



ANALYSIS AND REDUCTION OF OPTICAL LOSSES IN FIBER OPTICS CHANNEL USING IMPROVED OPTICAL REPEATER

C.B MBACHU¹ AND P.G. IRIMIAGHA²

1,2 Department of Electrical and Electronics Engineering Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria

Abstract

This research work, proposed six channel dense-wavelength-division- multiplexing (DWDM) optical transmission system using improved parallel semiconductor optical amplifiers (SOAs). The SOA amplifiers overcome the attenuation effects of transmitted signal in optical communication systems. To overcome attenuation effects, pre-, post (booster) and In-line SOAs techniques are modeled, analyzed and compared for investigating the performance of DWDM system. The proposed system is designed for both single and multiple optical signal modulation format with dispersion compensation fiber (DCF) and a single mode fiber (SMF). The system was implemented using Simulink. The input parameters of the optical amplifying system was 100GHz with a fiber optics length of 200km. The obtained result states that the improved parallel semiconductor optical amplifier was able to cover 154 kilometers and highest when compared to other optical amplifiers. In conclusion the improved optical amplifier has an ability to transmit optical signal to 154 Km and also reduce attenuation due to it amplifying strength. This system is also recommended to optical communication companies and telecommunication industries and also to be subjected for further improvements.

KEYWORDS: DWDM DCF Single Mode Fiber Optical Amplifier SOA

1.0 Introduction

Fiber optic communication is one of the fastest means of transmitting telecommunication data. The optical repeater has been a method used in improving the optical transmission due to attenuations induced by long distance. The major issues with regards to the optical transmission has been attenuation of signals, these simply means that is the optical signals travels along the optical fiber attenuations occurs other factors are also caused by light scatterings in the optical fiber due to the material of the optical fiber or the bending conditions of the fiber. Other researchers have made serious efforts in reducing optical attenuations by introducing several methods of optical amplifiers such as Semiconductor optical amplifiers and Raman optical amplifiers. The increasing demand in telecommunication capacity has led to wavelength -division multiplexing (WDM). This technology multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths of laser light [1]. This technique enables bidirectional communication over one strand of fiber as well as multiplication of capacity. WDM systems are divided into different wavelength patterns, coarse (CWDM) and dense (DWDM). Conventional WDM systems provide up to 8 channels in the 3rd transmission window (C-Band) of silica fibers around 1550 nm [1]. Dense wavelength division multiplexing (DWDM) uses the same transmission window but with denser channel spacing. Channel plans vary, but a typical system would use 40 channels at 100 GHz spacing or 80 channels with 50 GHz spacing. Some technologies are capable of 12.5 GHz spacing (sometimes called ultra-dense WDM).

However, many authors have done so many works on optical amplifiers, Kaman amplifiers and semiconductor optical amplifiers. But the optical amplifiers of these methods has a limited optical distance of 120 kilometers but

however, in this research work we will be improving the strength of the optical amplifier to 150 kilometers respectively using the improved semiconductor optical amplifiers.

1.1 Statement of the Problem

Optical attenuations affect the society badly in the sense of having broken down signals when needed. Communication systems has really gone wide in a such a way that almost every industries depends on it. From the companies, banks, schools, oil industries, financial institutions, broadcasting stations and hospitals depends on high speed data for effective communications. The issues relating to optical transmission in fiber optics cable is optical loss in transmission, this issue is directly relative to the society because the society depends on it. Most of the optical transmission losses are majorly caused by light scattering, bending losses and exceeding of optical limit along the transmission channel. It is also known that, as optical wave travels over a long distance from the light source, the signal tends to attenuate, this research work is will be reducing these problems to maintain an effective communication system for the society that depends on high data transfer.

