DESIGN ULTRA WIDEBAND USING RAMAN AMPLIFIERS IN WDM SYSTEMS

L. A. Al-Mayahi *, A. Y. Fattah**

*, ** Electrical and Electronic Department, University of Technology/ Baghdad/ Iraq

*E-mail: laithawda@yahoo.com

**E-mail: dralifattah@yahoo.com

Abstract

With the steadily increasing demand for fiber-optic communications, researches is more and more being placed in the method known as wavelength division multiplexing, or WDM. The key device supporting WDM technology is the optical amplifiers, and such amplifiers need to have a flat gain spectrum. In this paper, we will design Ultra wideband system that improved gain-flatness of a Raman amplifier while maintaining a wide gain-bandwidth and a high gain-output power in WDM systems [1] [2]. All simulation was implemented using the Optical Simulation software package.

1. INTRODUCTION

Wavelength Division Multiplexing (WDM) offers higher capacity and more flexibility to optical networks, and is being actively researched and developed throughout the world; and standardized in ITU-T. Current WDM applications utilize the 1550 nm region due to the limited bandwidth of EDFAs and EDFFAs; around 40 channels (wavelength) are available with 100 GHz channel spacing. In addition, recent progress in devices and sub-systems has made it possible to use much wider bandwidth, especially in 1580 nm region [3].

So widening the gain-bandwidth of fiber amplifiers is the primary issue in enlarging the capacity of wavelength-division multiplexing (WDM) transmission systems. Present usable bandwidths in long distance transmissions over 500 km or more are limited to less than 30 nm due to the insufficient gain-bandwidth of

conventional erbium-doped fiber amplifiers (EDFAs). Optical amplifiers having wider gain-bandwidths as well as high output powers are essential to further increase the bandwidth.

Recent progress in ultra-wide amplifiers has achieved gain-bandwidths of approximately more than 30 nm with configurations such as a parallel configuration, combining a distributed Raman amplifier (DRA) with an erbium-doped fluoride fiber amplifier (EDFFA), and changing the fiber host, while maintaining high output powers and/or high gains over 20 dB. Some of these methods have also confirmed error-free operation through WDM transmission experiments. However, imperfect gain-flatness (typically 3 dB) causes a large difference in the signal powers after only several concatenated amplifications, thus leading to OSNR degradation of the lowest power channel. Thus far, in ultra-wide WDM systems having a bandwidth exceeding 40 nm, the transmission distance has been confined to several hundreds of kilometers [4] [5].

2. LAYOUT OF THE PROPOSAL SYSTEM THAT IS USED IN ORDER TO GET FLAT RAMAN GAIN AND WIDE BANDWIDTH BY USING RAMAN AMPLIFIERS

Because the gain bandwidth of erbium-doped fiber amplifiers (EDFA) is much narrower than the low loss window of standard optical communication fibers, there is growing interest in wideband flat-gain optical fiber amplifiers (OFAs) to exploit more of the available fiber bandwidth and increase the capacity of wavelength division multiplexing (WDM) systems. Raman gain is observed for a frequency differential range (range of difference between pump signal and data signal nominal frequencies) Therefore, if the number of pumps, their wavelengths, and the power values are chosen carefully, we can achieve the desired gain shape for the input DWDM channels. In the case of Raman amplifiers with multiple pumps, the gain profile can be adjusted by appropriately choosing the relative positions and powers of the pump waves. In principle, this can allow for the design of amplifiers with any required gain spectra, e.g., the ones that would provide flat net gain [6].

The layout of the proposal system for 96 channels and with 10 Gb/s for a distance of 717.5 Km and channel spacing equal to 100GHz is shown in Figure 1. This figure

shows the simulation design that is used to obtain flat Raman gain in a wide bandwidth by using the Raman multipump configuration.

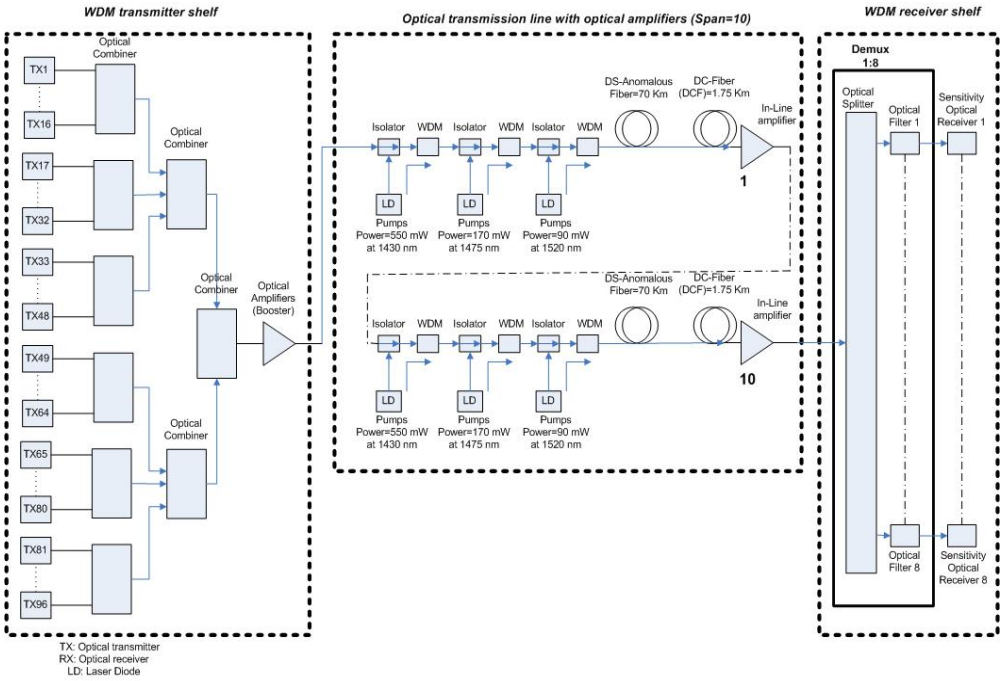

Figure 1. layout of the first proposal system that include all components of transmitter, optical link and receiver

