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Mathematical Model of Amplified Stimulated Raman Scattering and Fiber Raman Amplifier

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Abstract

The result of a developed mathematical model for predicting the design parameters of the fiber Raman amplifier (FRA) are demonstrated. The amplification parameters are tested at different pump power with different fiber length. Recently, the FRA employed in optical communication system to increase the repeater distance as will as the capacity of the communication systems. The output results show, that high Raman gain can be achieved by high pumping power, long effective area that need to be small for high Raman gain. High-stimulated Raman gain coefficient is recommended for high Raman amplifier gain, the low attenuation of the pump and the transmitted signal in the fiber lead to high Raman gain.

نموذج رياضي لاستطارة رامان المحتثة وتضخيم ألياف رامان

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الخلاصة

تم تطوير نموذج رياضي يحدد من خلاله المعلمات التصميمية لتكبير الياف رامان. أختبر النموذج المطور لعدة طاقات ضخ مع عدة أطوال لليف البصري. تستخدم مكبرات الياف رامان في أنظمة الاتصالات الحديثة لزيادة مسافات وسعة نقل انظمة الاتصالات. النتائج المستحصلة توضح انه للحصول على ربح عالي في ليزر رامان فأن طاقة ضخ عالية تكون مطلوبة مع طول الليف البصري الفعال، وفي نفس الوقت فأن ربح رامان يرتبط بعلاقة مع قطر الليف البصري الفعال. ان معامل تحصيل رامان المحتث العالي يعتبر شرطا للحصول على ربح تكبير عالي لمضخم رامان، وكذلك اقل توهين في الاشارة المنتقلة في الليف البصري.

Introduction

An optical amplifier is the enable in high capacity long- haul dense wave length division multiplexing (DWDM) transmission. Compared with conventional erbium doped fiber amplifiers (EDFA), a FRA has the advantage of wider bandwidth and low noise, which leads to increased system capacity and distance [1,2]. Raman amplification in optical fiber is based on Raman scattering. Raman scattering is divided into two categories called spontaneous Raman scattering and stimulated Raman scattering. Spontaneous Raman scattering is an interaction between light and a material that causes some of the incident light to be shifted to deferent frequencies spontaneously. Light down shifted in frequency from the incident frequency is called a stokes shift and up-shifted frequency is called a anti-stokes shift. The amount of the frequency shift depends on the vibration modes (optical phonons) of the material. Now on the same material, if we send a weaker signal at a stokes frequency along with the stronger incident beam, called a pump, it stimulated the Raman scattering. This is called stimulated Raman scattering and lead to the Raman amplification of the weaker signal at the cost of the stronger incident pump. During scattering process energy is transferred from the pump photon is created of reduced energy at lower frequency (referred to as stokes shift) [3]. The schematic diagram of a Raman amplifier is shown in Fig. (1), the pump light is coupled into the transmission fiber either in the same direction as the transmission signal 9 co-directional pumping) as shown in Fig. (1-a), or is coupled into the transmission fiber in the opposite direction (contra-directional) pumping as shown in Fig. (1-b), or both as shown in Fig. (1-c).

