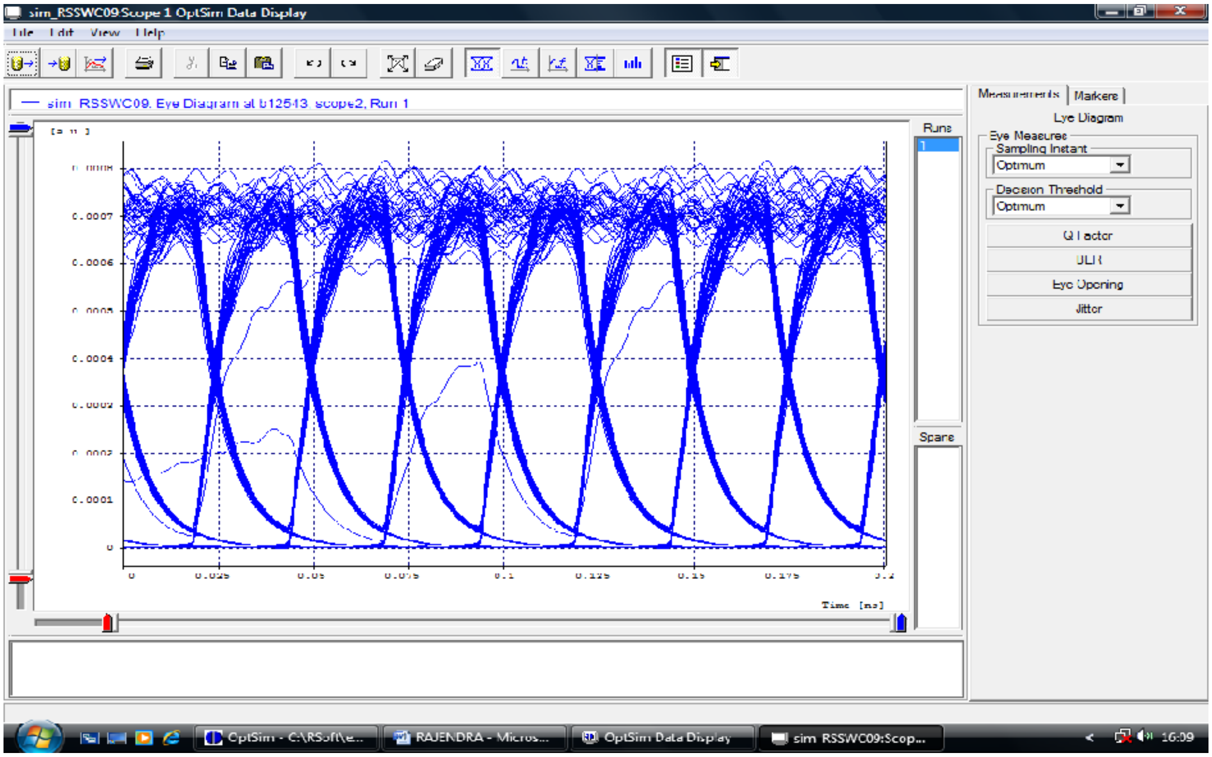
Fig. 4.22 wavelength conversion at I(BAIS)=80mA,t=1ns

[Type text]



Sampling Instant: Optimum
Decision Threshold: Optimum

Fig. 4.23 eye digram of conversion at I=40ma, ,t=0.6ns



Sampling Instant: Optimum
Decision Threshold: Optimum

Fig. 4.24 eye digram of conversion at I=80ma, ,t=0.4ns

[Type text]