1.2 Aim and objectives of the Study

The aim of this research work is to improve the optical signal of an optical transmission line using the improved DWDM semiconductor optical amplifier and the objectives are as follows:

- i. To determine the generated optical signal
- ii. To analyze the optical signal using the improve DWDM semiconductor optical amplifying method.
- iii. To evaluate the attenuated optical signal
- iv. To evaluate the optical Dispersion Compensation of the system
- v. To compare the optical results of the improved Semiconductor Amplifier to Kaman optical amplifier

According to [2] In their research work, they proposed sixteen channel dense-wavelength-division- multiplexing (DWDM) optical transmission system using semiconductor optical amplifiers (SOAs). The SOA amplifiers overcome the attenuation effects of transmitted signal in optical communication systems [4]. To overcome attenuation effects, pre-, post (booster) and In-line SOAs techniques are modeled, analyzed and compared for investigating the performance of DWDM system. The proposed system is designed for 10Gbps network using non-return-to- zero (NRZ) modulation format with dispersion compensation fiber (DCF) of length 14kms and a single mode fiber (SMF) of length 70kms using Optisystem7.0 simulator. Performance of designed system is explored and compared in terms of eye shape (eye-diagram), Q-factor and bit error rate (BER) by varying the input power (mw) parameter of CW laser source. It is observed that the In-line SOA amplifier provides the best performance as attenuation compensator for proposed optical transmission systems.

According to [3], he concluded that analytical method of noise in the semiconductor optical amplifier (SOA) has not been established yet. [3] iterated that, the basic problem is how to introduce quantized optical field with the Langevin noise sources in the open wave guide, because the SOA has not have facets mirrors to confine the optical field in the device. The author's group introduced an idea to define finite size of photons based on the quantum mechanical property of the spontaneous emission [7]. The longitudinal mode for the traveling optical field is defined for optical signal and the generated spontaneous emission. Then, the intensity (IM) noise, the frequency (FM) noise and the spectral linewidth were theoretically calculated. Characteristics of these noise were also experimentally confirmed [5].

According to [1] Their research work investigated and analyzed the performance of radio frequency (RF) signal over optical fiber for wireless communication systems in terms of bit rate, bit error rate (BER), quotient factor (Q-factor), signal strength and length of transmission. The RF signal is transported over optical fiber using direct Intensity Modulation – Direct Detection (IMDD) technique [6]. The simulations are implemented for the bit rates (bandwidth) within the range of 0.5Gbit/s to 15Gbit/s and length of 30km, 50km and 70km. The output shows that increase in the bit rate for a given length of optical fiber indicates an increase in the minimum bit error rate (BER) and decrease in the maximum quotient-factor (Q-factor).

3.0 Methods

3.1 Determining of Optical Signal (Laser) Analysis

Under the irradiation of a laser beam, the target material is first heated from room temperature to melting temperature. Depending on laser intensity and material properties, the molten part of material will be evaporated by additional heating when it reaches the vaporization point and a vapour-filled cavity is formed (Figure 3. 1). A thin, so-called Knudsen layer exists at the melt–vapour interface, where the state variables undergo discontinuous changes across the layer. When the incident laser intensity exceeds a certain threshold, vaporization leads to plasma formation, which will absorb a certain percentage of laser energy. The more the intensity exceeds the threshold, the denser the plasma, and the greater the percentage of absorption. In practice, an assisting gas jet could disperse the plasma plume sideward and lower the plasma density. However, the plasma effects still exist. By introducing a correction coefficient in the modelling of laser intensity, the plasma effects are corrected. The motion of molten material caused by the Marangoni effect is neglected. The governing equation for energy balance can be written as where α is heat diffusivity and ρ is density, x and r are distances along axial and radial directions. The enthalpy of the material (the total heat content) can be expressed as $H = h + \Delta H$, i.e. the sum of sensible heat, $h = cpT$ (cp is the heat capacity, and T is the temperature), and latent heat ΔH . It either varies with L_{mv} , the latent heat for melting, or is zero. The enthalpy formulation allows the melting boundary to be traced as a function of time without regeneration of the calculation grids. At the melt–vapour front, the Stefan boundary condition is applied [1],

$$\frac{\partial h}{\partial t} + \frac{\partial \Delta H}{\partial t} = \frac{\partial}{\partial x} \left(\frac{\partial h}{\partial x} \right) + \frac{1}{r} \frac{\partial}{\partial r} \left(r \alpha \frac{\partial h}{\partial r} \right) \quad (3.1)$$

$$Q + K \left(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial r} \right) + p_i v_i L_v - p_v V_v (c_p T_i + E_v) = 0 \quad (3.2)$$

$$E_v = \frac{RT_v}{(\gamma-1)M_v} + \frac{1}{2} v_v^2 \quad (3.3)$$

$$Q = C(1 - Rl)I(t) \exp\left(-\frac{r^2}{b^2}\right) \exp(-\beta x) \quad (3.4)$$