The characteristics of each component are:

2.1. WDM TRANSMITTER:

A 96-channel DWDM system that is transmitted at 10 Gb/s and with channel spacing 100 GHz and the frequency range is from 185.8 THz to 195.3 THz. The center frequency that is used is 193.1 THz, the driver for each transmitter is NRZ and laser with linewidth of 10 MHz, the real laser frequencies for each transmitter are:

a- (185.8, 185.9,……..187.3)THz for the first 16 transmitter (1 to 16) and using real center frequency 186.55 THz.

b- (187.4,……..188.9)THz for the second 16 transmitter (17 to 32) and using real center frequency 188.15 THz.

c- (189,……..190.5)THz for the third 16 transmitter (33 to 48) and using real center frequency 189.75 THz.

d- (190.6,……..192.1)THz for the fourth 16 transmitter (49 to 64) and using real center frequency 191.35 THz.

e- (192.2,……..193.7)THz for the fifth 16 transmitter (65 to 80) and using real center frequency 192.95 THz.

f- (193.8,……..195.3)THz for the sixth 16 transmitter (81 to 96) and using real center frequency 194.55 THz.

Other system parameters are listed in table 1.

Table 1. Standard parameters for WDM transmitter of figure 1.

Simulation Parameters	
Lower limit of Bandwidth	189.65 THz (1574.12684694 nm)
Upper limit of Bandwidth	190.45 THz (1580.76698128 nm)
Reference Bit Rate	10 Gbit/s
Channel spacing	100 GHz
Driver	NRZ
Source linewidth	10 MHz
PRBS Order	$2^k - 1 = 7$
Excess Loss	3 dB
CW power	0 dBm

2.2. OPTICAL AMPLIFIERS:

In the proposal system in figure 1. we use optical amplifiers (Booster) and the input of optical fiber and In-line optical amplifiers at the other end of optical fiber all optical amplifiers have the following characteristic:

a- Output power =7 dBm.

b- Maximum small signal gain =35 dB.

c- Noise figure =4.5 dB.

2.3. OPTICAL TRANSMISSION LINE:

The optical transmission line consisted of two optical fibers (DS-Anomalous 70 Km and DCF 1.75 Km). The DS-Anomalous fiber are pumped by three counter-propagating Raman pumps (550 mW at 1430 nm, 170 mW at 1475 nm and 90 mW at 1520 nm), the pumps attenuation are (0.3 at 1420 nm, 1440 nm, 1480 nm and 1520 nm), other system parameters are listed in table 2.

Table 2. Standard parameters for optical transmission line of figure 1.

Simulation Parameters		
Total Fiber length	717.5 Km	
Ds-Anomalous (70 Km)		
Losses	α_0 [dB/Km]	0.2
	α_1 [dB/Km/THz]	0
	α_2 [dB/Km/THz2]	0
Dispersion	β_2 [ps2/Km]	-2.55089639899
	β_3 [ps3/Km]	0.118071878922
	β4 [ps4/Km]	0
	β5 [ps5/Km]	0
	D [ps/nm/Km]	2
	D'[ps/nm2/Km]	0.07
	Zero-Dispersion frequency/wavelength	196.852968837 THz (1522.92576419 nm)
Dispersion standard deviation	σ_D [ps/nm/Km]	0
	$\sigma_{\beta 2}$ [ps2/Km]	0
Dispersion Correlation length [Km]	20	

Fiber Non Linearity Coefficient [1/W/Km]	1.8425763364	
Fiber Non Liner Refractive Index [m2/W]	2.5e-20	
Core Effective Area [μm^2]	55.0000000005	
Fiber Average Beat Length [m]	5	
Birefringence Correlation Length [Km]	0.2	
Beat Length Standard Deviation [m]	0.5	
Fiber PMD [ps/Km0.5]	0.1	
Raman Profile	Reference frequency/wavelength	299.792458 THz (1000 nm)
	Raman Constant	0.18
	First Raman Time Constant [fs]	12.2
	Second Raman Time Constant [fs]	32
DCF (1.75 Km)		
Losses	α_0 [dB/Km]	0.55
	α_1 [dB/Km/THz]	0
	α_2 [dB/Km/THz2]	0
Dispersion	β_2 [ps2/Km]	102.03585596
	β_3 [ps3/Km]	0.1411614908
	β4 [ps4/Km]	0
	β5 [ps5/Km]	0
	D [ps/nm/Km]	-80
	D'[ps/nm2/Km]	0.19
	Zero-Dispersion frequency/wavelength	78.3724137714 THz (3825.2293578 nm)
Dispersion standard deviation	σ_D [ps/nm/Km]	0
	$\sigma_{\beta 2}$ [ps2/Km]	0

