# The Parameters affecting on Raman Gain and Bandwidth for Distributed Multi-Raman Amplifier

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## Abstract

Due to the benefits of Raman amplifier for Long-Haul UW-WDM Optical Communications Systems, we interest in this paper to investigate the parameters affecting on Raman gain and bandwidth, and also we are analyzed four and eight Raman pumping of special pump power and pumping wavelengths to show the effect of this parameters on gain and bandwidth. The model equations are numerically handled and processed via specially cast software (Matlab). The gain is computed over the spectral optical wavelengths (1.45μm ≤ $\lambda_{signal}$ ≤ 1.65μm).

*Keywords:* *Raman amplifier, Distributed multi-pumping Raman amplifier (DMRA), Raman gain, pumping power and wavelength, ultra wide-wavelength division multiplexing (UW-WDM).*

## 1. Introduction

There are mainly three reasons for the interest in Raman amplifier. First its capability to provide distributed amplification second is the possibility to provide gain at any wavelength by selecting appropriate pump wavelengths, and the third is the fact that the amplification bandwidth may be broadened simply by adding more pump wavelengths. An important feature of the Raman amplification process is that amplification is achievable at any wavelength by choosing the pump wavelength in accordance with the signal wavelength [1].

The term distributed amplification refers to the method of cancellation of the intrinsic fiber loss. the loss in distributed amplifiers is counterbalanced at every point along the transmission fiber in an ideal distributed amplifier [1].

In the late eighties, Raman amplification was perceived as the way to overcome attenuation in optical fibers and research on long haul transmission was carried out demonstrating transmission over several thousand kilometers using distributed Raman amplification. However, with the development and commercialization of erbium-doped fiber amplifiers through the early nineties, work on distributed Raman amplifiers was abandoned because of its poor pump power efficiency when compared to erbium-doped fiber amplifiers (EDFAs). In the mid-nineties, high-power pump lasers became available and in the years following, several system experiments demonstrated the benefits of distributed Raman amplification including repeater-less undersea experiments, high-capacity terrestrial as well as submarine systems transmission experiments, shorter span single-channel systems including 320 Gbit/s pseudo linear transmissions, and in soliton systems [1].

distributed Raman amplifiers improved noise performance because of amplification at any wavelength controlled simply by selecting the appropriate pump wavelength, extended bandwidth achieved by using multiple pumps when compared to amplification using EDFAs, and finally control of the spectral shape of the gain and the noise figure, which may be adjusted by combining and controlling the wavelength and power among multiple pumps [1].

The use of distributed Raman amplification has already been demonstrated in ultra-high-capacity optical communication systems as the enabling method to transmit 40Gbit/s per channel in a wavelength-division-multiplexed transmission system [1].

Ultra long-haul (ULH) and ultrahigh-capacity (UHC) dense wavelength-division-multiplexed (DWDM) optical communication systems have recently attracted considerable attention due to their potential to greatly reduce bit-transport costs while addressing the ever-increasing demand for voice and data traffic. A flexible all-Raman pumping scheme, including forward-and backward-pumping of the fiber span and backward pumping of the dispersion compensation modules (DCMs), can be used as a common platform yielding excellent system performance for 10 Gb/s ULH and 40Gb/s signals and ULH transmission over 2500 km in a hybrid configuration [2]. It was shown how that amplification scheme provides enough gain to handle discrete losses from optical add/drop multiplexers (OADMs) inserted along the transmission. A comprehensive experimental investigation of an all-Raman ultra wide signal-band transmission system for both 10 and 40 Gb/s line rates was done [2].

The most important feature of Raman-gain spectrum is that the peak-gain wavelength only depends on the pump wavelength. The peak-gain wavelength for each pump still exists although the total gain spectrum of a multi-pumped fiber Raman amplifier (FRA) is the comprehensive result of all pumps [3].

Two critical merits of distributed Raman amplifier (DRA) are the low noise and the arbitrary gain band. Experiments show that 2.5 Gb/s system could be up graded to 10Gb/s by only adding a Raman amplifier [4].

Raman amplifiers pumped at multiple wavelengths draw significant attention in high-speed long-haul WDM transmission, for example, because of their wideband flat-gain profile (100nm with 12 channel-WDM pumping) and superior signal-to-noise ratio (SNR) performance. However, they require numbers of high power pump lasers to achieve high-gain and high bandwidth which makes it very expensive at the initial deployment stage where the WDM bandwidth is not in full use. While modular band-by-band and high upgrade like EDFA-based WDM systems reduces system introduction cost very much, in which either C or L-band EDFAs can be added later when a new bandwidth becomes needed. However, such modular addition of amplifiers is not possible for a DRA in which a transmission fiber is shared as common-gain medium. Neglecting nonlinear pump interaction or saturation WDM-pumped Raman amplifier gain can be approximated as the linear superposition of Raman gains induced by each pump laser [5].

Currently, RFAs are the only silica-fiber based technology that can extend the amplification bandwidth to the S band while providing performance and reliability comparable with those of EDFAs. However, the noise figure remains high compared to that of the C and L bands [6].

