

Improvement of Raman Gain with Different Parameters in Discrete Raman Amplifier

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ABSTRACT

The objective of this paper is to study the Raman gain of discrete Raman amplifier in the counter propagating pumping configuration. The performance is analyzed in terms of different parameters such as pump power, fiber length, figure of merit and optical signal-to-noise ratio.

Keywords- Discrete Raman Amplifier, Optical Signal-to-Noise Ratio, Stimulated Raman Scattering and Raman Gain.

I. INTRODUCTION

Fiber optic communication system is also called light wave systems because they employ optical fibers to transmit information. In order to transmit signals over long distances, it is necessary to compensate the attenuation losses within the fiber. Initially, this was accomplished with an optoelectronic module consisting of an optical receiver, regeneration and equalization system and an optical transmitter to send the data. Although functional but this arrangement is limited by the optical to electrical and electrical to optical conversions. Several types of optical amplifiers have since been demonstrated to replace the OE- electronic regeneration systems [1]. These systems eliminate the need for E-O and O-E conversions.

Raman amplifier is based on the phenomena of Stimulated Raman Scattering (SRS) is a nonlinear optical process in which a photon, called the pump photon is absorbed by a material while simultaneously a photon of a different energy is emitted. The difference in photon energy is compensated by a change of the vibrational state of the material [2]. In stoke's scattering a pump photon of energy $h\nu_p$ is absorbed, and a stoke's photon of energy $h\nu_s < h\nu_p$ is emitted while the material undergoes a transition to a higher vibrational state. On the other hand, anti stoke's scattering can occur when the material already is in an excited vibrational state. Then, a pump photon of energy $h\nu_p$ is absorbed, and a quantum of vibrational energy is added to that energy to yield an anti stoke's photon of higher energy $h\nu_{as} > h\nu_p$ as shown in Fig. 1.

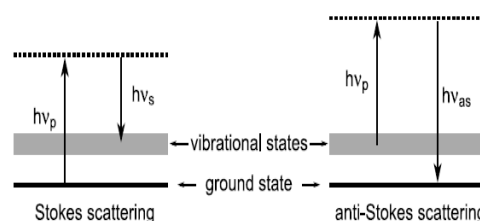


Figure 1: Illustration of spontaneous Stokes and anti-Stokes Raman scattering

II. DISCRETE RAMAN CONFIGURATION

In Lumped fiber Raman Amplifier (LRA), highly nonlinear fiber with a small core is utilized to increase the interaction between signals and pump wavelengths and thereby reduces the length of fiber required. Because of small scattering cross section Raman amplification may better fit in a Distributed Raman Amplifier (DRA) rather than a discrete one. Therefore, in designing LRAs, several challenges such as increasing efficiency and solving fundamental trade offs are required. The important parameters representing LRAs are: the wavelength and input power level of signal, the wavelength and input power level of pump and the type and length of the gain fiber. The length of the fiber in LRA is between 5 km to 40 km. In order to design the amplifier in detail, the attenuation coefficient, the Raman gain coefficient for the given pump wavelengths, the Rayleigh backscattering coefficient and the nonlinear coefficient are required in signal and pump wavelengths bands.

The targeted optical characteristics of a LRA are usually gain, noise figure, output signal power level, optical signal to noise ratio, double Rayleigh

backscattering noise power, nonlinear phase shift, and pump to signal power conversion efficiency. In this paper, the work is done on the gain of the Raman amplifier. However, discrete Raman amplifiers have many attractive aspects over rare-earth-doped fiber amplifiers such as an Erbium-Doped Fiber Amplifier (EDFA) including arbitrary gain band, better adjustability of gain shape, and better linearity. The principal advantage of Raman amplification is its ability to provide distributed amplification within the transmission fiber, thereby increasing the length of spans between amplifier and regeneration sites.

Fig. 2 shows the basic configuration of discrete Raman amplifier. It generally comprises a gain fiber, a directional coupler for combining the pump and the signal wavelength, and isolators at the input and output ends.