Dispersion Correlation length [Km]	20	
Fiber Non Linearity Coefficient [1/W/Km]	5.06708492514	
Fiber Non Liner Refractive Index [m2/W]	2.5e-20	
Core Effective Area [μm^2]	20	
Fiber Average Beat Length [m]	5	
Birefringence Correlation Length [Km]	0.2	
Beat Length Standard Deviation [m]	0.5	
Fiber PMD [ps/Km0.5]	0.1	
Raman Profile	Reference frequency/wavelength	299.792458 THz (1000 nm)
	Raman Constant	0.18
	First Raman Time Constant [fs]	12.2
	Second Raman Time Constant [fs]	32

2.4. DEMULTIPLEXER AND SENSITIVITY OPTICAL RECEIVER:

We take the output of only eight channels (from channel 40 to channel 47) to discuss the results, so the 1:8 Demultiplexer have the following characteristic:

a- Demultiplexer center frequency =190.05 THz.

b- Filter bandwidth =50 GHz.

c- Filter Roll off =0.2.

d- Insertion loss =3 dB.

The sensitivity optical receivers have the following characteristic:

a- Sensitivity under test condition = -23.0224802811 dBm.

b- Sensitivity reference error probability = $1*10^{-9}$.

c- Overall receiver responsivity = 1 [A/W] or [V/W].

d- Reference frequency/Wavelength for responsivity = 193.414489032 THz/1550 nm.

e- Quantum efficiency = 0.75.

f- Responsivity = 0.937611858402 [A/W].

g- Photodiode type= PIN.

The system parameters for optical transmitter, optical fiber, receiver and other system components are given in tables 1. and 2. A configuration with 3 pumps at 1430 nm, 1475 nm and 1520 nm with respectively 550 mW, 170 mW and 90 mW is used to provide a flat gain into a broad bandwidth (around 10 THz).

Figure 2. shows the optical spectrum at the input of optical fiber and it reached to 28 dB and this is taking for only eight channels, but after optical fiber (717.5 Km) it drops to 18 dB (Figure 3.) and this is before using Raman Amplifier. After using Raman Amplifier, the optical spectrum is 28 dB and this is the same at the input of optical fiber as shown in Figure 4. From this figure, we can find that the SRS and FWM effects are minimized.

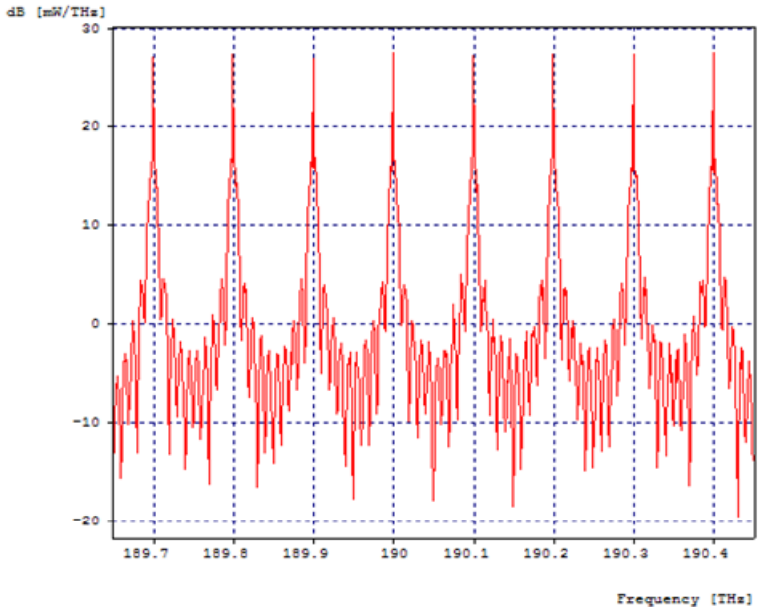

Figure 2. Optical Spectrum at the input of fiber for only eight channels.

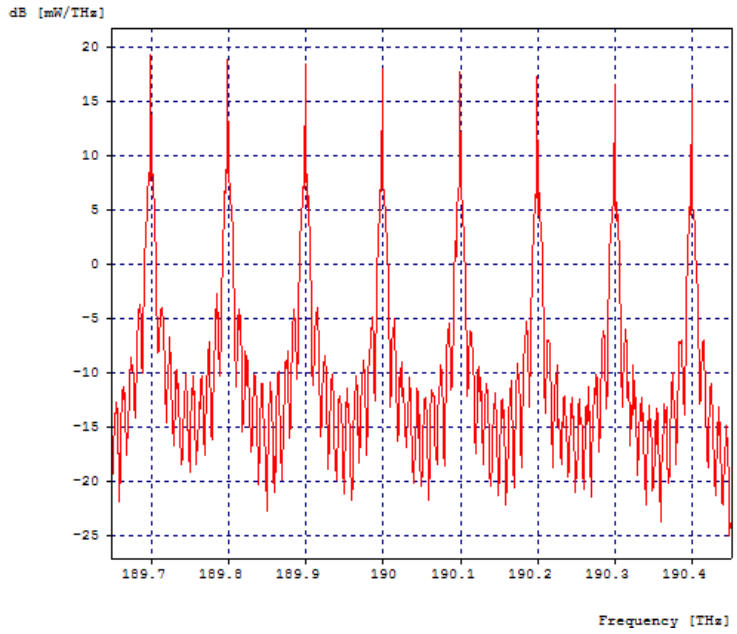

Figure 3. Optical Spectrum at the output of fiber (for only eight channels) before using Raman Amplifier for span 10 (717.5 Km).

