A SCHEME FOR GAIN FLATTEN OF FIBRE RAMAN AMPLIFIER FOR WDM TRANSMISSION SYSTEMS

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ABSTRACT

The most attractive feature of Fiber Raman amplifiers are extremely large gain bandwidth and play an important role in wavelength division multiplexing (WDM) systems. However, the weakness of Raman amplifier is that the gain spectrum is flat for very small narrowband. So, it is necessary to flatten the Raman gain profile to achieve the desire performance for the WDM systems. This paper has proposed an extrinsic gain flattening technique for WDM transmission systems using Polarization-diversity Loop Filter (PDLF). With this technique, an equalize bandwidth of 114nm (1536nm – 1650nm) can be achieved with a gain ripple of 0.5dB.

Keywords: Raman amplifier, FRAs, WDM, Raman gain spectrum, PDLF.

1.0 INTRODUCTION

Fibre Raman amplifiers (FRAs) are extensively studied for their flexible control of bandwidth and spectral position of optical gain. FRA has attracted a considerable interest because of its potential applications as a discrete and distributed amplifier in Wavelength-Division-Multiplexing (WDM) transmission systems. Distributed Fibre Raman amplifiers (DFRAs) improves the Noise Figure (NF) and reduces the nonlinear penalty of the fibre systems, allowing longer amplifier spans, higher bit rates, closer channel spacing, and operation near zero-dispersion wavelength. For the simple single platform of FRAs, a wide range of deployment of DFRAs in the next few years could be observed for every new long-haul and ultra long-haul Fiber Optic transmission systems. Besides their large bandwidth, the advantages of the Raman amplifier over other optical amplifiers include the possibility of operating in any wavelength region, superior noise performance of distributed amplification, and a non-resonant gain.

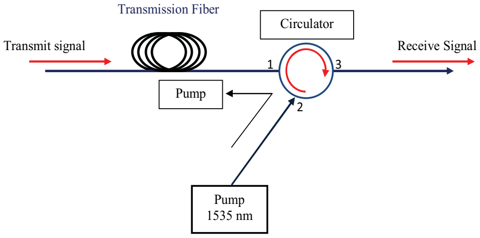

Figure 1: Basic Structure of Fibre Raman amplifiers

In a Raman amplifier, the signal is intensified by Raman amplification which is achieved by a nonlinear interaction between the signal and a pump laser within an optical fiber. Figure 1 shows the basic structure of a Raman amplifier. It consists of a pump source, an optical circulator, and fiber link. The pump light may be coupled into the transmission fiber in the same direction as the signal (forward pumping), in the opposite direction (backward pumping) or bidirectional. Backward pumping is more common as the transfer of noise from the pump to the signal is reduced.

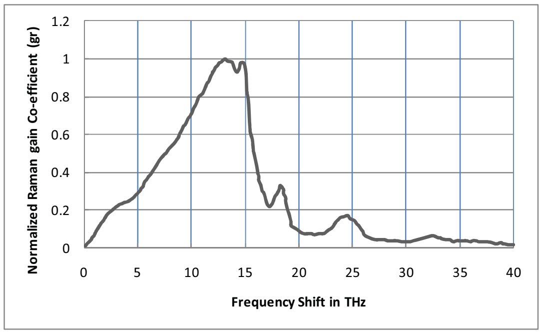

Figure 2: Normalized Raman Gain Co-efficient (g_r) Vs Frequency Shift (THz)

Raman gain spectrum in a conventional Single-Mode Fibre (SMF) has a gain bandwidth of 40THz. However, the spectrum is flat only over a narrow range of wavelengths. So, there is a significance power deviation among the amplified signals. Raman gain spectrum in a conventional Single-Mode Fibre (SMF) is shown in Figure 2, which needs to be equalized for the utilization in a long-haul WDM Fibre Optic transmission network.

