

# SURVEY ON VARIOUS PERSPECTIVES OF RAMAN AMPLIFIERS

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## ABSTRACT

Raman Amplifier (RA) is the fiber amplifier that follows Stimulated Raman Scattering (SRS) mechanism. For broadband amplification it is used, because of low noise and better gain. Raman amplification was investigated in multiple views. Many research works had focused in the views of pumping schemes, gain flattening, transmission system and noise analysis. In this paper, Raman amplification is studied in the views of varying Refractive Index profile of core, varying core gap radius, hybrid combination of RA with Erbium Doped Fiber Amplifier (EDFA). This paper also studies the investigations of this hybrid combination in Dispersion compensation at C and S bands, recycling of pump power and location of EDFA.

## KEYWORDS

Refractive index profile, Hybrid Amplifiers, Dispersion compensation.

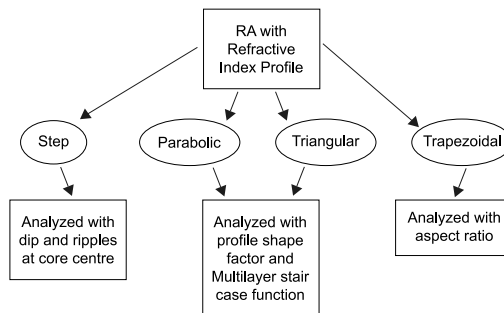
# 1. INTRODUCTION

In long distance Optical communication system, whenever the signal strength becomes low, we need to boost up it. At the beginning, Regenerators were used to rejuvenate the signal. Here, the optical signal is converted into the electrical signal. After the regeneration, the electrical signal is again converted into optical signal which is a very costly process. Then Semiconductor Optical Amplifiers (SOA) were used. From the studies (Elndash, Mohammed & Rashed 2010; Fugihara & Pinto, 2008), these amplifiers have disadvantages like, low output power, high noise figure. In order to avoid these, Fiber amplifiers were used. Fiber amplifiers are the amplifiers where a fiber itself becomes amplification medium by using pumping. There are two fiber amplifiers are mostly used. One is EDFA and second one is Raman Amplifier. In EDFA, a rare earth element Erbium is doped. When EDFA is compared with RA, gain bandwidth is low and wavelength of operation is limited. But in RA, at any wavelength we can obtain amplification. So Raman amplifications are now mostly used in long distance optical communication system. The researches (Bromage, 2004; Islam, 2002; Namiki & Emori, 2001) concluded that Raman amplification has important advantages of having very low noise and suitable for broadband applications, particularly in WDM systems, where simultaneous amplification is required for multi-channel light. Raman amplification may be Distributed Raman amplification (DRA) or lumped Raman amplification. Dhir and Gupta (2013), found that DRA has benefits like high gain, high data rate and less fiber loss. Raman amplifier also provides better performance when it is combined with EDFA or SOA. Many research works had been done in various aspects like flat gain amplification, noise performance, pumping schemes, & hybrid system. Lot of ideas to pump powers and wavelengths selection was discussed in the literatures (Ferreira, Cani, Pontes & Segatto 2011; Neto, Teixeira, Wada, & André, 2007). Raman amplification is happening from the process SRS. SRS is a notable non-linear effect which affects the Signal to Noise Ratio (SNR) in a WDM system. It can also be used for amplification of the optical signals in a long distance optical communication link. The spontaneous Raman scattering was found by Sir C. V. Raman. In case of this scattering, a small quantity of the incident light is changed into light signal of either low or high frequency. SRS gives the amplification if the pump signal with suitable wavelength enters the fiber (Dhir *et al.*, 2013; Ferreira *et al.*, 2011; Fugihara *et al.*, 2008). In SRS, photon form pumping source is

absorbed by material and emits a photon with energy at its vibrational state. In fact, energy is transmitted from a high frequency optical signal to lower frequency optical signal (Dhir and Gupta, 2014). Raman amplification is not only possible for single mode fiber but also for multimode fiber which was discussed in a research (Polley & Ralph, 2007). In this work, For fundamental mode LP<sub>0,1</sub>, the Raman gain was compared. This multimode amplification is mainly used in space-division multiplexing (Antonelli, Mecozzi & Shtaiif 2013; Namiki & Emori, 2001). We can make any fiber into a Raman amplifier by suitable selection of pumping wavelength (Anwar & Aly, 2010). This paper investigates two important views in RA. Section 2 investigates about RA performance in various Refractive Index Profiles and Section 3 investigates about the performance of RA with EDFA hybrid configuration.