where Q is the laser heat flux which depends on the reflectivity Rl , absorptivity β

and the plasma correction coefficient C . I is the laser intensity which is a function of time, and b is the laser beam radius. The subscripts l , v , and i denote liquid phase, vapour phase, and vapour-liquid interface, respectively. The gas energy E_v includes the internal energy and the kinetic energy. k is the heat conductivity, v the velocity, R the universal gas constant, the specific heat ratio, L_v the latent heat of vaporization, and M_v the molecular mass. The velocity, the laser energy flux and the heat conduction flux are given along the normal direction of the cavity profile. The vapour-liquid front is determined by tracing the temperature. As long as the temperatures at certain grid points reach vaporization temperature, the grids which have temperatures larger than vaporization temperature are taken as the gas phase, and the calculation starts from the newly determined vapour-liquid front. A photodiode sensor is used to record the actual temporal distribution of the laser intensity. In simulation, $I(t)$ takes the coefficients. For pure copper at a wavelength [1]

$\lambda=0.355 \mu\text{m}$, $n = 1.34$, and $k = 1.93$, the absorption coefficient is given by

$$\beta = \frac{4\pi k}{\lambda} \tag{3.5}$$

As shown in the figure 3.1 is the 6 transmission channel improved DWDM semiconductor optical amplifier. The system multiplexes 6 channels that goes through the DCF module that is finally amplified by the improved optical amplifier.

From table 3.1 are the input parameters of the improved SOA and other optical amplifiers. The parameters show the input frequency and the chosen frequency and the desired lengths of the optical cable. The comparative input frequencies for the optical amplifiers are shown in the table 3.1

OPTICAL AMPLIFIER	INPUT FREQUENCY (GHZ)	LENGTH OF THE FIBER OPTICS CABLE(KM)
SEMICONDUCTOR OPTICAL AMPLIFIER	100	200
SEMICONDUCTOR OPTICAL AMPLIFIER	100	200
CONVENTIONAL OPTICAL AMPLIFIER	100	200
KAMAN AMPLIFIER	100	200
IMPROVED SEMICONDUCTOR AMPLIFIER	100	200