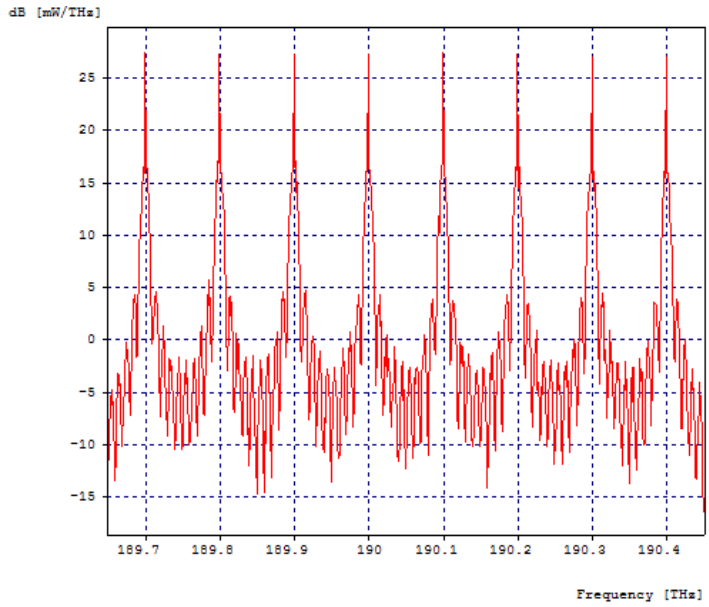

Figure 4. Optical Spectrum at the output of fiber (for only eight channels) after using Raman Amplifier for span 10 (717.5 Km).

Figure 5. shows the Raman Amplifier Designed gain that it is used in Raman multipump configuration and before multi-span. This figure shows the better gain variation and gain flatness equal to 0.6 dB.

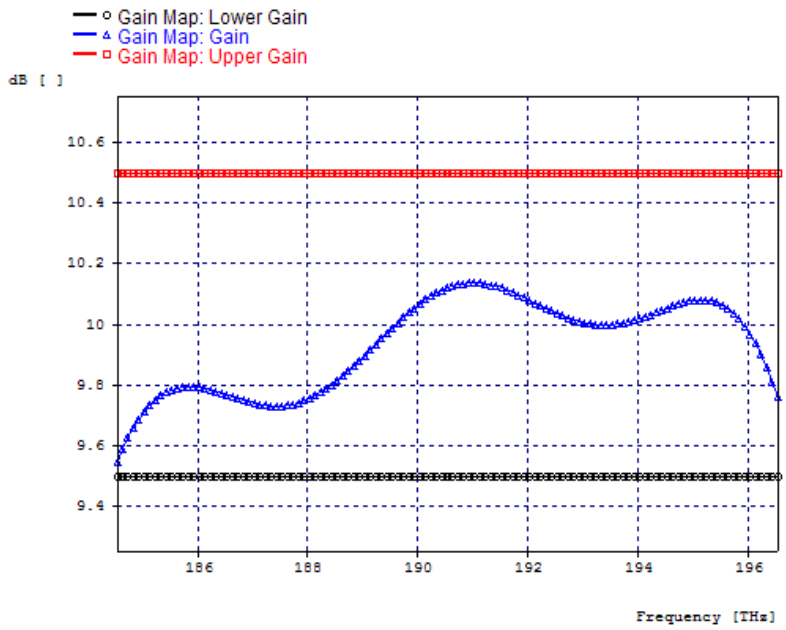

Figure 5. Total Flat gain after three pumps by using Raman multipump configuration.

Figures 6. and 7. shows the total optical spectrum before and after using Raman Amplifier for 96 channels for 717.5 Km optical fiber length. From this figures we can see that the variation of optical spectrum after using Raman Amplifier (23 dB) is better than without using it.

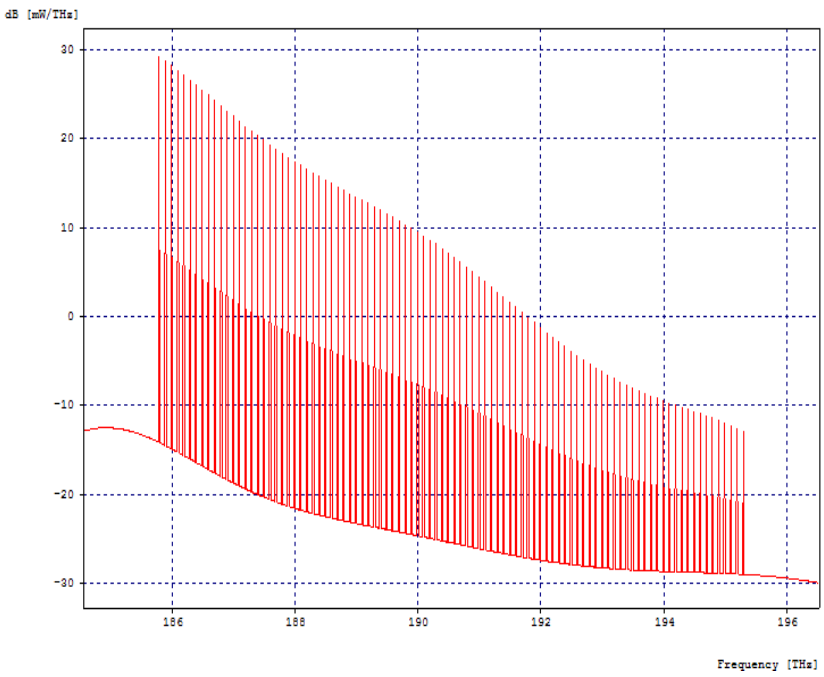

Figure 6. Total optical Spectrum before optical splitter (inside the span loop) and before using Raman Amplifier for Span 10 (717.5 Km).