## 2. INVESTIGATIONS OF REFRACTIVE INDEX PROFILE (RIP)

Raman amplifiers are used not only for amplification but also for dispersion compensation. In Dispersion compensation, the refractive index profile of fiber plays a major role.



**Figure 1.** Study of Raman Amplifier based on Refractive Index Profile.

In the design of RA, the operating wavelength range is adjusted by correctly selecting suitable RIP structure and inner core radius. In this paper, RIP based performance of RA is studied as per Figure 1 Among step, parabolic and triangular refractive index profiles, a parabolic profile provides good effective Raman gain results at 20Gbps. The paper (Chan & Premaratne 2007) also reports the change in dispersion co-efficient and gain as the function of RIP. For obtaining better flattening of Raman gain, the core gap radius of a fiber is varied with step index profile. Additional to this, large negative dispersion coefficient is achieved by varying core gap radius (Bandyopadhyay & Sarkar 2013) From this, dispersion compensation is achieved at C and S bands. A research (Pramanik, Das, & Sarkar, 2010)

found that Trapezoidal index profile also affects the gain performance of RA. The aspect ratio  $S$  is modified, and same phase matching is achieved for various values of core radius. During the design of RA, step index profile at both inner and outer cores was considered in another research (Pramanik & Sarkar, 2014). This work says that the occurrence of axial dip at core center is unavoidable. Up to 0.25% dip depth and 25% dip width, RA is performing as perfect as RA without any dip or profile imperfections. But above this limit of dip depth and dip width, the performance becomes poor. This paper concluded that step index profile in core is most excellent for better performance of RA.

From the investigations of these research works, the Raman gain of various profiles are observed at 1550nm wavelength window for fundamental mode LP (0, 1) and tabulated in Table 1.

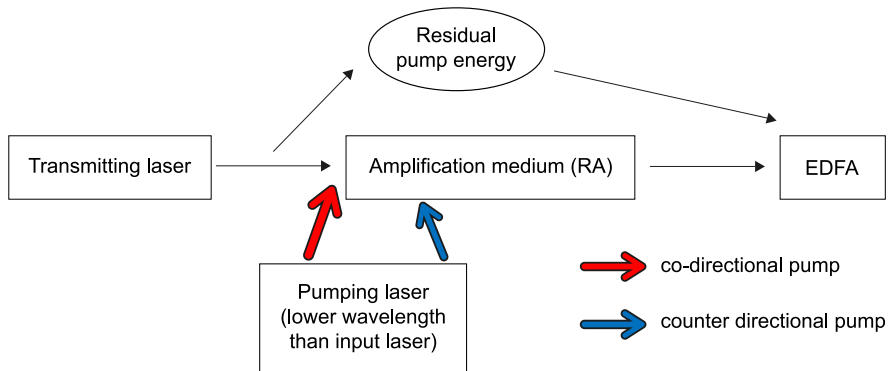
**Table 1.** Raman Gain values at 1550nm Window.

Type of profile	Raman gain (m/W)
Parabolic index	0.7x10-13
Triangular index	0.62x10-13
Step index	0.76x10-13
Trapezoidal index	1.04x10-13

From this Table 1, trapezoidal index profile gives the better Raman gain. But even with dip at core centre step index profile gives the better performance (Pramanik *et al.*, 2014).

### 3. INVESTIGATIONS ON HYBRID COMBINATION OF EDFA & RAMAN AMPLIFIERS

Many research works have used benefits from both the fiber amplifiers RA and EDFA. When RA is combined with EDFA, cross talk becomes very less even for channel spacing of 0.4nm and 0.2nm. This hybrid RA and EDFA performance is inspected for 16X10Gbps DWDM system (Singh & Kaler, 2015). And this paper concluded that hybrid RA and EDFA is better than other hybrid optical amplifiers. Better power utilization also possible with this hybrid RA and EDFA. It is investigated in the research (Lee, Chang, Han, Kim, Chung & Lee, 2004) that recycling the residual Raman pump to make pumping on EDFA. Choosing proper pump wavelength is the only thing to be considered. This gives the possibility for the design of broadband amplifiers with high gain.



**Figure 2.** RA-EDFA hybrid configuration with single pump.

As shown in Figure 2, the pumping may be given either in forward direction (co-direction) or in backward direction (counter-direction).