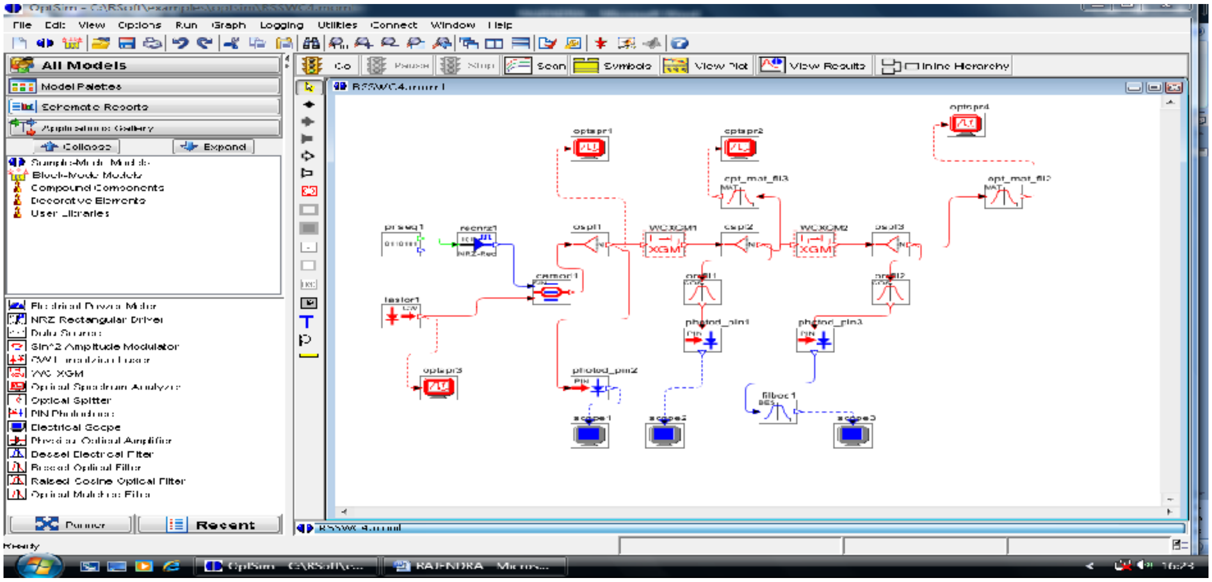
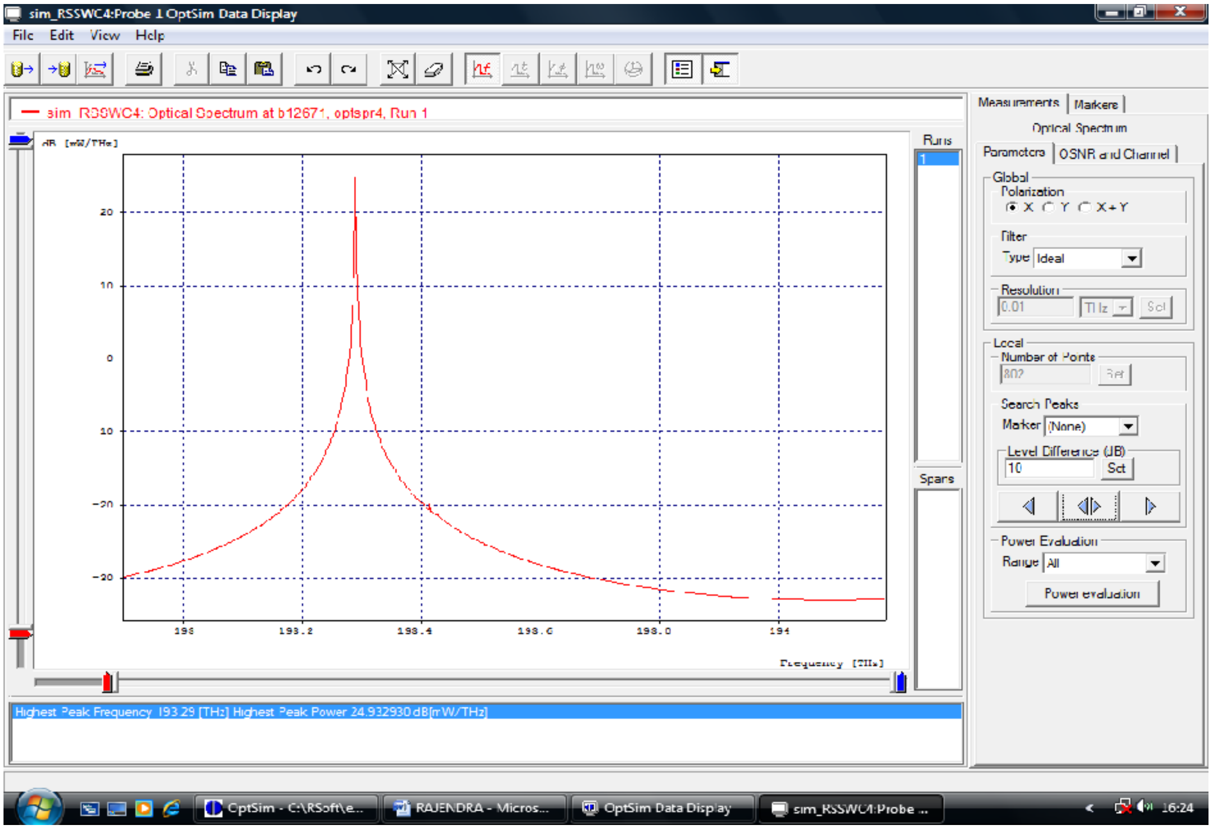