In this paper, the parameters affecting on Raman gain coefficient and Raman differential gain and bandwidth are processed through a numerical solution of the mathematical model.

## 2. Mathematical Model

In the present section, we cast the basic model and the governing equation to process N-Raman amplifiers in a cascaded form of special pumping powers $P_{r1}$, $P_{r2}$, $P_{r3}$, $P_{r4}$, ……., $P_{rN}$ and corresponding pumping wavelengths $\lambda_{r1}$, $\lambda_{r2}$, $\lambda_{r3}$, $\lambda_{r4}$, ……., $\lambda_{rN}$. The map of δ-g is as shown in Fig. 1, where δ is the Raman shift and g is the Raman differential gain coefficient; both were cast based on [7-11] as:

$$\delta = \frac{\lambda_s - \lambda_r}{\lambda_s \lambda_r} \times 10^4 \, , cm^{-1} \qquad (1)$$

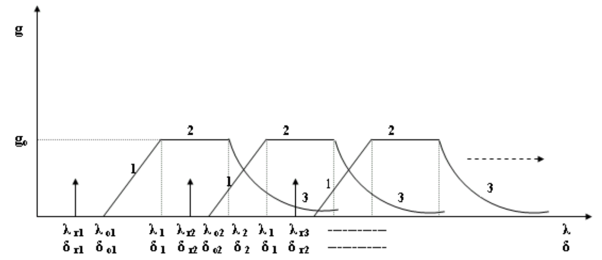

Figure 1 Gain, g, of multi-pump Raman amplifier.

The map of δ–g shown in Fig. 1 describes the basic model. This section depends on the position of the gain of each amplifier with wavelength, where the gain of each amplifier consists of three parts (three equations). A special software program is used to indicate the position of $\delta_{o,i}$ or $\lambda_{o,i}$ and studying the total gain of the amplifiers. In this case, the basic model depends on using more than one amplifier which is put in a cascaded form to increase the bandwidth of the amplifier to multiplexing more signals in the transmission system. The overall amplifier bandwidth increases and the gain flatness improved depend on the position of each amplifier corresponding to other amplifiers. This is achieved by more trials of changing of $\delta_{o,i}$ or $\lambda_{o,i}$ for each amplifier.

The general equations representing the Raman gain in the three regions are respectively [11].

$$g_{1,i} = g_o \frac{\delta}{440} \quad , \quad 0 \le \delta \le 440 \qquad (2)$$

*Where*

$$\delta = \frac{\lambda_s - \lambda_r}{\lambda_s \lambda_r} \times 10^4 \, , cm^{-1} \qquad (3)$$

$$g_{2,i} = g_o\,,\ \ \delta_{1,i} \le \delta \le \delta_{2,i}\ and\ \lambda_1 \le \lambda \le \lambda_2 \qquad (4)$$

Where $g_o = 7.4 \times 10^{-14}\, m/W$ and

$$\delta_{1.i} = \frac{\lambda_{1,i} - \lambda_{r.i}}{\lambda_{1,i}\lambda_{r,i}} \times 10^4\,, cm^{-1} \qquad (5)$$

$$\delta_{2.i} = \frac{\lambda_{2,i} - \lambda_{r.i}}{\lambda_{2,i}\lambda_{r,i}} \times 10^4\,, cm^{-1} \qquad (6)$$

And

$$g_{3,i} = g_o e^{-0.005(\delta - 440)}\quad ,\qquad \delta \ge 440 \qquad (7)$$

$\Delta\lambda = \lambda_2 - \lambda_1$ = 15 nm = (fixed value)

$$\lambda_1 = \frac{\lambda_{r1}}{1 - 0.044\lambda_{r1}} \times 10^4\,, \mu m \qquad (8)$$

$$g_{1,i} = g_o \frac{\delta - \delta_{o,i}}{440} \qquad (9)$$

Where

$$\delta_{o,i} \le \delta \ge \delta_{1.i}\quad ,\qquad 0 \le \delta - \delta_{o,i} \le 440 \qquad (10)$$

With

$$\delta_{o.i} = \frac{\lambda_{o,i} - \lambda_{r.i}}{\lambda_{o,i}\lambda_{r,i}} \times 10^4\,, cm^{-1} \qquad (11)$$

With 1 $cm^{-1}$ = 30 GHz [12], where $\lambda_{o,i}$ indicates the offset wavelength and $\lambda_{r,i}$ indicates the pumping wavelength of each amplifier. These wavelengths are then used to indicate $\delta_{o,i}$ for each amplifier.

$$g_{2,i} = g_o\quad ,\qquad \delta_{1,i} \le \delta \le \delta_{2,i} \qquad (12)$$

Where, $g_o = 7.4 \times 10^{-14}\, m/W$ is the differential Raman gain constant (of pure $SiO_2$ at $\lambda$ = 1.34 μm), and

$$\delta_{1.i} = \frac{\lambda_{1,i} - \lambda_{r.i}}{\lambda_{1,i}\lambda_{r,i}} \times 10^4\,, cm^{-1} \qquad (13)$$

$$\delta_{2.i} = \frac{\lambda_{2,i} - \lambda_{r.i}}{\lambda_{2,i}\lambda_{r,i}} \times 10^4\,, cm^{-1} \qquad (14)$$