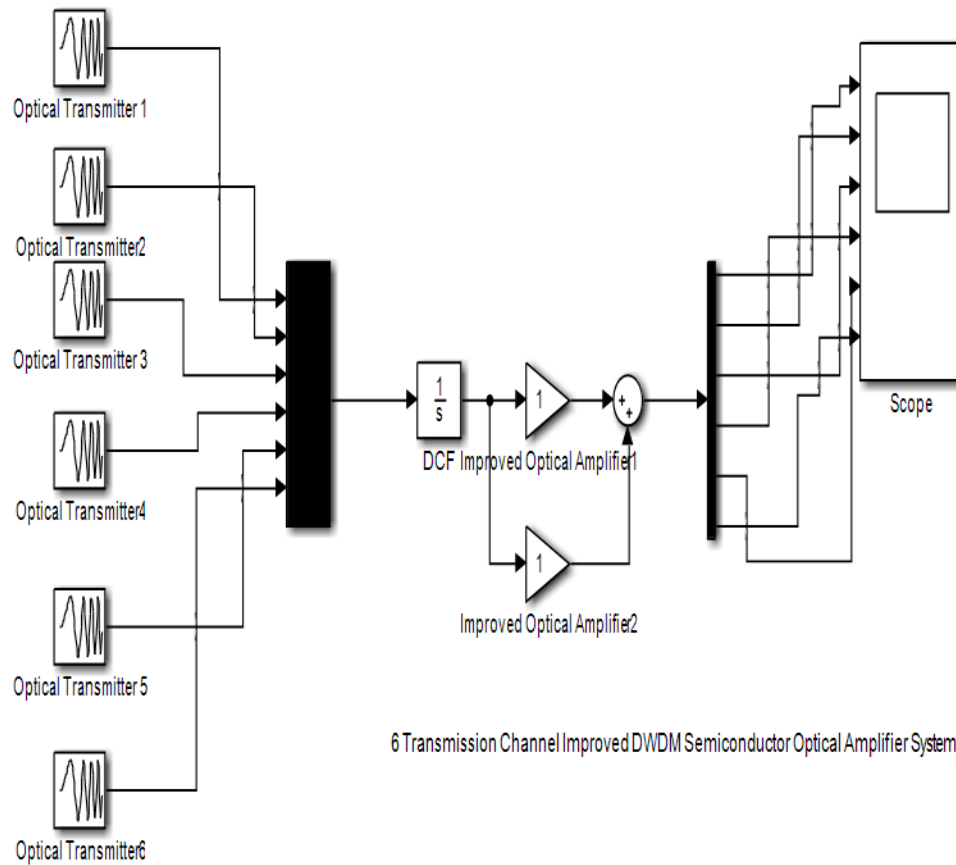


Figure 3.1 six channels improved optical amplifying system

Figure 3.1 of this research work is a clear functional diagram of the improved optical amplifying system, from the block diagram of the system it is described that the optical signal is transmitted along the optical multiplexer, the signal from the optical multiplexer is been channeled to the DCF/DWDM channel, the signal in this section gets into the improved parallel semiconductor optical amplifier before displaying the results on the scope. It is shown in this research work that paralleling the optical amplifier improved the optical strength of the signal.

3.2 Evaluation of Optical Dispersion Compensation

Dispersion supervision plays an important role for designing of optical DWDM transmission systems because; dispersion degrades the performance of longer optical transmission link due to the fiber nonlinearity. So, dispersion compensation fiber (DCF) is the most universal technique to reduce the impact of dispersion. For this purpose, a special single mode fiber is designed to reverse the deleterious consequence of dispersion and improve the transmission quality of optical fiber. Hence, dispersion compensation fiber is competent to compensating the group velocity dispersion (GVD) and insignificant nonlinear effect inside the fiber if optical power is kept small. The pulse propagation equation for optical signal propagates through the segments of SMF and DCF at L transmission distance can be given as [1] [3]:

$$V(L, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} L p \left(\frac{i}{2} \beta \omega^2 I = i\omega t \right) d\omega \quad (3.6)$$

where, I, is Fourier transform of pulse amplitude V(0,t) and β is GVD parameter, which is related to dispersion. Dispersion induced deficiency of optical signal is cause by the phase aspect

$\exp\left(\frac{i}{2} \beta \omega^2 I\right)$ which can be acquired by signal during its

transmit throughout the optical fiber. If the length of two fiber segments L_{SMF} , L_{DCF} are due to SMF and DCF, respectively then from the Eq.(3.7):

$$V(L, t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} I p \left(\frac{i}{2} \omega^2 \left(\frac{\beta_{SMF} L_{SMF}}{\beta_{DCF} L_{DCF}} \right) - i\omega t \right) d\omega \quad (3.7)$$

where, overall length of fiber segments is $L = L_{SMF} + L_{DCF}$ and β_{SMF}, β_{DCF} are GVD parameters for the segments of fiber length L_{SMF} and L_{DCF} , respectively. If we choose DCF then ω^2 term disappear thus original pulse shape can be recover. Therefore, perfect condition for dispersion compensation beside DCF can be given as

$$\beta_{SMF}L_{SMF} + \beta_{DCF}L_{DCF} = 0 \tag{3.8}$$

$$D_{SMF}L_{SMF} + D_{DCF}L_{DCF} = 0 \tag{3.9}$$

$$D = \frac{2\pi c}{\lambda^2} \beta \tag{3.10}$$

where, λ is wavelength of pulse signal, C is the light speed. Because in case of SMF, $D_{SMF} > 0$, Eq.(3.11) shows that dispersion coefficient DCF (in ps/nm.km) (at certain wavelength λ in nm) of DCF should be negative for dispersion compensation and length L_{DCF} (in km) of DCF must be satisfy as.

$$L_{DCF} = -L_{SMF}(D_{SMF}/D_{DCF}) \tag{3.11}$$

Further, to overcome remaining dispersion in very high speed optical transmission systems, the dispersion slop SDCF of DCF must be satisfy as:

$$S_{DCF} = S\left(\frac{D_{SMF}}{D_{DCF}}\right) = L_{DCF} = S_{SMF}(D_{DCF}/D_{SMF}) \tag{3.12}$$

where, SSMF is dispersion slope of SMF. According to above analysis, the components/mechanisms of DCF are wide band- width performance, more stable and negligible temperature dependence/effect. Hence, DCF is the most appropriate technique for dispersion compensation. Therefore, the physical arrangement of SMF and DCF can be situated at three different positions in optical DWDM transmission system for dispersion pre- compensation, post-compensation and symmetrical compensation.