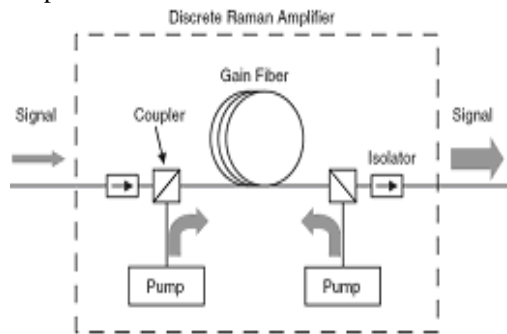


Figure 2: Discrete Raman amplifier in counter propagation configuration

The orientation of the pump can be either forward or backward with respect to the signal propagation, whereas the counter propagating one is called counter pumping; the co-propagating pumping scheme is called co-pumping. There is also an option of bidirectional pumping, in which the gain fiber is pumped in both directions [3].

III. PERFORMANCE METRICS

The saturated gain of the amplifier is given by:

$$G_s = \frac{G_A}{1 + r_o G_A}$$

where r_o is related to the signal to pump power ratio at the fiber input as:

$$r_o = \frac{F_s(0)}{F_p(0)} = \frac{w_p P_s(0)}{w_s P_p(0)}$$

and G_A is unsaturated gain or we can say that G_A is the total amplifier gain or on-off Raman gain. Once the gain fiber and pump power are given, the net gain $G(z)$ can be written explicitly as a function of the fiber length z .

$$G(z) = \exp(g_R P_0 L_{eff} - \alpha_s z)$$

The first term indicates the on off Raman gain and other is the fiber attenuation. Now, the final proposed model is as follows:

$$Gain = - \frac{w_s P_p(0) G_s}{w_s P_p(0) - w_p P_s(0) G_s} \exp\left(-\frac{\alpha_s}{\alpha_p}\right) \ln \frac{\alpha_s}{g_R P_0}$$

Where,

w_s = angular frequency of signal

P_p = pump power

w_p = angular frequency of pump

P_s = signal power

Negative sign in the above equation shows that counter-propagating direction is being used. Better noise performance can be achieved with the implementation of Raman gain and noise figure. According to the equations given above, the better results of noise and gain can be obtained.

The figure of merit (FOM) is the ratio of Raman gain coefficient to the pump attenuation coefficient. By knowing figure of merit, the efficiency of the fiber for LRAs can be estimated and compared. Mathematically,

$$FOM = \frac{g_R}{\alpha_p}$$

For optical signal-to-noise ratio (OSNR):

$$OSNR = 10 \log \frac{P_{out}}{P_{ASE}}$$

where

P_{out} = signal's output power

P_{ASE} = Power spectral density of ASE

P_{ASE} is also expressed as $S_{ASE} * b$, where b is optical bandwidth further

$$S_{ASE} = h\nu * n_{sp} [G-1]$$

where

$h\nu$ = electron density

n_{sp} = spontaneous scattering factor

G = gain of the amplifier

So, from all the above relations we conclude the OSNR as below:

$$OSNR = 10 \log \frac{P_{out}}{h\nu * \eta_{sp} * b * (G-1)}$$

IV. RESULTS AND DISCUSSIONS

The aim is to compare the Raman gain characteristics performance with the help of different parameters. The parameters analyzed are pump power, fiber length, figure of merit and optical signal-to-noise ratio. In this common setup, some standard values are also taken [4]. The common setups of these simulation cases are summarized in

the Table1.

Table 1: Common Setup for Simulaton Cases

Optical frequency/ angular frequency of pump	980 nm
Optical frequency/ angular frequency of signal	1350 nm
Saturated gain	19 dB
Pump power	0-1000 mW
Signal power	20- 500 mW
Signal attenuation constant	0-1 dB/km
Pump attenuation constant	0-1 dB/km
Raman gain coefficient	0.38-6.08 (kmW) ⁻¹

Case 1: Raman gain taken as a function of pump power:

It can be seen that to reach the Raman gain as optimum value, the pump power required is 1000 mW. As for the improvement in Raman gain, the signal power is varied and gain is observed as 44.5 dB. The value of signal power is taken as 450 mW. Raman gain is directly proportional to the pump power so it increases with increase in pump power as shown in Fig. 3.