And

$$g_{3,i} = g_o e^{-0.025(\delta - \delta_{2,i})}\quad ,\qquad \delta \ge \delta_{2,i} \qquad (15)$$

$\Delta\lambda = \lambda_2 - \lambda_1$ = 16 nm = (fixed value)

$$\lambda_1 = \frac{\lambda_{o1}}{1 - 0.044\lambda_{o1}} \times 10^4\,, \mu m \qquad (16)$$

Where, $\lambda_r$ is Raman pump wavelength and $\lambda_o \ge$ 1.35um.

The shift $\delta_{o,i}$ is the Raman shift that indicates the position of each amplifier. By changing this position, the total bandwidth and the flatness of the amplifier are changed. We are interested in obtaining a large bandwidth with flatness by more trials of changing $\delta_{o.i}$ or $\lambda_{o,i}$. In this case, one uses $\delta > \delta_r$ or $\lambda > \lambda_r$ and $\delta_o \ge \delta_r$ or $\lambda_o \ge \lambda_r$, where $\lambda_r$ is Raman pump wavelength. Raman differential gain constant, g, and the effective core area, A, are defined as [8]:

$$g = 1.34 \times 10^{-6} \times g_o \frac{1 + 80\Delta}{\lambda_r} \qquad (17)$$

$$A = \frac{\pi}{2}(W_s^2 + W_r^2), \qquad (18)$$

Where

$$W = \frac{0.21\lambda}{\sqrt{\Delta}} = \frac{0.3\lambda n_1}{N_A}\,, \qquad (19)$$

Where, $\lambda_r$ is the pump wavelength, $W_s$ and $W_r$ are the mode field radii of two light waves coupled with each other with $W=W_s$ at $\lambda = \lambda_s$ and $W=W_r$ at $\lambda = \lambda_r$ and $\Delta$ is the relative refractive index difference, $n_1$ is refractive index of the core and $N_A$ is the numerical aperture.

Neglecting the cross coupling among the signal channels, one has the differential equation governing the signal propagation for N-channels Raman pumping [9]:

$$\frac{ds_i}{dz} + \sigma_{si}s_i = \left(\sum_{i=1}^{i=N}\sum_{j=1}^{j=M} \frac{\boldsymbol{g_{ij}}}{\boldsymbol{A_{ij}}} \boldsymbol{P_{Rj}}\right)\boldsymbol{s_i}\,, \qquad (20)$$

Where, i = 1,2,3,…….N, M is the number of pumps, $S_i$ is signal power and $P_{Rj}$ is the pump power. Assume the R.H.S of equation (20) equals $g_{ti}$ , as:

$$\boldsymbol{g_{ti}} = \left( \sum_{\boldsymbol{i=1}}^{\boldsymbol{i=N}} \sum_{\boldsymbol{j=1}}^{\boldsymbol{j=M}} \frac{\boldsymbol{g_{ij}}}{\boldsymbol{A_{ij}}} \boldsymbol{P_{Rj}} \right), \qquad (21)$$

The total gain coefficient in $m^{-1}$ which represents the total gain coefficient of the $i^{th}$ signal due to the N-pumping. It is clear that $g_{ti}$ is a function of the set of variables {signal wavelength, fiber radius, Raman wavelength, relative refractive index difference, Raman power}. This term can be written in the form:

$$\boldsymbol{g_{ti}} = \left( \sum_{\boldsymbol{i=1}}^{\boldsymbol{i=N}} \sum_{\boldsymbol{j=1}}^{\boldsymbol{j=M}} \boldsymbol{g_{di}} \boldsymbol{P_{Rj}} \right), \qquad (22)$$

Define $g_{ci}$ , the total gain coefficient per watt, as

$$g_{ci} = \left( \sum_{i=1}^{i=N} \sum_{j=1}^{j=M} \frac{g_{dij}}{A_{ij}} \right), m^{-1} W^{-1} \qquad (23)$$

Then, the total differential gain, $g_{di}$, is:

$$g_{di} = \left( \sum_{i=1}^{i=N} \sum_{j=1}^{j=M} g_{ij} \right), mW^{-1} \qquad (24)$$

The three gain coefficients $g_{di}$, $g_{ci}$ and $g_{ti}$ are also functions of the propagation distance.

## 3. Simulation Results and Discussions

The gain and bandwidth for distributed multi-pump Raman amplifier (DMRA) is optimized. Optimal results show that the parameters effecting on the Raman gain and bandwidth, where the gain of the amplifier change according to the pumping wavelengths and relative refractive index difference and also the bandwidth, $\Delta\lambda_r$, can be evidently broadened by means of increasing the number of pumps and according to the position of each amplifier and the gain is increases with increase the relative refractive index difference.