3.6 Optical power Amplifier

The material gain of the active region can be described by a complex refractive index. Suppose the real part of the refractive index of the active region is n_a , the material group index of the active region n_{ag}^M , the group index of the waveguide optical mode is n_g , the material gain of the active region is g , and the mode confinement factor of the active region is F_a . Then the change in the propagation vector $\Delta\beta$ of the waveguide optical mode due to gain in the active region is given by the waveguide perturbation theory,

$$\Delta\beta = \frac{\omega}{c} F_a \left(\frac{n_g}{n_{ag}^M}\right) \Delta n_a = -i F_a \left(\frac{n_g}{n_{ag}^M}\right) \frac{g}{2} = -i F_a \frac{\tilde{g}}{2} \tag{3.13}$$

Where,

$$\tilde{g} = \left(\frac{n_g}{n_{ag}^M}\right) g \tag{3.14}$$

In the presence of gain, the light field amplitude will increase with distance as $e^{F_a(\tilde{g}/2)z}$ and the optical power will increase as $F_a \tilde{g} P(z)$. The factor $F_a \tilde{g}$ is called the modal gain. If $P(z)$ represents the optical power (units: energy per sec) then one can write a simple equation for the increase in the optical power with distance,

$$\frac{dP(z)}{dz} = F_a \tilde{g} P(z) \tag{3.15}$$

A time dependent form of the above equation for power propagating in the +z-direction will be,

$$\left[\frac{\partial}{\partial z} + \frac{1}{v_g} \frac{\partial}{\partial t}\right] P(z, t) = F_a \tilde{g} P(z, t) \tag{3.16}$$

As the optical signal gets stronger with distance inside the waveguide, and the rate of stimulated emission also gets proportionally faster, the carrier density inside the active region also changes and cannot be assumed to be the same as in the absence of any optical signal inside the waveguide. In the next Section, we develop rate equations for the carrier density in the active region.

Optical Power Loss

The optical power loss of the optical channel system can be express as follows:

$$L_{dB} = P_{Source} (dBm) - P_{Received} (dBm) \tag{3.17}$$

And the received signal of the optical power system can be expressed as:

$$P_{Received (dBm)} = P_{Source (dBm)} - L_{(dB)} \tag{3.18}$$

Where

L_{dB} is the optical loss, $P_{Source (dBm)}$ is the optical source power and $P_{Received (dBm)}$ is the received optical power

4.0 six transmission channel Optical Signal

As shown in figure 4.1 is a 6 transmission DWDM improved optical amplifying system. The result displays the signals from the first channel to the last channel. Each of this channel as shown in the figure are operating at different bandwidth. From 100 GHz to 600 GHz. The result shows that the system is capable of transmitting 6 different optical signal at same time with the DWDM multiplexer and de-multiplexer, the signal passes through the dispersion coefficient system then get amplified by the improved semiconductor optical amplifier. The result also confirms that the semiconductor optical amplifier has compensated the optical losses from the conventional amplifiers with it amplifying strength that covers a 154 km.

