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Characteristic of Discrete Raman Amplifier at Different Pump Configurations

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Abstract: Discrete Raman amplifier have many attractive aspects over rare-earth doped fiber amplifier such as (EDFA) including arbitrary gain band, better adjustability of gain shape, and better linearity. This paper shows that discrete Raman amplifier has higher gain in bidirectional pumping than counter pumping. The gain increases with increasing fiber length, and the noise figure remain at the same value for short fiber length.

***Keywords*:** optical amplifier, stimulate Raman scattering **(SRS),** stimulate Brillion scattering (**SBS),** Rama Amplifiers, Discrete Raman Amplifier (DRA), wave length division multiplexing (WDM).

Introduction

Non linear effects within optical fiber provide optical amplification, this is achieved by stimulated Raman scattering, stimulated Brillion scattering or stimulated four photon mixing by injecting a high power laser beam into undoped or doped optical fiber .Raman amplification exhibits the advantage of self phase matching between the pump and signal together with a broad gain- bandwidth or high speed response in comparison with the other nonlinear processes[1]. There are two types of Raman amplifiers discrete (lumped) and distributed Raman amplifier. Distributed type Raman amplifier (DRA) utilizes transmission optical fiber as an active medium[2] if the amplifier is contained in a box at the transmitter or receiver end of the system it is called a discrete Raman amplifier.

This paper first considers the gain and noise figure characteristics of discrete Raman amplifier as a function of fiber length at different pump configurations since the amount of noise transferred between the pump and the signal will depend on the pump configuration also in addition to the pumping configuration. The amount of noise transferred will depend on the gain and the length of fiber used.

The variation of gain as a function of signal power at different pump configurations and the variation of signal power as a function of fiber length was studied since the important parameters representing discrete Raman amplifiers is the input power level of the signal[1].

Discrete Raman Configuration

Figure 1 shows the basic configuration of discrete Raman amplifier. It generally comprises a gain fiber, a wavelength-division-multiplexed (WDM) coupler for combining the pump and the signal wavelength, and isolators at the input and output ends. 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 copropagating pumping scheme is called copumping. There is also an option of bidirectional pumping, in which the gain fiber is pumped in both directions. [3]

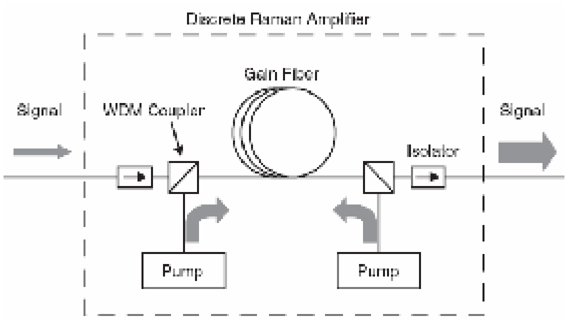

Fig. (1): Schematic of an optical communication system employing Raman amplification.

Theory of Raman Amplifier signal-pump amplification

The evolution of the pump, ***Pp***, and signal, ***Ps***, powers along the longitudinal axis of the fiber z in a Raman amplified system can be expressed by the following equations [4]:

$$\frac{dP_S}{d_Z} = {}_{gR}P_P\ P_S - a_S P_S \quad (1)$$

and

$$\mp\frac{dP_S}{d_Z} = -\frac{w_P}{w_S}{}_{gR}P_P\ P_S - a_P P_P \quad (2)$$

Where $gR(W^{-1}m^{-1})$ is the Raman gain coefficient of the fiber normalized with respect to the effective area of the fiber A_{eff} , α_s and α_p are the attenuation coefficient at the pump and signal wavelength, and ω_s and ω_p are the angular frequencies of the pump and signal. The ± signs represent a co- and counter propagating pump wave, respectively. Equations (1) and (2) show that the signal receives gain proportional to the pump power with a proportionality constant given by the Raman gain efficiency and loss due to the attenuation of optical fiber, while the pump power receives loss due to the energy transfer to the signal and the attenuation of optical fiber. In many practical situations, pump power is very large compared with the signal power that the pump depletion can be neglected by setting gR =0 in Eq. (2), As an example, $Pp(z) = P\text{o}\exp^{-\alpha\text{-}z}$, where Po is the input pump power at z = 0. If we substitute this solution in Eq. (1), we obtain