Practically, gain flattening in Raman amplifier is achieved by using different intrinsic and extrinsic techniques. Usually, this is done by using properly chosen multiple pump wavelengths with specific power level. Fibre design is one of the intrinsic gain flattening mechanisms and have reported in [1]-[2], in which refractive index of the fiber is control to achieve the goal. Pumping at different wavelengths and the use of available optical filters are two major extrinsic gain equalization methods. Such types of gain flattening technique have reported in [3]-[5]. Polarization-independent interfere metric filter (PIIF) can flatten the gain within ±0.5% over a bandwidth of 43nm at the centre wavelength of 1550nm [5]. Therefore, a simple approach of gain flattening technique for FRA with large bandwidth is still in demand. In this paper, a simple method for the flattening of Raman gain spectrum is proposed by means of Polarization Diversity-loop Filter (PDLF) and is achieved an equalized bandwidth of 114nm (1536nm-1650nm) with a gain ripple of 0.5 dB.

2.0 PROPOSED SCHEME FOR THE GAIN FLATTEN FIBRE RAMAN AMPLIFIER WDM RANSMISSION SYSTEMS

The schematic diagram of the proposed model for fibre Raman amplifier is shown in figure 3. The model is constructed by interfacing FRAs with a Polarization-diversity Loop Filter (PDLF).

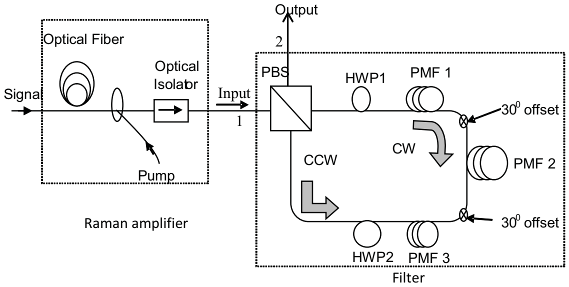

Figure 3: Proposed schematic for the broadband gain flattened Raman amplifier for WDM transmission systems.

Broadband Raman gain flattened amplifier is constructed in association with Raman amplifier of backward pumping configuration and PDLF. Here, PDLF is arranged at the output of the amplifier section in order to get equalized amplification of the WDM channels. Optical Isolator at the amplifier section prevents the backward flow of the amplified optical signals.

The filter consists of three sections of Polarization Maintaining Fibre (PMF1, PMF2, & PMF3) of equal length that are concatenated with 30° angle offset among their adjacent primary axis, two half wave plates (HWP1 & HWP2), and a Polarization Beam Splitter (PBS). At the input of the filter (Port 1 of PBS), the PBS decomposed the arbitrarily polarized amplified Optical signals into horizontally polarized (x polarized) and vertically polarized (y polarized) components. This separated polarized wave is then rotates in clockwise (CW) and counter clockwise (CCW) direction respectively through the three sections of Polarization Maintaining Fibre (PMF1, PMF2, & PMF3) & two Half Wave Plates (HWP1 & HWP2). Therefore, the transmitted intensity becomes the superposition of the intensity outputs of two interference spectra due to x and y input polarization, which maximize the filter transmittance, filter. As a result, an equalized amplified output is achieved at the output port of the filter (port 2 of PBS).

Along the fibre length of the Raman amplifier, shorter wavelength channels are depleted their power, and transfer it to the longer wave length channels. This is the essence of stimulated Raman scattering, existing between signals and signals (refer to as Raman cross talk), pumps and pumps (refer to as pump interaction), and pumps and signals (refer to as pump depletion).

In Multi-wavelength FRA, each pump is amplified by the previous pump and transfers the energy to the next pump and channels. The same things are happened for the channels. So, the equation for the pumps and the channels are:

$\frac{dP_1}{dz}$ = (-Loss for the fibre - Energy transfer to the next pumps and channels)

$\frac{dP_2}{dz}$ = (-Loss for the fibre + Gain from the previous pump - Energy transfer to the next pumps and channels).

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$\frac{dP_n}{dz}$ = (-Loss for the fibre + Gain from the previous pumps - Energy transfer to the next pumps and channels)

$\frac{dS_1}{dz}$ = (-Loss for the fibre + Gain from the pumps - Energy transfer to the next channels)

$\frac{dS_2}{dz}$ = (-Loss for the fibre + Gain from the pumps and previous amplified channels - Energy transfer to the next channels)

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$\frac{dS_n}{dz}$ = (-Loss for the fibre + Gain from the pumps and previous amplified channels)