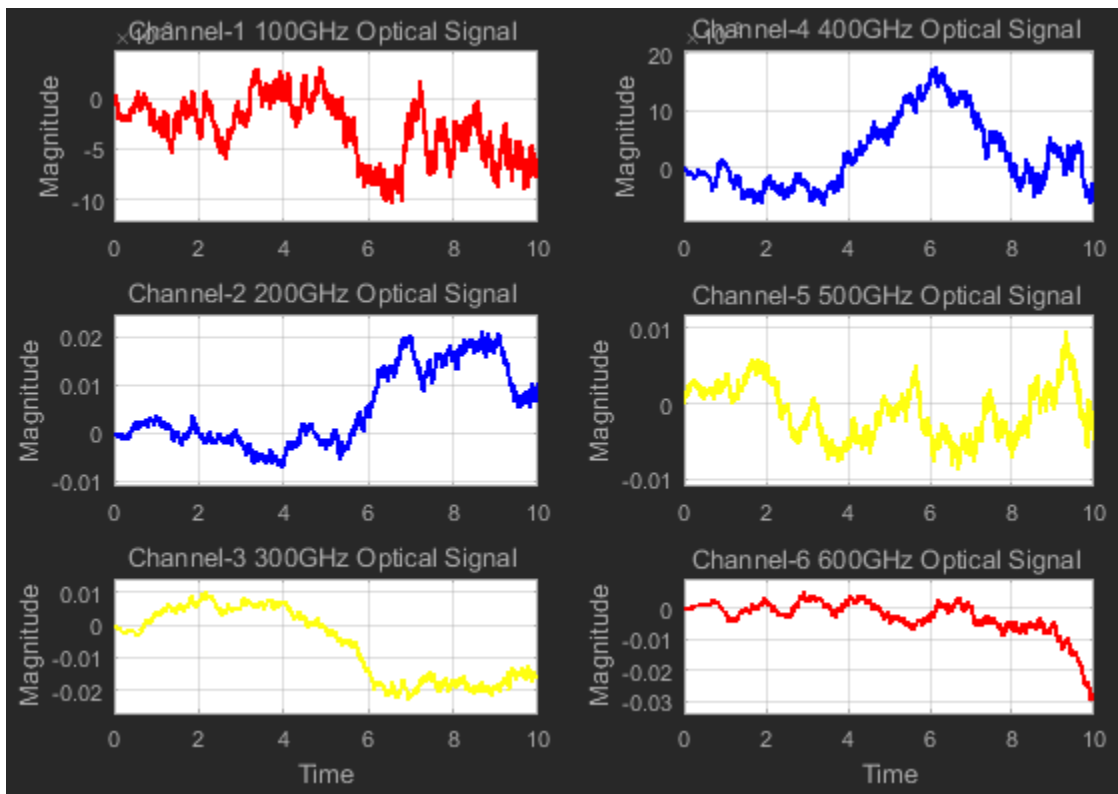


Figure 4.1 six channel optical signal

4.2 Attenuated Optical Signal along the Channel

As optical signals travel along the single mode fiber optic channel, the signal strength tends to reduce, though this signal degrading are caused by too many factors. Some are due to bending loss, Rayleigh scattering or poor optical amplification etc. from the result shown in this figure 4.2, we can clearly see the optical signal degrading with respect to time due to poor optical amplification of the signal.