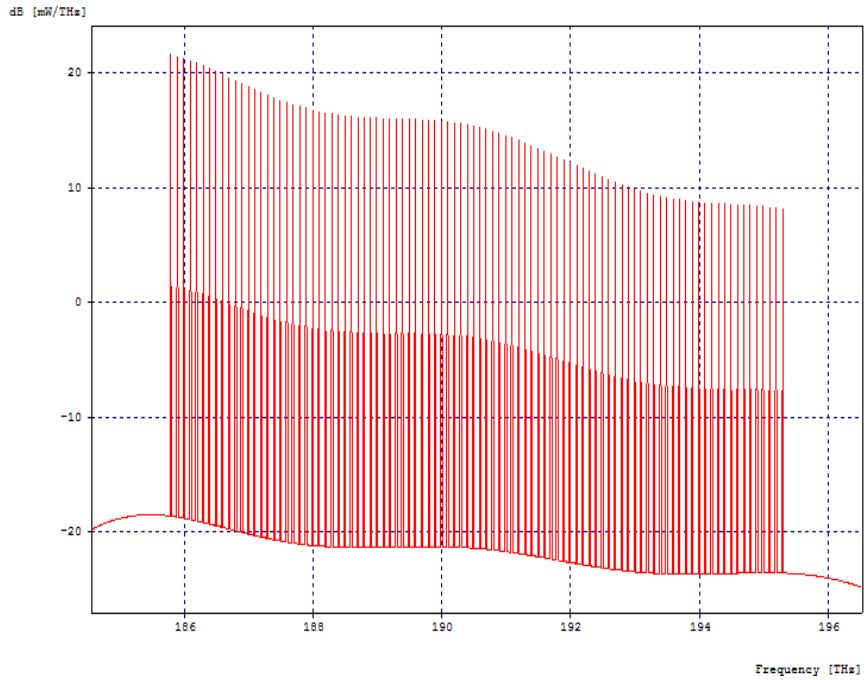

Figure 7. Total optical Spectrum after optical splitter (inside the span loop) and using Raman Amplifier for Span 10 (717.5 Km).

Figure 8. shows the Noise Figure after three pumps, and its value is equal to 2 dB so it is low value.

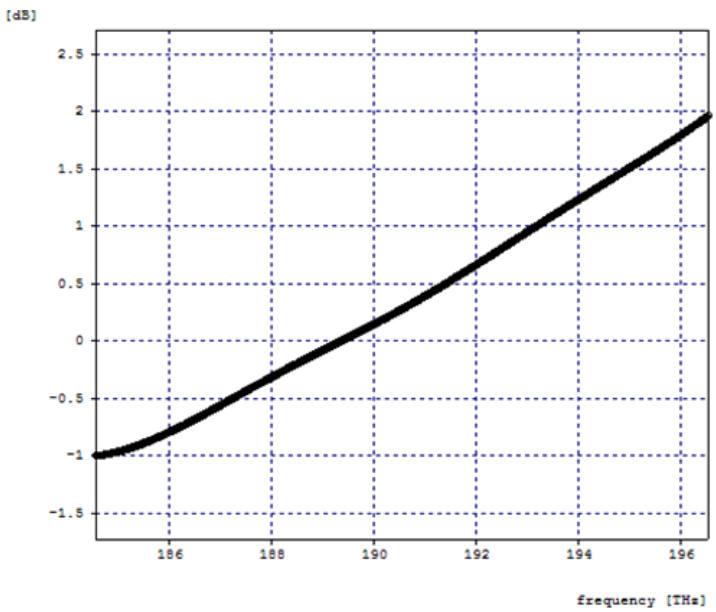

Figure 8. Total Raman Noise Figure after three pumps by using Raman multipump configuration.

Figures 9 and 10 show the eye diagram for channels 40 and 47 with and without using Raman Amplifier, so as shown in this figures the eye is more open with Raman Amplifier than that without using it.