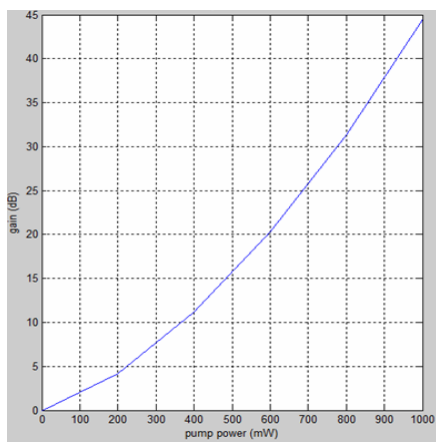


Figure 3: Raman gain with Pump power

Case 2: Raman gain taken as a function of fiber length:

Raman gain is dominant for shorter length and the Raman gain increases with increase in fiber length. The fiber attenuation plays a major role for this increase. The observed highest value of Raman gain in this case is 37.2 dB at 15.5 km as shown in Fig. 4.

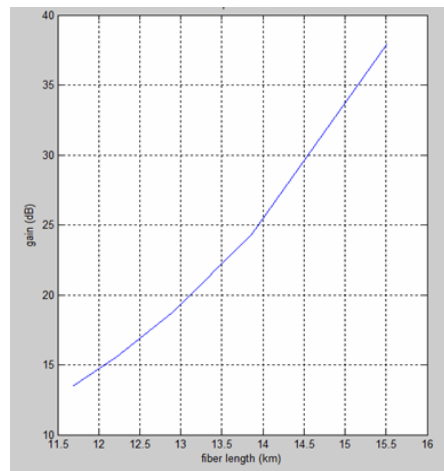


Fig 4: Raman gain with fiber length

Case 3: Raman gain taken as a function of figure of merit:

In FOM, it totally depends on pump attenuation constant. Less the α_p , more will be the FOM and so is Raman gain. The Raman gain attained is 39.8 dB when the signal power is 33 mW and the value of figure of merit is 81 (1/W) as shown in Fig.5.

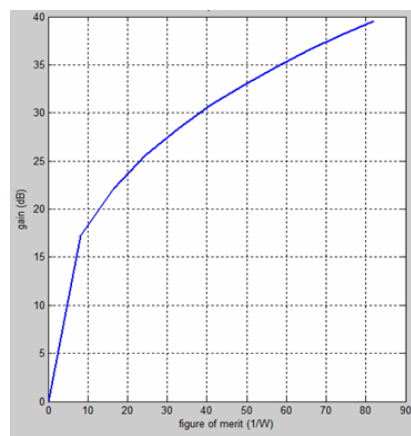


Fig 5: Raman gain with figure of merit

Case 4: Raman gain taken as a function of optical signal-to-noise ratio:

With the increase in signal bandwidth, the value of OSNR starts decreasing. If the signal propagates along the fiber with no loss and no amplification, its OSNR would be equal to its input value and the noise figure to one. To get a better Raman gain of 40.2 dB the value of OSNR is 6 dB. With decrease in value of OSNR, the value of Raman gain increases and vice -versa. The counter-propagation pumping is used and in this OSNR is less from the co-pumping because the spontaneous

noise generated near the input and experiences losses over the full length of the fiber in forward pumping as shown in Fig.6.

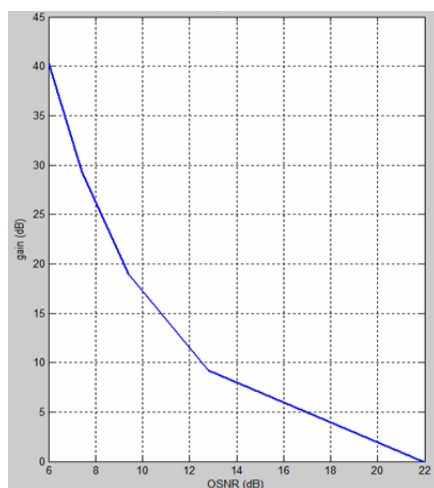


Fig 6: Raman gain with optical signal-to-noise ratio

V. CONCLUSION

The backward or counter pumping evolutions along the fiber for pumps, including the effects due to Rayleigh backscattering, Stokes and anti Stokes spontaneous emission are discussed. The simulations are carried out to analyze the proposed modeling on FRAs. Raman gain is improved in our simulation model. The Raman gain obtained in the results is 44.5 dB at 1000 mW, 37.2 dB at 15.5 km, 39.8 dB at 82 (1/W) and 40.2 dB at 6 when taken as a variable function of pump power, fiber length, figure of merit and optical signal-to-noise ratio respectively.

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