In this paper, we discuss two different models namely four and eight Raman pumping optical wavelengths and pumping power are shown in the table I and II respectively, where the sum of pumping power is one watt. The three gain coefficients $g_{di}$, $g_{ci}$, and $g_{ti}$ are displayed for each case.

### 3.1 Effect of Relative Refractive Index Difference on Raman Gain

Figure 2, explains the relation between Raman gain and relative refractive index difference, and this figure is plotted for special pumping wavelengths. It's found that Raman gain increases with the relative refractive index difference.

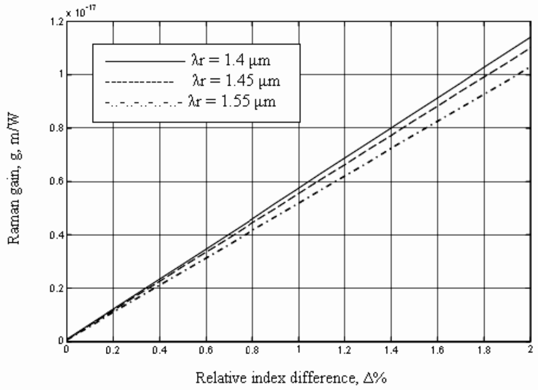

Figure 2 Raman gain versus relative refractive index difference.

Then for Raman amplifier to get amplifier with high gain must be design or used fiber with high relative refractive index difference and also used pumping source suitable wavelength's where if pumping wavelength increased we get losses is increases and this not required in design.

So, the relative refractive index difference of the materials must be taken in account in design for optical amplifiers.

### 3.2 Effect of Pumping Wavelength on Raman Gain

If pumping wavelengths increases, Raman gain decreases. Figure 3, explains the relation between Raman gains, g m/w, and pumping wavelength, $\lambda_r$, μm. This figure is plotted at different values of relative refractive index difference, where pumping wavelengths for optical signals is in a range from 1.4 to 1.55 μm. This range is suitable for Raman amplifier to avoid noise and losses.

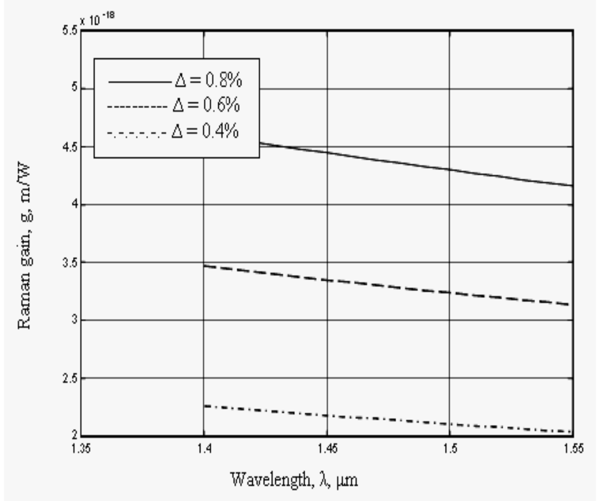

Figure 3, Variation of Raman gain, g, with pumping wavelength, $\lambda_r$, um

Where if pumping wavelength above 1.55 μm we get losses and noise is large and this not required for the signal transmitted (this is disadvantages) but we need amplifier with high gain, so to avoid this problem must be increase relative refractive index difference to get balance between gain and pumping wavelength.

Then, any source having a pumping wavelength and pumping power must be suitable for the choice design to obtain suitable gain and bandwidth.

### 3.3 Relation between Mode Field Radii and Relative Refractive Index Difference

The mode field radii are inversely proportional to the relative refractive index difference.

Figure 4, explains the variation of the mode field radii with relative refractive Index difference at special pumping wavelengths.

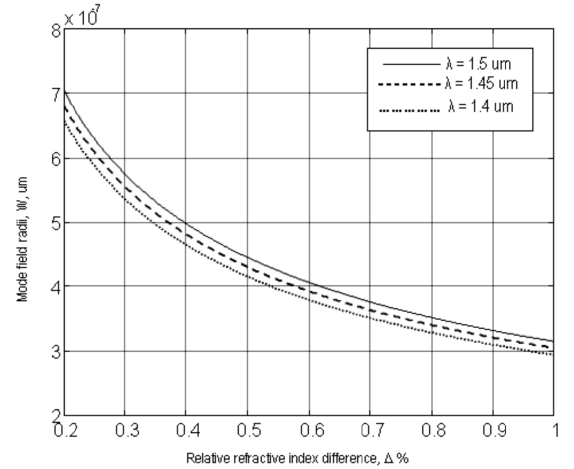

Figure 4, Variation of mode field radii with relative refractive index difference , Δ%

we get if relative refractive index difference increases the mode field radii decreases but the numerical aperture increases and we need the two are increases in design, to avoid losses in transmitted signal when you are coupling between the different fibers this achieved by using sources with high pumping wavelength's.

### 3.4 Relation between Mode Field Radii and Pumping Wavelength

The mode field radii are proportional to the pumping wavelengths. Figure 5, explains this relation at special values of the relative refractive index difference in the wavelength range 1.4 – 1.5 μm. Then, one can get the Raman gain which depends on pumping wavelengths and mode filed radii which depend on the relative refractive index difference.