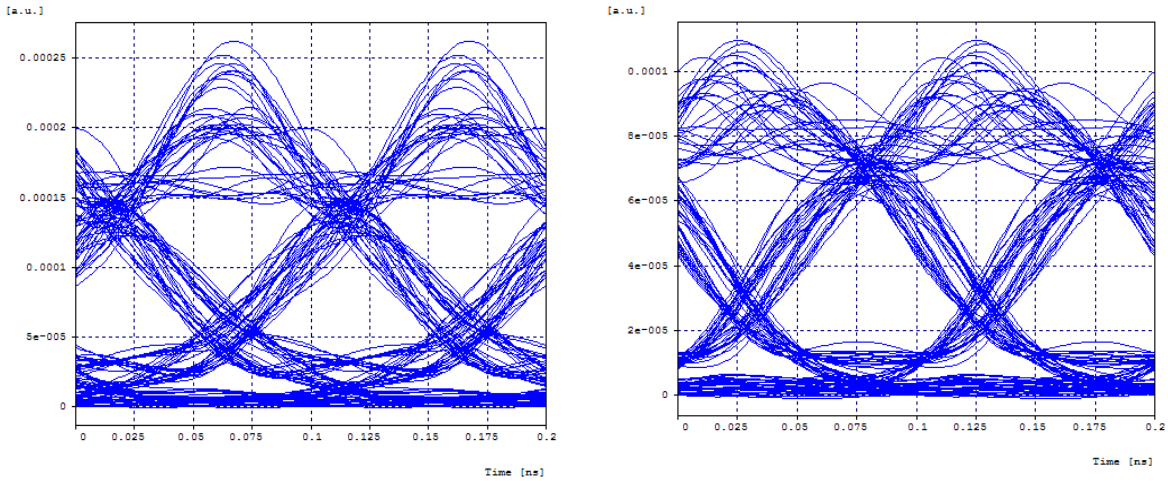

Figure 9. Eye Diagram output for channel 40 & 47 without using Raman Amplifier.

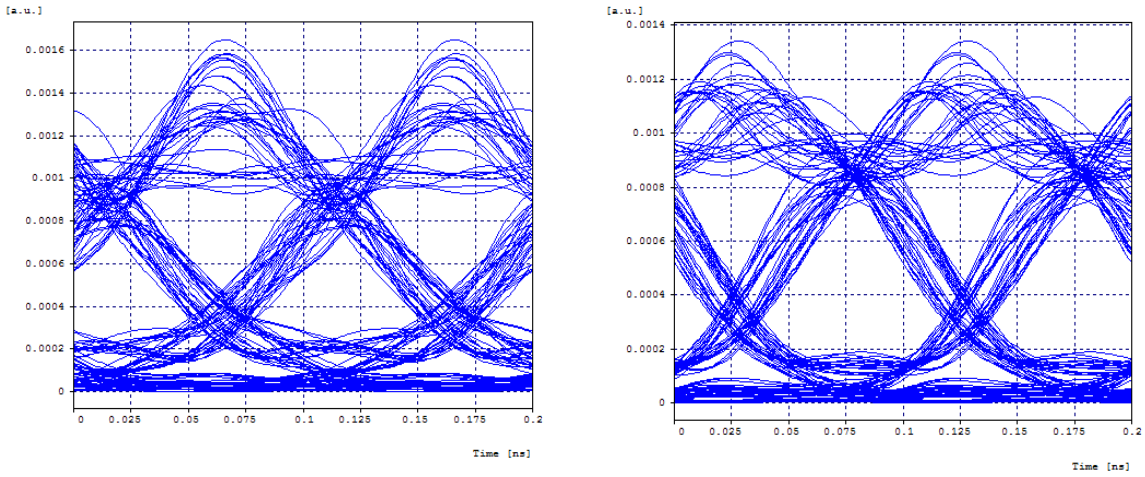

Figure 10. Eye Diagram output for channel 40 & 47 by using Raman Amplifier.

Figure 11. shows the Raman On-Off Gain using Raman Amplifier that is equal to 14 dB and without using Raman Amplifier that is equal to 12 dB (before DCF), so this figure shows that the flat gain is obtains by using Raman Amplifier.

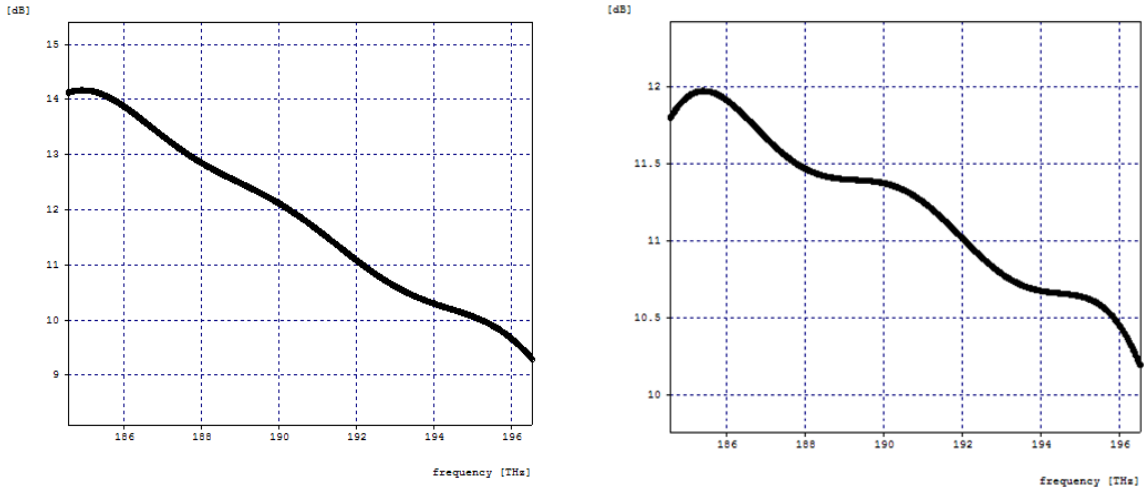

Figure 11. Raman On-Off Gain for span 10 (717.5 Km) with and without using Raman Amplifier.