$$\frac{dP_S}{d_Z} = {}_{gR}P_O\ \exp(-a_p z)P_S - a_S P_S \quad (3)$$

This equation can be easily integrated to obtain [4]

$$P_S(L) = P_S(0)\exp(gRp_0 L_{eff} - \alpha_S L) = G(L)P_{S(0)} \quad (4)$$

Where G (L) is the net signal gain, L is the amplifier length, and L_{eff} is an effective length defined as

$$L_{eff} = [1 - \exp(-aL)]/a_P \quad (5)$$

The relation between the on–off Raman gain and the Raman gain efficiency is given as [4]

$$G_A \equiv \frac{P_S(L)\ \ with\ \ pump\ on}{P_S(L)\ \ with\ \ pump\ off} = \exp(g_R P_O L_{eff}) \quad (6)$$

where L is the physical length of the optical fiber and ***Ps(L)*** with pump on is assumed to be the amplified signal power without the amplified spontaneous emission (ASE) and thermal noise where L is the physical length of the optical fiber and ***Ps(L)*** with pump on is assumed to be the amplified signal power without the amplified spontaneous emission (ASE) and thermal noise.

ASE Noise Figure

Equation (1) with the pertinent noise term [4].

$$\frac{dP_S}{d_Z} = -gRP_P\ P_S - a_S P_S + 2hv\Delta gRP_P \quad (7)$$

The pump power ***Pp*** has a simple exponential form in the co pumping scheme as

$$P_P(z) = P_O\exp(-a\ \ z) \quad (8)$$

While, in the counter pumping scheme,

$$P_P(z) = P_O\{-a_P(L - z)\} \quad (9)$$

The noise figure can be calculated based on Eqs. (7,8,9) through the following definition:

$$NF(dB) = 10\log\left(\frac{s_{in}/N_{in}}{s_{off}/N_{off}}\right) \quad (10)$$

Where *S* and *N* denote the signal and noise parts in optical power at the given frequency, respectively.

Simulation Model and Results

Average power model is used to decrease the computational time required to solve Raman amplifier differential equations. In this mode pump- to- pump, pump-to-signal, and signal to signal Raman interactions, Raleigh back scattering, fiber loss, spontaneous Raman emission noise and its temperature dependency and pump depletion due to Raman energy transfer are included.

After entering the required parameters for a desired amplifier in the main menu and sub menus of the program (opisystem7.) gain and noise figure can be obtained as a function of fiber length at different pump configurations. Fiber length swept from (0 to 100 km) for signal wavelength=1550nm, so the pump wavelength taken to be 1450 nm since the difference between pump and signal wavelength must be 100nm so as to obtain Raman amplifications[5].

The default set of parameters for the simulations is listed in table (1), the simulation layout is shown in Fig.(2).