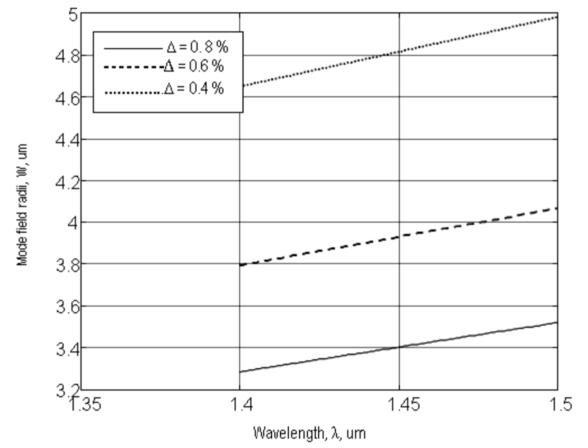

Figure 5, Variation of mode field radii versus pumping wavelengths.

If pumping wavelength increase the mode field radii increase so, in design we must take in account the pumping wavelength and also relative index difference where, if relative index difference increase the mode field radii decreases.

### 3.5 Relation between Mode Field Radii and Effective Core Area

Figure 6, explains the relation between mode field radii of pumping signal, $w_r$, and effective core area, A, where the mode field radii increases with the effective core area.

This curve is plotted at special values of mode field radii of the signal, $w_s$. This result is useful where; the effective core area affects in Raman gain and must be taking into account.

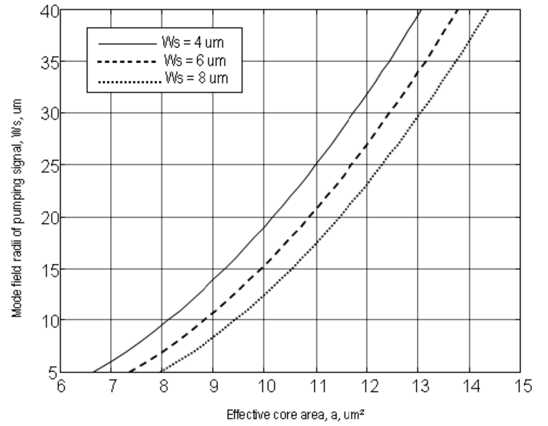

Figure 6, Variation of mode field radii of pumping signal, $w_r$, with effective core area, A, μm$^2$.

Figure 7, displays the relation between mode field radii of signal, $w_s$, and effective core area, A, where, the mode field radii increases with the effective core area exponentially according to above equation. This curve is plotted for special value of mode field radii of pumping signal, $w_r$ .

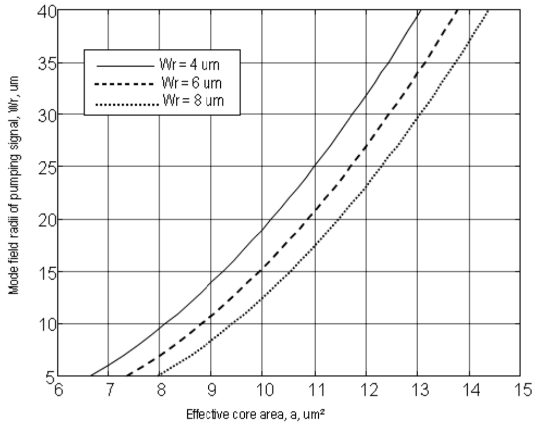

Figure 7, Variation of mode field radii of signal, $w_s$, versus effective core area, A, μm$^2$

Then from figures 6 and 7, we get for increase the area of the fiber (diameter of the core of the fiber) we get mode field radii increase and this also advantages for coupling signals between different fibers to get high efficiency to transmitted the signals between different joints and different fibers.

## 3.6 Relation between Effective Core Area and Relative Refractive Index Difference

Figure 8, shows the relation between the effective core area and the relative index difference, Δ. This curve is plotted at special pumping wavelengths. It is clear that the effective core area decreases (exponentially) with Δ.

Since Raman gain is proportional to relative refractive index difference and effective core area, then this result is very useful to indicate the parameters affecting in Raman gain to obtain a maximum and flat gain.

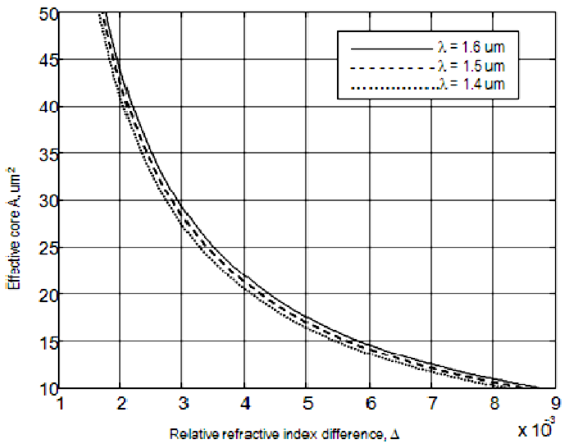

Figure 8, Variation of effective core area, A, um$^2$ versus relative index difference, Δ.