In order to get better performance and improve the gain flatness we can use four counter-propagation Raman pumps at 1521.4 nm, 1516.8 nm, 1472.1 nm and 1428.6 nm with respectively 23.849 mW, 29.886 mW, 151.4 mW and 490.59 that is used to provide a ultra wideband (83 nm).

Figures 12. & 13. shows the optical spectrum and OSNR before optical fiber. As shown in this figures the optical spectrum is reach to 23 dB, OSNR is 26.9 dB, and this is the best performance that we can get it.

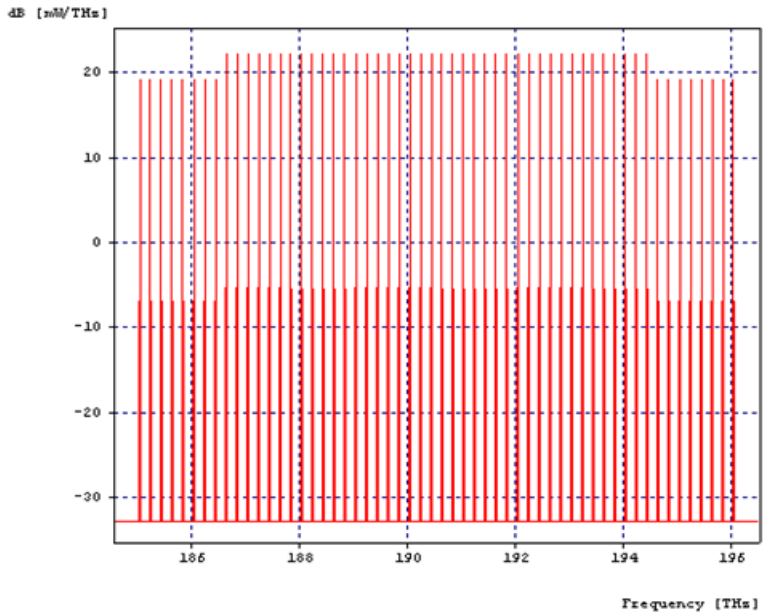

Figure 12. Total optical Spectrum before optical fiber.

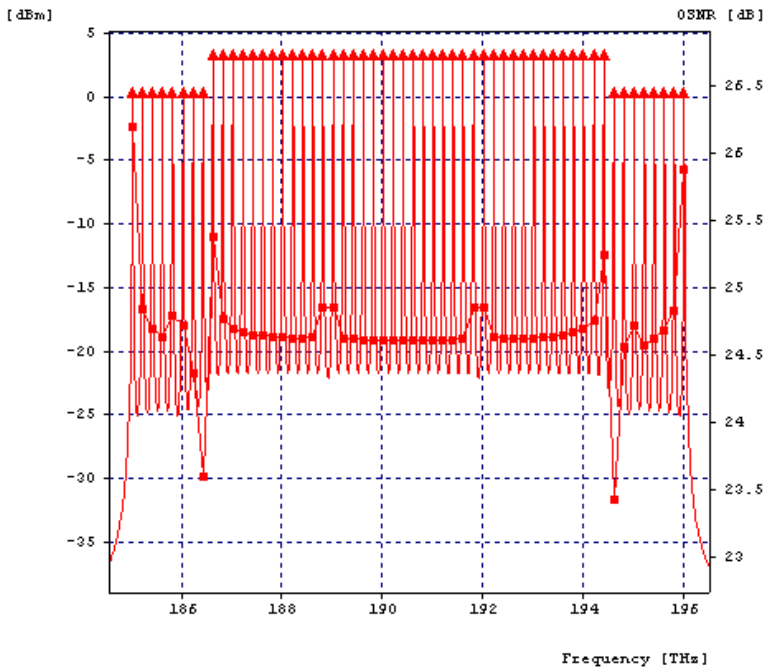

Figure 13. OSNR spectrum before optical fiber.

Figures 14. & 15. shows the optical spectrum and OSNR after optical fiber and by using four pumps configuration. As shown in this figures the optical spectrum is reach to 23 dB and OSNR is 26.5 dB with gain flatness 9 dB and SRS & FWM effects are minimize.

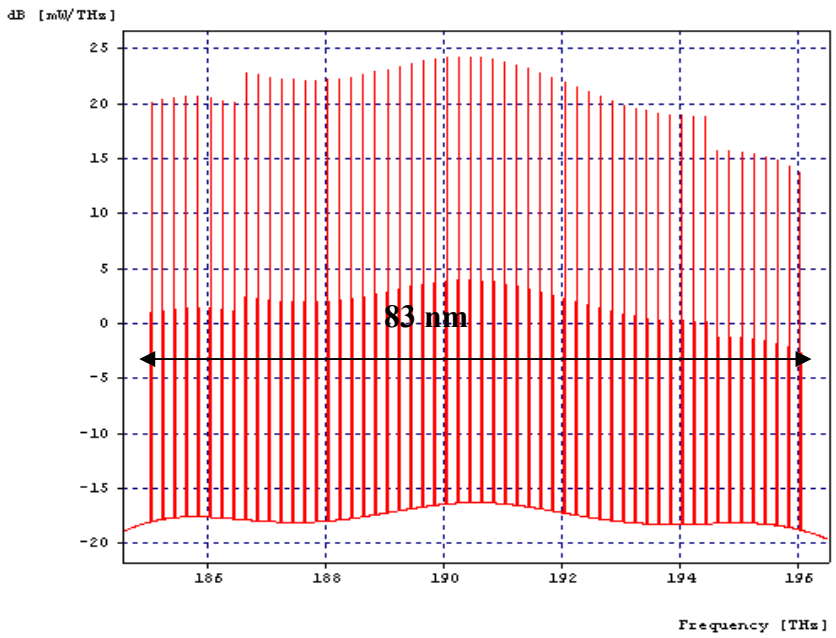

Figure 14. Total optical Spectrum after optical splitter (after In-Line-Amplifier) and using Raman Amplifier for Span 10 (717.5 Km).