In the optical fibre Raman amplifier, this interaction between pump and the amplified signals are described by set of coupled equations [12]. To reduce the complexity of simulation process the following simplified form of generalized equation can be modelled for forward and backward propagating waves as:

$$\pm\frac{dP_i}{dz}=\left[-\alpha_i+\sum_{j=1}^{i-1}\frac{g_R\left(v_j,v_i\right)}{\Gamma A_{eff}}P_j-\sum_{j=i+1}^{n}\frac{v_i}{v_j}\frac{g_R\left(v_i,v_j\right)}{\Gamma A_{eff}}P_j\right]P_i \text{....(1)}$$

Where + and – symbol denote the direction of propagation; P_i is the power of the i^{th} pump or channel around v_i (i= 1……..n); $g_R(v_j,v_i)$ & $g_R(v_i,v_j)$ are the Raman gain coefficient for v_j over a specific v_i; v_i is the frequency of the i^{th} pump or channel; v_i/v_j accounts for vibrational losses; A_{eff} is the effective core area of the fibre; n is the overall number of pump and channels; α_i is the fiber attenuation for pumps and channels; and the factor Γ accounts for polarization randomization effects whose values lies between 1 and 2. The subscriber index is arranged in such a way that the larger the subscriber the longer the wavelength.

An advantage of generalized equation is that it is not necessary to identify the pump and signal independently. Signals of lower wavelength acts as a pump for the higher wavelength and thereby amplify the signal throughout the length of the fiber. The above model is then simulated using MATLAB$^{(TM)}$ boundary value problem solver. In order to get an equal amplified WDM signal at the end of the fiber link, the simulated output of the amplifier is then feed into the input port of the filter. Here, the filter parameter is adjusted in such a way, so that an equal amplified WDM signal is achieved at the end of the fibre link.

The transmittance, t_{filter} of the filter can be expressed as follows [6]:

$$t_{filter}=\frac{9}{8}\begin{bmatrix}\cos\left(2\theta_{h1}-2\theta_{h2}+\frac{\pi}{3}\right)\cos\Gamma+\frac{1}{6}\cos(2\theta_{h1}-2\theta_{h2})+\\ \frac{\sqrt{3}}{2}\sin(2\theta_{h1}-2\theta_{h2})\end{bmatrix}^2 \times(\cos\Gamma)$$

$$+\frac{9}{8}\left[\cos\left(2\theta_{h1}+2\theta_{h2}-\frac{\pi}{3}-2\theta_{p1}\right)\left(\cos\Gamma+\frac{1}{3}\right)\right]^2(1-\cos\Gamma) \quad (2)$$

Where θ_{h1}, θh_2, and θ_{P1} are the field orientation (with respect to x axis) by HWP1, HWP2, PMF1, PMF2, and PMF3, respectively, and Γ=2πBL/λ, that is generated due to birefringence, B, Length, L of one PMF, and λ is the wavelength in vacuum. The resultant Raman gain spectrum for the proposed scheme at the output of the filter can be found using the following relationship:

Output (dB) = 10log(g_r) + 10log(t_{filter}) ---------- (3)

Where, g_r is the Raman gain co-efficient and t_{filter} is the filter transmission parameter (transmittance).

3.0 RESULTS AND DISCUSSION

For the proposed scheme, at first the WDM signals are amplified by the Raman amplifier and then the amplified signals are feed into the input port (port 1 of PBS) of the filter (PDLF), where the gain of the amplified signals are equalized by properly adjusting the filter's parameters.

In this paper, gain flatten of the Fibre Raman amplifier is verified by writing simulation program in MATLAB$^{(TM)}$ for the amplifier and for the filter transmittance, t_{filter},. Finally, the filter transmittance, t_{filter} is combined with the normalized Raman gain co-efficient, g_r of the amplifier in order to achieve the desired equally amplified output at the end of the Fiber Optic Transmission link. Here, the filter parameters θ_{h1}, θ_{h2}, and θ_{P1} & length of PMF and birefringence of PDLF are so adjusted that the filter transmission parameter is higher for the lower values of Raman gain co-efficient and the transmission parameter becomes relatively smaller for higher values of Raman gain co-efficient. Such a transmission characteristics of the filter is shown figure 4, which is achieved by the fine adjusting of the field orientation for HWP1, HWP2. For this case, the length of each section of the Polarization Maintaining Fibre (PMF) is 0.02m with a birefringence value of 3.84×10^{-4}.