In design to avoid this disadvantage must be used source with high pumping wavelength in range ($1.45\mu m \le \lambda_{signal} \le 1.55\mu m$) because of it is important for used fiber with effective core area is large to avoid the losses in signals which occurs when coupling between different fibers.

## 3.7 Effect of Number of pumping (number of optical amplifier) on the Gain and the Flatness of the Gain

In this case we discuss two different models namely four and eight Raman pumping optical wavelengths and pumping powers in this case we get the gain of the amplifiers increased and the flatness of the gain is improved with increasing the number of pumping.

### 3.7.1 Number of optical amplifier = 4

Table I Number of amplifiers = 4

$$\lambda_1 = \frac{\lambda_o}{1 - 0.044\lambda_o} \times 10^4 \,, \mu m$$

$\lambda_1 - \lambda_o$ = fixed (0.096294798) and $\lambda_2 - \lambda_1$ = 16 nm

| $\lambda_r$ | $\lambda_o$ | $\lambda_1$ | $\lambda_2$ | $P_p$(W) |
|---|---|---|---|---|
| 1.4 | 1.432 | 1.528294799 | 1.544294799 | 0.2 |
| 1.42 | 1.452 | 1.548294799 | 1.564294799 | 0.25 |
| 1.467 | 1.499 | 1.595294799 | 1.611294799 | 0.25 |
| 1.5 | 1.52 | 1.616294799 | 1.632294799 | 0.3 |

### Differential gain

Figure 9, displays the differential Raman gain, g, with wavelength, λ, at different values of the relative refractive index difference. If relative index difference increases, Raman gains increases.

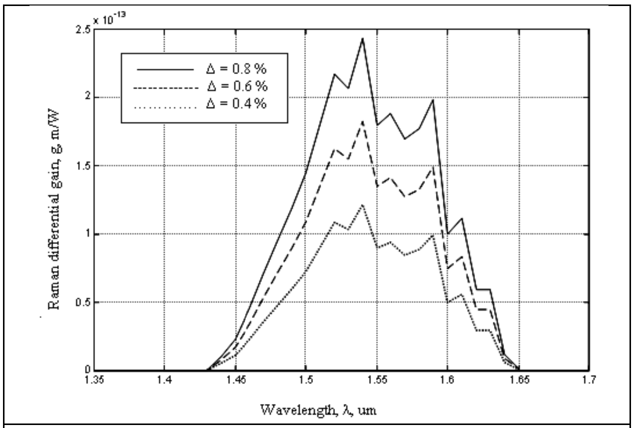

Figure 9, Variation of differential Raman gain with wavelength.

We note that Raman gain is starts to increase from the first pumping wavelength to reach to peak value at 1.54 μm, then the gain is start to decrease exponentially tended to zero at 1.65 μm. Because of optical amplifiers and optical signals are operated in range 1.45 μm to 1.65 μm.

In this case we obtained, total bandwidth =100nm, where $\lambda_{1t}$ = 1.49 μm (for all amplifiers) and $\lambda_{2t}$ = 1.59 μm (for all amplifiers).

### Gain coefficient per unit watt

The gain coefficient/unit watt, ∑ gi / Ai, $m^{-1}$ $W^{-1}$ against wavelength is shown in Fig. 10, at different values of relative refractive index difference.

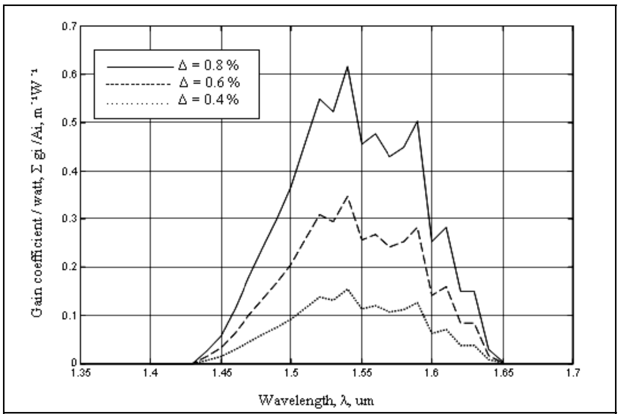

Figure 10, Gain coefficients per unit watt against wavelength.

We note that gain coefficient/unit watt is starts to increase from the first pumping wavelength to reach to peak value at 1.54 μm, then the gain is start to decrease exponentially tended to zero at 1.65 μm.

In this case more than one parameter can be control in gain coefficient per unit watt such that effective core area, relative refractive index difference, pumping wavelengths and pumping powers. So these parameters take in account for any design. Where each parameter can effected in design.

In this case we obtained, total bandwidth =100nm, where $\lambda_{1t}$ = 1.49 μm (for all amplifiers) and $\lambda_{2t}$ = 1.59 μm (for all amplifiers).