Fig.4.25 wavelength convesion with matched filter



Type Ideal

Resolution 0.01 THz

Number of Points 802

Marker (None)

Level Difference (dB) 10

Range All

Highest Peak Frequency 193.29 [THz] Highest Peak Power 24.932930 dB[mW/THz]

Fig 4.26 Single wave at 1449nm

[Type text]

The frequency response of XGM-SOA wavelength conversion at a rate of 40Gb/s for differnet value of current biasing and carrier lifetime is shown in fig 4.4he to 4.23. As ahown in fig. 4.4 the evalution is come out to be 16.69122db at biasing of 10 mA and carrier life time of .6ns while at a biasibg of 40mA and .6ns carrier lifetime the power is 26.041746 shown in fig. 4.14 and no as such extra wave ia generated along with the output 1549nm wavelength signal. Similarly if we increase the biasing current the eye diagram show the bit error increases and the Q decreses. So by this method it is possible to get converted wave without using amplifier at the receiver end.

CHAPTER 5

DENSE WAVELENGTH DIVISION MULTIPLEXING

5.1 Introduction

It is needless to mention that the 21st century activities will be drastically hindered without the advent of modern communication system. Off all, the most advanced communication system has been culminated in the form of Internet,” allowing all computers on the planet and in the orbit to be connected to each other – simultaneously! While telecommunication remains as a major medium and has its own demand for higher bandwidth, the demand for even higher bandwidth is skyrocketed by exponential growth of the Internet traffic. The cu-mulative demand for bandwidth poses a serious limitation for the existing carrier technologies. However, this extraordinary growing demand, coupled with the advent of dense wavelength division multiplexing (DWDM) fiberoptic systems to meet those demands, have sparked a revolution in the optical component and networking industry.

DWDM has been proven to be one of the most capable technologies for communication systems. Although usually applied to optical networks (ONs), wavelength division multiplexing (WDM), in general, can manyfold the capacity of existing networks by transmitting many channels simultaneously on a single fiberoptic line. In the few short years of deployment, DWDM performance has been improved dramatically. Channel count has grown from 4 to 128 and channel spacing has shrunk from 500 GHz to 50 GHz. This boost has been built upon, and has been driven by, advancements in fiber optic components, photonic inte-grated circuits (PICs) and advanced packaging technology.

Although “all-optical” technologies are replacing most transmission lines, the nodes of the networks, such as switching and cross-connect nodes, still de-pend on relatively slow electronic technologies. This poses a problem, because, nodes in the networks will limit the throughput due to the limitations of the elec-tronic circuitry. Only solution to this problem is to make the nodes all-optical as well. Migration from electronic and/or electro-optic nodes to all-optical nodes requires multiplexing, demultiplexing and cross-connection via optical technolo-gies.

Presently time division multiplexing (TDM) systems are widely used in optical communication networks. TDMs are inherently dependent on electronic technology for multiplexing and demultiplexing (MUX/DMUX). The nodes in TDMs use optical-to-electronic conversion, MUX and DMUX in the electronic domain, and electronic-to-optical conversion. Thus, the throughput is limited by the processing speed in the electronic domain. Wavelength Division Multiplex-ing (WDM) technologies, on the other hand, are based on all-optical MUX/DMUX; thereby enabling construction of WDM networks where node functionality is supported by all-optical technologies without back and forth opti-cal and electronic conversions.