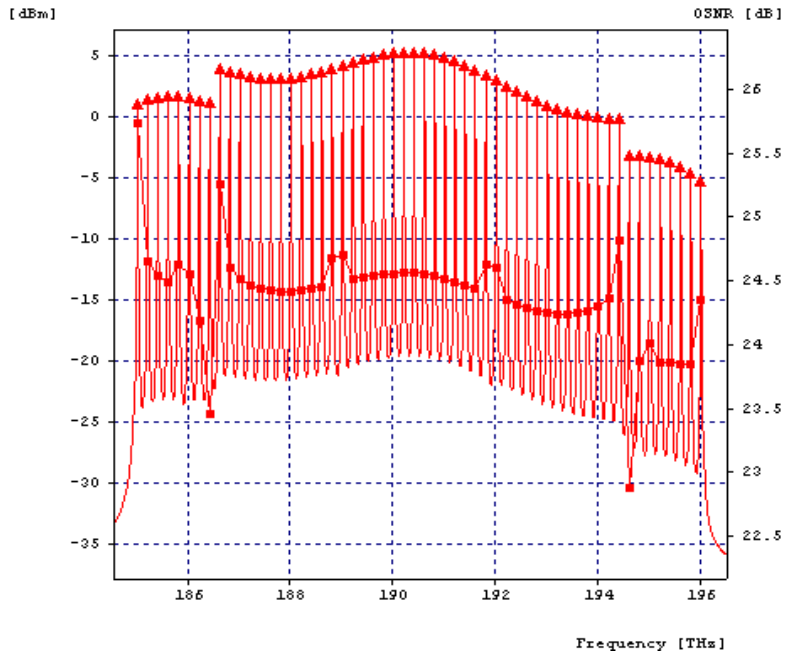

Figure 15. OSNR Spectrum after optical splitter (after In-Line-Amplifier) and using Raman Amplifier for Span 10 (717.5 Km).

3. CONCLUSIONS

In this proposal system we can transmit 96 channels and with a distance larger than 700 Km (with channel spacing 100 GHz) with a little distortion and with a bandwidth around 10 THz. The Amplifiers spacing is equal to 71.75 Km. Therefore, we have achieved the high gain 24 dB over the wavelength range of 83 nm (1533-1616 nm) by using multipump configuration.

Note that we use DCF because we need it in high-speed systems but there is losses that appear when use DCF so we use multipump configuration to compensate this losses [7].

The proposal system in figure 1. shows that we can be achieved bandwidths of around 10 THz without any gain equalization devices. This constitutes a substantial improvement in gain flatness compared to the existing wide-band optical fiber amplifiers.

REFERENCES

[1] Shingo Kawai, Hiroji Masuda, Ken-Ichi Suzuki and Kazuo Aida, "Wide bandwidth and long distance WDM transmission using highly gain-flattened hybrid amplifier" IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 11, NO. 7, JULY 1999.

[2] L.D Garrett, A.H Gnauck, R.W. Tkach, B. Agogliati, L. Arcangeli, D. Scarano, V. Gusmeroli, C. Tosetti, G. Di Maio, and F. Forghieri, "Ultra-wideband WDM transmission using cascaded chirped fiber gratings" IEEE, Phot. Tech. PD 15, 1999.

[3] Kimio Oguchi, Masahiko Jinno and Takeshi Kitagawa, "Ultra-wide band WDM networks and supporting technologies" IEEE PHOTONICS TECHNOLOGY LETTERS, pp. 1277, 1999.

[4] Wonkyoung Lee, W. J. Shin, H. S. Seo, K. Oh " Study on the design of Non Zero Dispersion Shifted Fiber for ultra-wide band WDM transmission" Conf. on Opt. Comm. 2001.

[5] Hiroji Masuda, Shingo Kawai, Ken-Ichi Suzuki, and Kazuo Aida, "Ultra wide 75-nm 3-dB Gain-Band Optical Amplification with Erbium-Doped Fluoride Fiber Amplifiers and Distributed Raman Amplifiers", IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 10, NO. 4, APRIL 1998.

[6] A. Carena, Member, IEEE, V. Curri, Member, IEEE, and P. Poggiolini, Member, IEEE, "On the Optimization of Hybrid Raman/Erbium-Doped Fiber Amplifiers" IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 13, NO. 11, NOVEMBER 2001.

[7] Y. Sun, J.W. Sulhoff, A.K. Srivastava, A. Abramov, TA. Strasser, P.F. Wysocki, J.R. Pedrazzani, J.B. Judkins, R.P. Espindola, C. Wolf, J.L . Zyskind, A .M. Vengsarkar, and J. Zhou," Y. Sun, J.W. Sulhoff, "A Gain-Flattened Ultra Wide Band EDFA For High Capacity WDM Optical Communications Systems", IEEE PHOTONICS TECHNOLOGY LETTERS, September 1998.