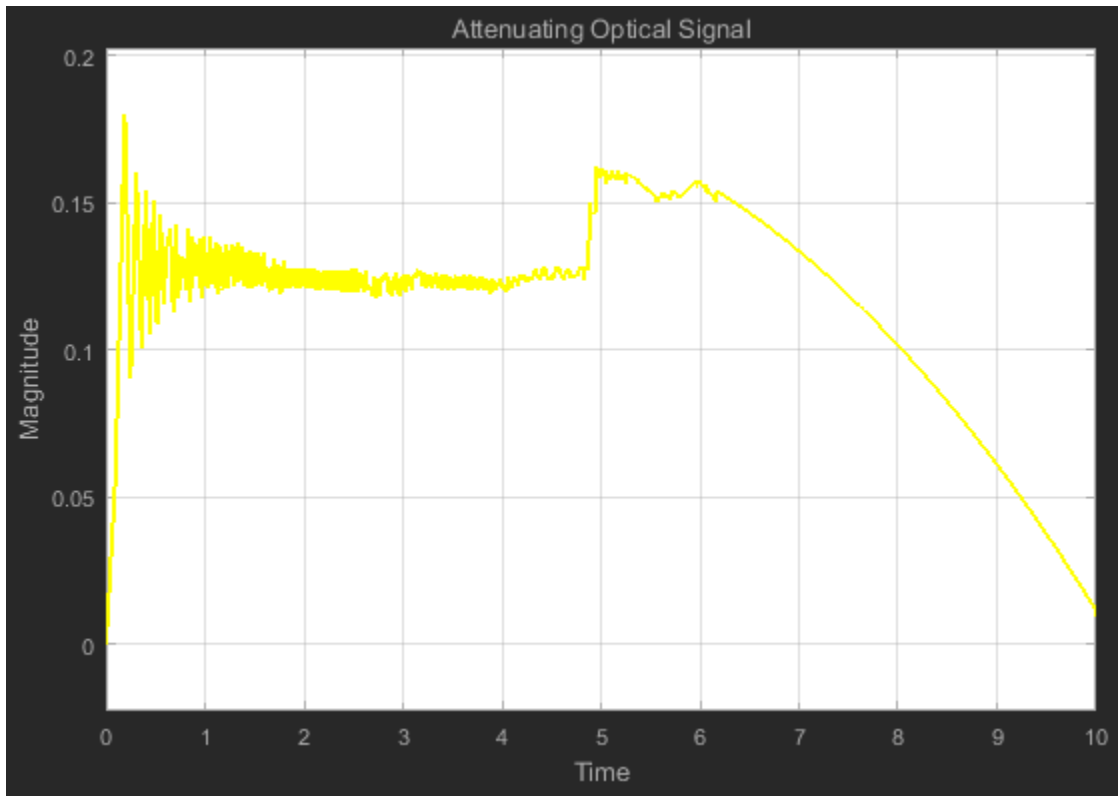


Figure 4.2 attenuating optical signal

4.3 Comparative Results of Different Optical Amplifiers

From the figure 4.3 it can be seen clearly that among all the optical amplifiers shown. The improved semiconductor amplifier with DWDM system has the maximum distance covered. The result shows that the conventional optical amplifier has the lowest maximum speed covered at 69km, then followed by the semiconductor optical amplifier and the Raman amplifier before the Raman SOA amplifier at 121km. however, the improved SOA has the highest rate when it comes to optical amplification due to the cascaded method of amplification.

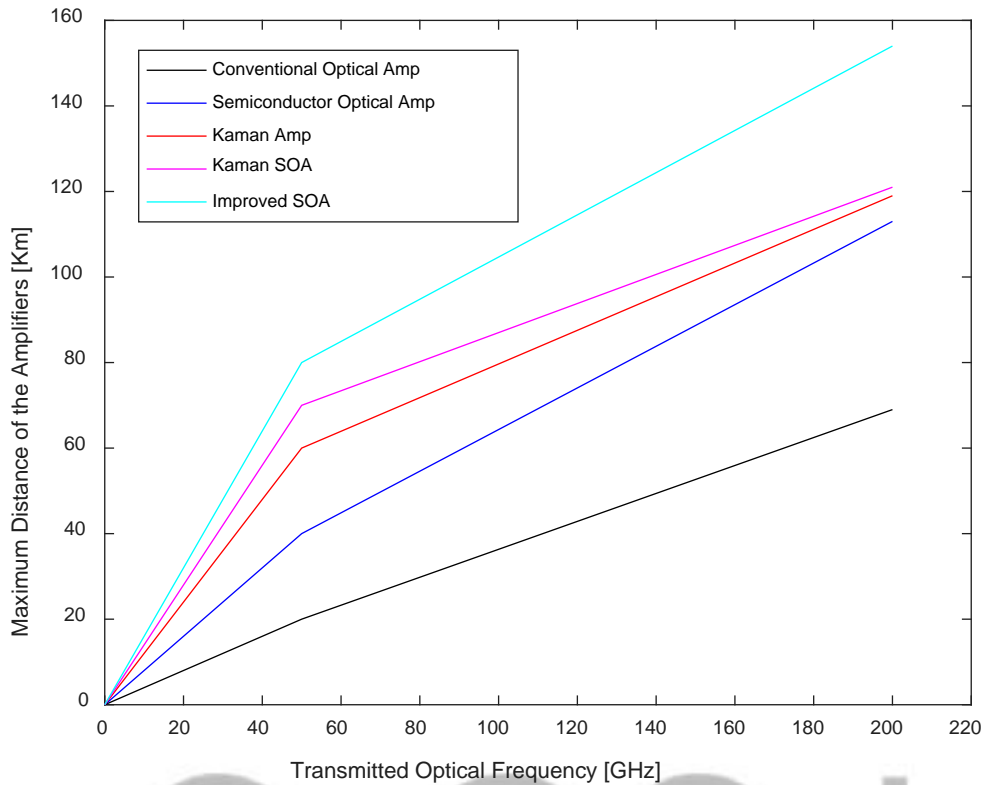


Figure 4.3 comparative results of optical amplifiers

From table 4.1 we can easily see the results of the maximum distance traveled by the optical signals

Table 4.1 shows the respective distance covered by the optical amplifiers at same wavelengths. The results show that at input of 100GHz and the maximum distance covered by the optical amplifiers are shown in the table 4.1. it is noted that the optical amplifiers covered different distances but the improved SOA covered the longest distance.