5.2 WDM Communication Basics

One of the important enabling technologies for optical networking is wavelength division multiplexing (WDM) and demultiplexing (WDDM). The basic concept of a WDM is

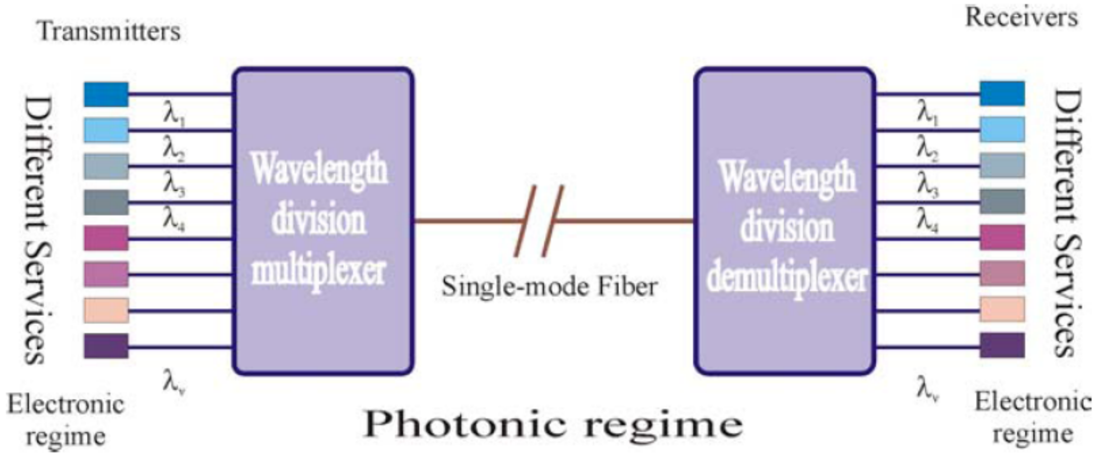


Fig.5.1 basic DWDM system

illustrated in Fig.5.1. At the heart of the WDM system is the optical multiplexing and demultiplexing devices. Optical signals are gener-ated by laser diodes (LDs) at a series of monochromatic wavelengths , (in the appropriate wave length range) and sent through N fibers to a WDM.

The WDM combines these input signals into a polychromatic output signal, a process known as multiplexing. Multiplexing allows to access very large band-width available in an optical fiber.

5.3 DWDM Simulation setup

This is the application part of the cross gain modulation bassed wavelength conversion mechanism at a rate of 40Gb/s in which DWDM 1×4 system is simulated using the parameter obtained from the result in in chapter 4. The simulation setup is shown in fig 5.2.