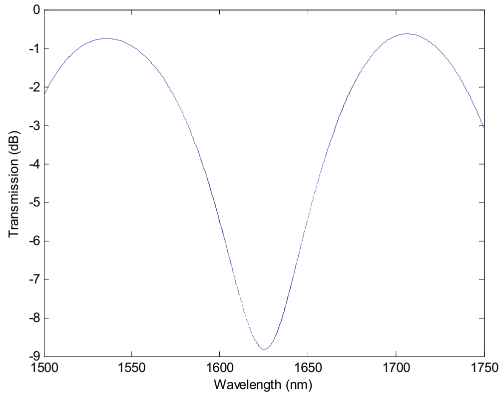

Figure 4: Filter Transmission Characteristic Vs Wavelength

Figure 5 shows a plot of normalized Raman gain co-efficient (dB) as a function of wavelength (nm) for the fibre Raman amplifier with filter and Filter Transmission (dB) as function of wavelength (nm).

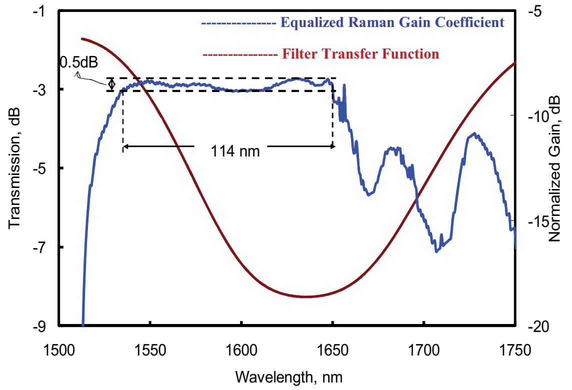

Figure 5: Normalized Raman gain coefficient as a function of Wavelength with Filter & Filter Transmission as a function of Wavelength.

After the fine tuning of filter parameters, such as the field orientation for HWP1, HWP2, and PMF fiber length of 0.02m with birefringence value of $3.84\text{x}10^{-4}$, it is found that the 0.5dB Raman gain spectrum as large as 114nm (1536nm-1650nm) and 3dB Raman gain spectrum as large as 150nm (1510nm-1660nm) can be achieved for the filter with transmission characteristics (transmittance, t_{filter}) as like as shown in the figure 4. Here, the drawback is that the peak Raman gain coefficient is reduced by almost 3dB. The gain reduction and variation can significantly be reduced by adjusting the filter parameters for different wavelengths. However, there is a trade-off between gain flattened bandwidth and the values of Raman gain co-efficient which is needed to be optimized for getting better results. Higher the values of Raman gain co-efficient smaller the flattened bandwidth that can be achieved.

4.0 Conclusion

A method for the gain flattened of the Fiber Raman amplifier has been proposed for WDM transmission systems by using of Polarization-diversity Loop Filter (PDLF). An equalized bandwidth of 114nm (1536nm-1650nm) has been achieved with a gain ripple of 0.5dB for the reduction of normalized Raman peak gain of 3dB. PDLF would be the most promising gain equalizer for long-haul & ultra-long haul fiber optic communication systems.

V. Appendix A

MATLAB$^{(TM)}$ code for the filter Transmittance:

```
clear all
tic;
tStart=tic;
thetah1=pi/2.3;
thetah2=pi/2.0;
thetap1=pi/4.8;
B=3.84e-4;
L=0.02;
for i=1:1250;
lemda(i)=1499.80+0.2*i;
T(i)=2*pi*B*L/(lemda(i)*1e-9);
t(i)=(9/8)*(((cos(2*thetah1-2*thetah2
+(pi/3))*cos(T(i))+(1/6)*cos(2*thetah1-
2*thetah2)+(sqrt(3)/2)* sin(2*thetah1-
2*thetah2)))^2)* (1+cos(T(i)))+
(9/8)*((cos(2*thetah1+ 2*thetah2-(pi/3)-
2*thetap1)* (cos(T(i))+(1/3)))^2)*(1-
cos(T(i)));
end
t1=10*log10(t);
plot(lemda,t1)
toc;
disp(toc);
disp(t1');
```

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