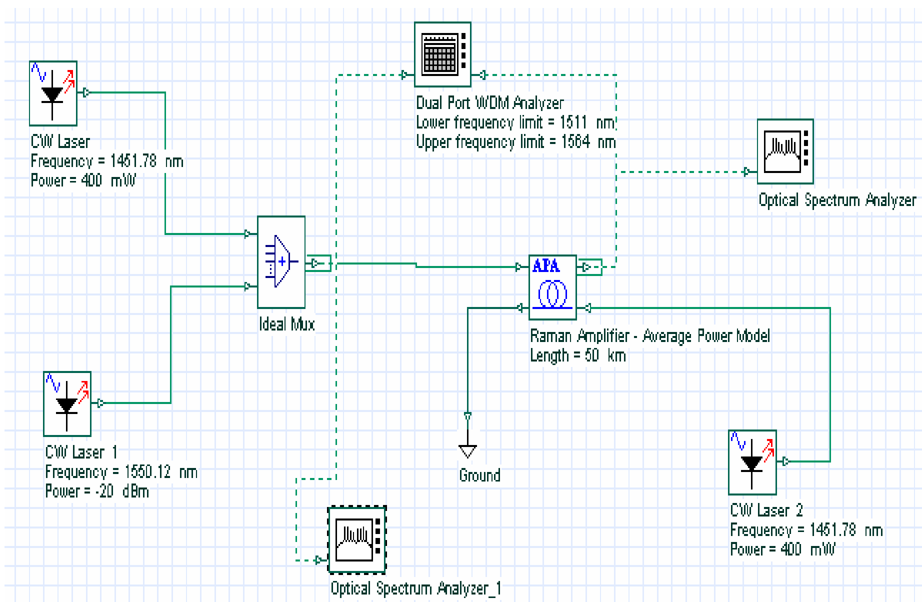

Fig. (2): the simulation layout, bidirectional pumping

Table (1): List of parameters used in the simulation.

Name	Value	Units	Mode
Length	50	km	Sweep
Attenuation data type	Constant		Normal
Attenuation	0.2	dB/km	Normal
Attenuation file	FiberLoss.dat		Normal
Effective area data type	Constant		Normal
Effective interaction area	55	um^2	Normal
Effective interaction area fi	EffectiveArea.dat		Normal
Raman gain type	Raman gain		Normal
Raman gain peak	9.5e-014		Normal
Temperature	300	K	Normal
Polarization factor	2		Normal
Rayleigh back scattering d	Constant		Normal
Rayleigh back scattering	5e-005	1/km	Normal

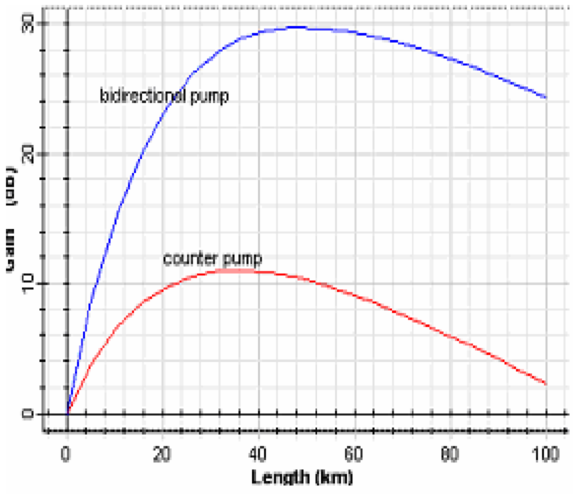

Fig.(3) shows the net gain verses the fiber length

As can be seen from Fig.(4) ,the Raman gain is dominant for shorter fiber length and the gain increases with increasing fiber length, while for longer fibers, the gain decreases and fiber attenuation plays a more important role. In between, the net gain has a maximum value.

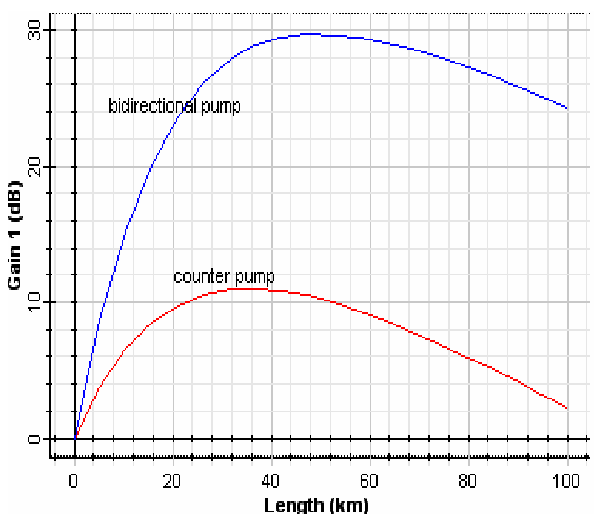

Fig. (4): Gain verses fiber length

Figure (5) shows noise figure as a function of the fiber length for counter pumping and bidirectional pumping. It is found that at short fiber length low noise figure is obtained with no significant difference between the counter and bidirectional pumping. On the other hand for longer fibers become remarkable because of the accumulation of noise along the fiber is different in the two cases.