In this case we obtained, total bandwidth =110nm, where $\lambda_{1t}$ = 1.51 μm (for all amplifiers) and $\lambda_{2t}$ = 1.62 μm (for all amplifiers).

### Total gain coefficient

Figure 11, displays the variation of the total gain coefficient with wavelength. In this case, a bandwidth of 100 nm is obtained.

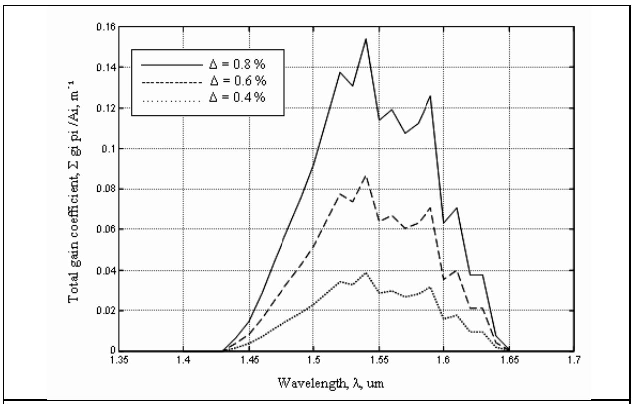

Figure 11, Variation of total gain coefficient with wavelength.

By similar we note the total gain coefficient is start to increase from the first pumping wavelength to reach to peak value at 1.54 μm, the gain is start to decrease exponentially tended to zero at 1.65μm. Gain in this case is affected by pumping powers, effective core area and relative index difference.

Where pumping powers increase the total gain is increase so Raman amplifiers is used to sources with high pumping powers.

### 3.7.2 Number of optical amplifier = 8

Table II Number of amplifiers = 8
$\lambda_1 - \lambda_o$ = fixed (0.093262399) and $\lambda_2 - \lambda_1$ = 16 nm

| $\lambda_r$ | $\lambda_o$ | $\lambda_1$ | $\lambda_2$ | $P_p$(W) |
|---|---|---|---|---|
| 1.41 | 1.41 | 1.503262399 | 1.519262399 | 0.14 |
| 1.44 | 1.444 | 1.537262399 | 1.553262399 | 0.12 |
| 1.45 | 1.455 | 1.548262399 | 1.564262399 | 0.14 |
| 1.46 | 1.466 | 1.559262399 | 1.575262399 | 0.10 |
| 1.47 | 1.478 | 1.571262399 | 1.587262399 | 0.14 |
| 1.48 | 1.489 | 1.582262399 | 1.598262399 | 0.12 |
| 1.49 | 1.501 | 1.594262399 | 1.610262399 | 0.11 |
| 1.5 | 1.512 | 1.605262399 | 1.621262399 | 0.13 |

The differential Raman gain and the gain coefficient per unit watt are displayed, respectively, in Figs. 12 and 13, while the total gain is displayed in Fig. 14. In this case, a 110 nm bandwidth is obtained. Peak value in this case at 1.55 µm for the different gain.

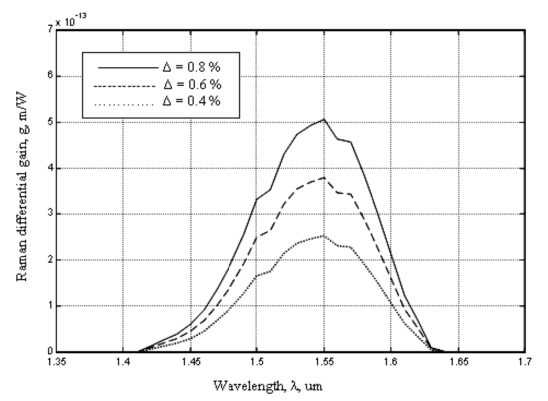

Figure 12, Variation of differential Raman gain with wavelength.

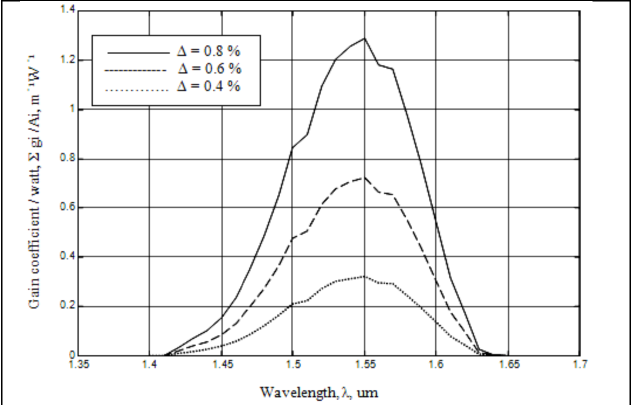

Figure 13, Gain coefficients per unit watt against wavelength.