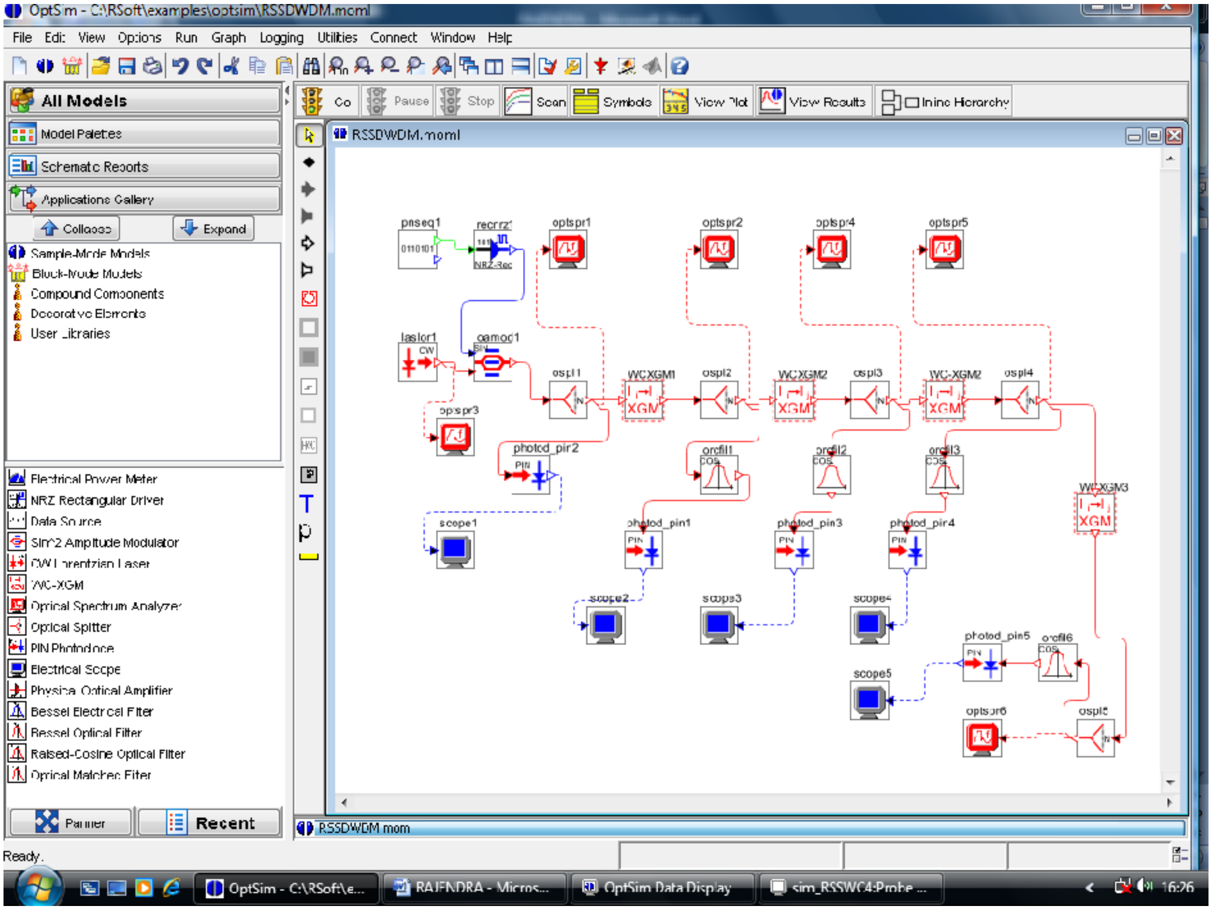


Fig. 5.2 simulation setup of DWDM system

In this above system setup of DWDM aystem the data source is generating the pseudorandom pulse at a rate of 40Gb/s which where then modulated by Sin² Mach-Zehnder modulator using lorentzian based generated optical signal having a wavelength of 1550nm. The parametric value of a given lorentzain laser is given in table 5.1.

Table 5.1 CW Lorentzian laser parametric values

Parameter	value
Centre emission frequency	193.414 THz
Centre emission wavelength	1550 nm

[Type text]

Source status	2
CW power	9mW
FWHM linewidth	10MHz
-20db linewidth	90.49874MHz
Initial phase	Random
Deterministic ideal phase	0.0 rad
Noise type	Ideal
Relaxation oscillation peak frequency	5 MHz
Relaxation oscillation peak overshoot	7.0dB

These optical modulated pulse is divided into two parts by optical splitter having a 0.0dB attenuation on each oytput, one for analyzing the effect in electrical domain and the other for conversion of 1550 nm signal to 1459nm through XGM having a parameters shown in table 5.2.The output of XGM is further used for next stage of conversion.at the output optical spectrum analyzer is used to observe the output. The above DWDM system performance has been evaluated by considering the realistic parameter at a conversion rate of 40Gb/s. The characterstics value of different parameter of an SOA is shown in table 5.2.