FIBER TYPE	OPTICAL AMPLIFIER	MAXIMUM DISTANCE COVERED(KM)	WAVE LENGTH (NM)
SINGLE MODE FIBER	Semiconductor optical Amplifier	113	1550
SINGLE MODE FIBER	Conventional Optical Amplifier	69	1550
SINGLE MODE FIBER	Kaman Amplifier	119	1550
SINGLE MODE FIBER	Kaman Semiconductor Amplifier	121	1550
SINGLE MODE FIBER	Improved Semiconductor Amplifier	154	1550

5.0 Conclusion

In this research work, we have been able to analyze the optical transmission source and system. The result shows that the improved DWDM dense wavelength division multiplexing and optical amplifying system emits a laser beam. The laser beam emitted passes through the dense wavelength division multiplexer of the system, then proceeds to the optical dispersion coefficient system. When light passes through this system we most times observe attenuation of signals, the signal is now sent in to the improved semiconductor optical amplifier. The result in the chapter 4 shows that the optical amplifier has a higher area covered at 154 km when compared to other optical amplifiers.

In this research work also investigated the optical dispersion compensation of the entire optical amplifying system. Though when light is being transmitted over a longer channel, attenuations occurs due to distance, heat and optical scattering. This way to compensate the lost energy is to repeat the signal. However, this research work has been able to provide a compensation plan which is the improved DWDM semiconductor optical amplifier.

The Improved DWDM semiconductor optical amplifier, was designed using a cascaded method to improve optical output power. When compared this method to others optical amplifiers, it was observed that the results became improved. However, boosting the range the optical wave can cover. The attenuation observed in the result became drastically low at 154km.

5.1 Recommendation

Improved DWDM semiconductor optical amplifying system, improves the optical communication reduces attenuation and signal degradations.

Haven designed the optical amplifier, that amplifies optical signal, it is therefore recommended that further research should be carried out based on the optical signal amplifications in terms of length of the covered signals.

REFERENCES

- [1] Olabomi., O., E., Petinrin., J., O., & Olaoye., A. (2016) Performance Analysis of Radio Frequency Signals Over Optical Fiber for Wireless Communication Systems, Department of Science Technology Federal Polytechnic, Offa, Kwara State, International Conference of Science, Engineering & Environmental Technology (ICONSEET), 1(11): 75-84, Nigeria.
- [2] Bhavesh., A., Meena., M., L., & Meena R., S. (2019), Design And Performance Analysis Of Semiconductor Optical Amplifier For 16×10gbps Dwdm Transmission Systems, Department of Electronics Engineering, Rajasthan Technical University, India.
- [3] Kyriakos E., Z. (2018) “Special Issue on Applications of Semiconductor Optical Amplifiers”, Applied Sciences, 8 (7) 1185-1189.
- [4] Elechi, P., Orike, S. & Anumbe, P.C. (2020). Mitigation of Micro and Macro Bends for Improved Bandwidth in Fiber Optics Communication, *Journal of VLSI Design and Signal Processing*, 6(3), 25-34.
- [5] Elechi, P., Orike, S. & Echendu, D.A. (2020). Simulated Bandwidth Improvement of Hexagonal Circular Photonic Crystal Fiber using Hybrid Cladding, *Journal of VLSI Design and Signal Processing*, 6(3), 10-24.
- [6] Bobrovs., V., Alsevska., S., Olonkins., S., Gegere., L., & Lvanovs., G.(2013) “Comparative performance of Raman-SOA and Raman-EDFA Hybrid Optical Amplifiers in DWDM Transmission Systems”, *International Journal of Physical Sciences*, 8(39), 1898-1906.
- [7] Deepak., M., Kuldip., P., & Amit., W., (2016) “Performance Optimization of SOA, EDFA, Raman and hybrid Optical Amplifiers in WDM Network with Reduced Channel Spacing of 50GHz”, *Optik*, 11131-11137.