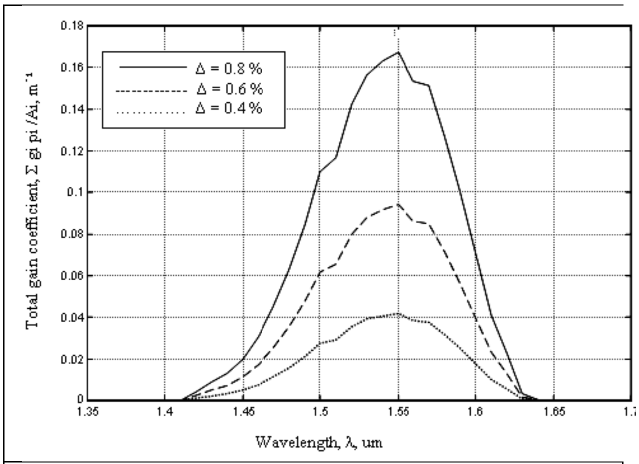

Figure 14, Variation of total gain coefficient with wavelength.

## 4. Conclusion

The bandwidth and the gain of multi-distributed Raman amplifier (MDRA) is effected by the set of variables {$\lambda_s$, $\lambda_r$, Δ, the locations of the maximum constant gain interval, number of optical amplifier, pumping power and effective core area}. We have obtained bandwidth and gain at different value of Δ % for use 4 and 8 optical Raman amplifiers. A summary of the obtained results, in two cases, is found in the following comparison table.

Table of maximum gain and bandwidth for two cases.

| No of optical amplifiers | $g_{max}$ | Δ % | BW(nm) |
|---|---|---|---|
| 4 | $2.4326 \times 10^{-13}$ | 0.8 | 100 |
| | $1.8245 \times 10^{-13}$ | 0.6 | |
| | $1.2163 \times 10^{-13}$ | 0.4 | |
| 8 | $5.0577 \times 10^{-13}$ | 0.8 | 110 |
| | $3.7933 \times 10^{-13}$ | 0.6 | |
| | $2.5289 \times 10^{-13}$ | 0.4 | |

From table we conclude that:

1- If number of optical amplifiers increases, Raman gains increase.
2- If relative index difference increase then we gets Raman gain is increase.
3- Also, for each case only if relative index difference increases, Raman gain is increase.
4- Bandwidth, flatness of the gain and maximum value of the gain depends on the position of amplifiers corresponding to each other's and number of amplifiers where, in case1 bandwidth is equal to 100 nm despite the number of optical amplifier is four, but case 2 bandwidth is equal to 110 nm for number of optical amplifiers is eight and gains in case 2 is maximum and more

flatness than in case 1, because of number of optical amplifiers is large.

## 5. References

[1] C. Headley, G. P. Agrawal "Raman Amplification in Fiber Optical Communication Systems", Elsevier Inc. 2005.

[2] D. F. Grosz, A. Agarawal, S. Banerje, D. N. Maywar, and A. P. Kung, "All-Raman Ultra Long-Haul Signal-Wideband DWDM Transmission Systems with OADM Capability", J. Lightwave Technol., Vol. 22, No. 2, pp. 423-432, 2004.

[3] P. Xiao. O. Zeng, J. Huang, and J. Liu, "A New Optimal Algorithm for Multi-Pumping Sources of Distributed Fiber Raman Amplifier," IEEE Photonics Technol. Lett., Vol. 15, No.2, pp. 206-208, 2003.

[4] X. Liu and B. Lee, "A Fast Stable Method for Raman Amplifier Propagation Equation," Optics Express, Vol. 11, No. 18, pp. 2163-2176, 2003.

[5] N. Kikuchi, "Novel In-Service Wavelength-Based Upgrade Scheme for Fiber Raman Amplifier, "IEEE Photonics Technol. Lett., Vol. 15, No. 1, pp. 27-29, 2003.

[6] Y. Cao and M. Raja, "Gain-Flattened Ultra-Wideband Fiber Amplifiers," Opt. Eng., Vol. 42, No. 12, pp. 4447-4451, 2003.

[7] M. S. Kao and J. Wu, "Signal Light Amplification by Stimulated Raman Scattering in an N-Channel WDM Optical Communication System", J. Lightwave Technol., Vol.7, No. 9, pp. 1290-1299, 1989.

[8] T. Nakashima, S. Seikai, N. Nakazawa, and Y. Negishi, "Theoretical Limit of Repeater Spacing in Optical Transmission Line Utilizing Raman Amplification," J. Lightwave Technol., Vol. LT-4, No. 8, pp. 1267-1272, 1986.

[9] Y. Aoki, "Properties of Fiber Raman Amplifiers and Their Applicability to Digital Optical Communication Systems," J. Lightwave Technol., Vol. 6 No. 7, pp. 1227-1239, 1988.

[10] W. Jiang and P. Ye., "Crosstalk in Raman Amplification for WDM Systems," J. Lightwave Technol., Vol. 7, No. 9, pp. 1407-1411, 1989.

[11] A. A. Mohammed, "All Broadband Raman Amplifiers for Long-Haul UW-WDM Optical Communication Systems," Bulletin of Faculty of Electronic Engineering, Menouf, 32951, Egypt, 2004.

[12] A. Yariv, Optical Electronics in Modern Communications, 5th ed., Oxford Univ. Press, 1997.

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