In hybrid optical amplifiers, the site of the Erbium doped fiber severely affects the performance of the dispersion compensation of Raman/EDF and this is discussed in a research (Ali, Abdullah, Jamaludin, Al-Mansoori, Al-Mashhadani & Abass, 2013). EDF may be placed before RA or after RA. In this work, these are considered as two cases. A 10m EDF and 7Km Dispersion Compensating Fiber (DCF) is considered. Here, DCF is acting as Raman Amplification medium. In first case, EDF is placed before RA. And in second case EDF is placed after RA. In this research, fiber has the following specifications. They are 0.55dB/Km of attenuation coefficient, 98ps/nm.km of dispersion coefficient, and 15.3 $\mu\text{m}^2$  of effective area. And EDF has the following specifications. Erbium concentration of 440ppm, 2.2 $\mu\text{m}$  core radius, and effective area of 15.2 $\mu\text{m}^2$ . If we place the RA firstly and EDFA secondly, then we obtain large input signal gain, noise figure and gain variation. RAMAN-SOA and RAMAN –EDFA are analyzed in the research of Upma (2015). This research proposed the 8 channel transmitter with constant attenuation value 0.2db/Km. And data speed of 10Gbps is considered. Under such case, Raman-EDFA gives highest Q factor of 19.92db, RAMAN-SOA provides highest eye opening, Raman –EDFA provides smallest jitter 0.0243. so RAMAN -EDFA is a hopeful alternative to all other hybrid amplifiers. With the help of mono pump source, dispersion compensating Raman/EDFA hybrid amplifier is achieved. Also overall power conversion efficiency is increased. Here mono pump source having two lasers is used for Dispersion Compensating Fiber (DCF) which has Raman Amplification. The remaining power from this DCF is again recycled

and utilized by EDFA. The laser pumps are operating at 1455nm and 1465nm. A total pump power of 500mW is launched into a 12.6Km DCF. Effective power utilization and larger amplifier efficiency is obtained in the research (Lee, Chang, Han, Chung, Kim & Lee, 2005).

Like Erbium, Ytterbium can also be used as fiber amplifier. By Yb-Raman combined non linear amplifier, an improved power of 1.5kW was obtained in the wavelength of 1100nm to 1200nm. In this work (Zhan, Tao, Zhou, Wang, & Xu, 2014), the amplifier is seeded by 1070 and 1120nm signal lasers simultaneously.

For 16 channel system (Lee, Oh, Lee, Lee, & Hwang, 2004), Q factor & BER for Raman-EDFA & EDFA-RAMAN-EDFA are same for short distance. For longer distance, EDFA-RAMAN-EDFA has largest Q value among all. For 32 channel system, RAMAN-EDFA provides good output power; BER & Q factor. In the hybrid combination of Raman-EDFA, EDFA may be used in parallel configuration and residual pumping is done. In order to minimize the cost, mono pump wavelength is used in Raman amplifier. Raman amplifier in the role of DCF has two benefits. First one is, obtaining low loss and dispersion compensation at the same time. Second is, amplification is done at wider band in optical wavelength window by changing the pump wavelength and it was discussed in a research (Singh & Kaler, 2015). In order to maximize capacity for amplification scheme and transmission distance, a variety of combinations of three 16QAM based coded modulation schemes with spectral efficiencies 4.86/5.4 for C+L EDFA experiment and 5.45/6.14 [bits/Hz] are used in this paper (Cai *et al.*, 2015).

A different research is done in this work (Mahran, 2015). Here, the bending loss in EDFA makes the gain of hybrid amplifier to increase up to 7db more than normal EDFA/Raman. OSNR calculations also show a better performance. In this paper bending radius is chosen as 4mm, EDFA is taken with length 10m where, forward pump power in the range of 100-500mW, Raman amplifier length is chosen between 12 to 55Km, where backward pump power in the range of 80-200mw and input signal power is -20dBm. Even for reduced channel spacing, this hybrid RA-EDFA provides better performance. This research (Singh & Kaler, 2012) investigated various combination of hybrid amplifiers. 100 channels were

used at channel spacing of 6.25GHz. Quality factors, acceptable bit rate, Bit Error Rate (BER) were calculated for all the configurations.

Pump power of RA is unused in Dispersion compensating modules (DCM). This wastage of pump power is avoided and utilized by using FBG at one side of DCM. This DCM is designed for short or medium distance mostly from 50Km to 100Km (Nicholson, 2003). Both the benefits of dispersion compensation and effective power utilization were obtained from this research.

## 4. SUMMARY

This paper assesses about various perspectives of Raman Amplifiers. The effort towards mitigating dispersion, improving gain bandwidth, effective power utilization, obtained low noise performance, dependency of Refractive index profile using RA and corresponding researches were described in this paper. When hybrid configuration of RA-EDFA is considered, the innovative research papers of bending loss in EDFA for dispersion compensation and locating EDFA for low noise were also depicted in this paper.



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