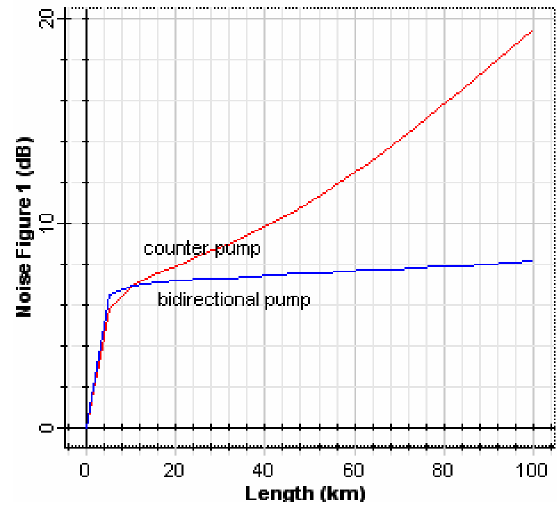

Fig. (5) Noise figure verses fiber length

To study the variation of gain as function of signal power in different pump configuration,

the signal power is swept from (-20dB to 20dB) for two fixed fiber length (5km and 12km) since discrete Raman amplifiers have lengths around these wavelengths. The other values of the simulation parameters are shown in Table (1).

The gain saturates differently for different pumping configurations. Figure(6) compares the difference for the fiber lengths of 5km and 12km. Saturation of gain increase as the pump configuration changes also saturation increases as the fiber length increases because the more interaction or coupling due to the longer length, the more energy is transferred from the pump to the signal.

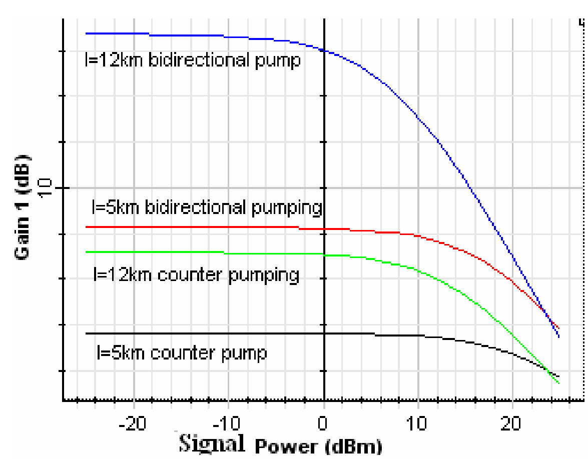

Fig. (6): gain verses signal input power for different pumping configurations and fiber length

Conclusions

The net gain increase with increasing fiber length and its higher for bidirectional pumping than counter pumping. Noise figure remains the same value for both configuration at short fiber length. Saturation of gain increase as the pump configurations changed and it is higher for bidirectional pumping than counter pumping.

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خصائص مكبرات رامان المنفصلة عند ترتيبات مختلفة للضخ

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الخلاصة في هذا البحث تمت دراسة خصائص الربح والضوضاء عند تضخيم موجة باستخدام مكبرات رامان المنفصلة كدالة لطول الليف الضوئي وقدرة الضخ للاشارة عند استخدام ترتيبات مختلفة للضخ. تم انجاز البحث باستخدام نظام محاكاة برمجية (Optisystem 7) عند اشارة طولها الموجي 1550 نانو متروموجة ضاخة طولها الموجي 1450 نانو متر. أظهرت النتائج بان مقدار الربح في الاشارة تتغير بتغيير طول الليف أما قيمة الضوضاء فتبقى ثابتة تقريبا عند الاطوال القصيرة لليف الضوئي، كما أن مقدار الزيادة في الربح يكون أكثر في حالة ضخ الموجة بالاتجاهين المعاكسين مقارنة بحالة الضخ بالاتجاه المعاكس للموجة و ان التوصل إلى حالة الاشباع في الربح كدالة لقدرة الاشارة تتغير بتغيير الترتيب المستخدم للضخ.