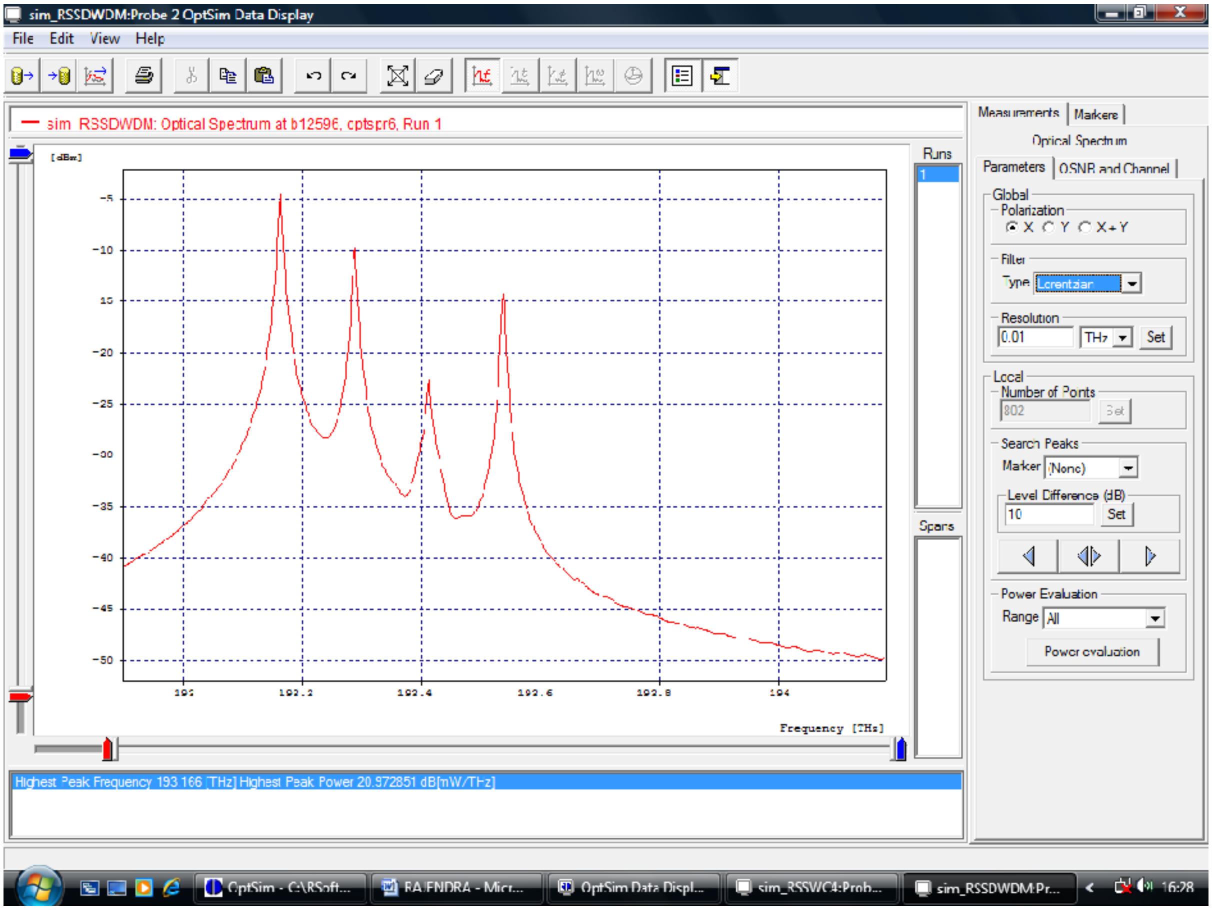
Table 5.2 XGM-SOA parameter value

Parameter	Value
New wavelength	1549nm
CW power	0 .3dbm
CW linewidth	10MHz
SOA Length	500µm
SOA Width	2.0µm
SOA thickness	0.15µm

SOA confinement factor	0.30
SOA carrier lifetime	0 .6ns
SOA LW enhancement factor	3
SOA material loss	10.5
SOA input loss	3dB
SOA output loss	3dB

5.4 Simulation result of DWDM system

In this chapter the by using wavelength convertor designed in the previous chapter is used to design a DWDM sub system at 40Gb/s. here signal having wavelength 1550nm is demultiplexed in to 1549,1551 ,1552nm wavelength signal the simulation result is shown in fig 5.3.



Polarization: ● X ○ Y ○ X+Y

Filter Type: Lorentzian

Resolution: 0.01 THz Set

Number of Points: 802 Set

Marker: (None)

Level Difference (dB): 10 Set

Range: All

Highest Peak Frequency 193.166 [THz] Highest Peak Power 20.972851 dB[mW/THz]

5.5 Summary

Despite the long carrier lifetime ,the potential of the SOA in very high bit rate all optical wavelength conversion based DWDM system is invetigated. A successful operatin at 40Gb/s has been demonstrated in this thises.

The probe power ,the injected current and the carrier lifetime should be carefully optimized to obtained good performance. This analysis can be lead to built up the system with ultra high speed in optical domain.

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