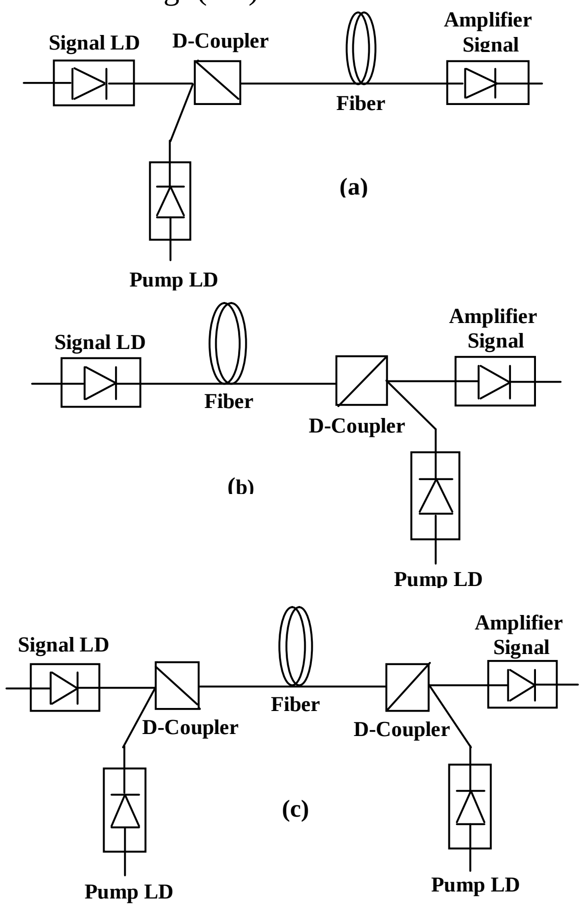

Fig. (1) Illustration Scheme for: (a) Forward (b) Backward (c) Bi-directional

The backward scheme has an advantage over the forward scheme in that the amplified signal does not see most of the pump variations [4,5]. Raman amplifier can be operated at any wavelength within the entire window of transparency of silica fiber along the transmission fiber in a distributed scheme [6]. An early application of fiber Raman amplifier was as a discrete preamplifier to improve their receiver sensitivity. It also can be used to post-amplify the signal before the signal is launched into the transmission lines. In 1992, 23 dB signal gains was obtained from a 140nsec pump laser with 1.4W peak pump power over 20km long dispersion shifted fiber [7]. In 1996 30dB gains was obtained when a heavily germanium-doped optical fiber was pumped with only 350 mW [8]. Recently the measurements of effective Raman gain of transmission fibers have been performed be several scientists to investigate the application of distributed Raman amplification [9].

Mathematical model

If we consider continuous wave (CW) or quasi-CW condition, the nonlinear interaction between the pump and stocks waves of SRS is governed by the following

$$\frac{dI_s}{d_Z} = g_R I_p I_s - \alpha_s I_s \quad (1)$$

$$\frac{dI_p}{d_Z} = -\frac{\omega_p}{\omega_s} g_R I_p I_s - \alpha_p I_p \quad (2)$$

Where I_p, Is, α_p, ω_p, ω_s are the intensity, the attenuation and frequency of pump and signal waves respectively. The pump and the signal beams at frequencies ω_p, ω_s are injected in to the fiber through a wavelength division multiplexing (WDM) fiber coupler. Coupler can be defined as devices with three or more fibers interconnected to provide mutual coupling between them.

Equation (2) is readily solved if we neglect the first term on its right-hand side that is responsible for pump depletion. If we substitute the solution in equation 1, we obtain:

$$\frac{dI_s}{d_z} = g_R I_o \exp(-\alpha_p z) I_s - \alpha_s I_s \qquad (3)$$

Where I_o is the incident pump intensity at Z=0, and g_R is the Raman gain coefficient. Value of g_R is dependent on the pump wavelength. Equation (3) can be easily solved, and result is

$$I_s(L) = I_s(o)\exp(g_R I_o L_{eff} - \alpha_s L) \quad (4)$$

Where L is the fiber length and the effective length of the fiber is given by[12]

$$L_{eff} = \frac{1-\exp(-\alpha_p L)}{\alpha_p} \qquad (5)$$

The gain provided by Raman amplification can be obtained from equation (4). With the common assumption that the intensity of signal remains much smaller than the pump intensity, the Raman amplification gain can be expressed.

$$G_A = \exp\left[\frac{g_R P_o L_{eff}}{KA_{eff}}\right] \qquad (6)$$

Where P_o is the pump power, A_{eff} is the effective core area of the fiber, and K is a numerical factor that account for polarization scrambling between the optical pump and signal. For complete polarization scrambling, as in conventional single mode fiber, K=2.

Result and discussion

The frequency different Ω_R, known as the stokes shift between the signal and the pump, plays an important role in the SRS process, the vibration energy levels of molecules dictate the value of Ω_R and the spared in Ω_R that can be tolerated for SRS to occur. In the presented work, the pump wavelength utilized are 1530, 1533, 1538 nm to get the stokes shift are 9, 13, 16THz respectively. The optical fiber utilized is a single mode optical fiber with a different length from0.5 Km to 3Km. By using the parameter values typical of standard single mode optical fiber used in optical communication system, A_{eff} =50 μm and K=2, the variation of the Raman gain as a function of the fiber length for different values of the pump power when the stokes shift 9 THZ (λ_P=1538.61nm), 13THZ (λ_P=1533.6nm) and 16THZ (λ_P=1530 nm) are shown in figures 2,3 and 4 respectively.

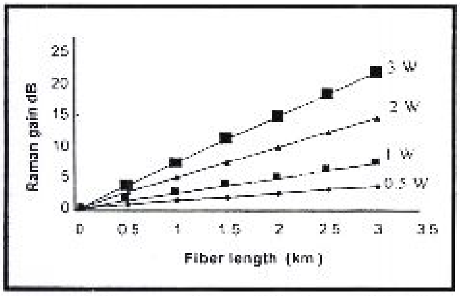

Figure 2: Raman gain as a function of the fiber length for different pump power when the stocks shift is 9 THz.

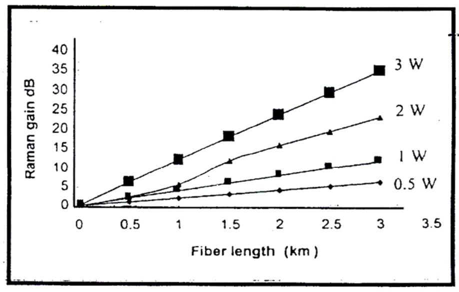

Figure 3: Raman gain as a function of the fiber length for different pump power when the stocks shift is 13 THz.

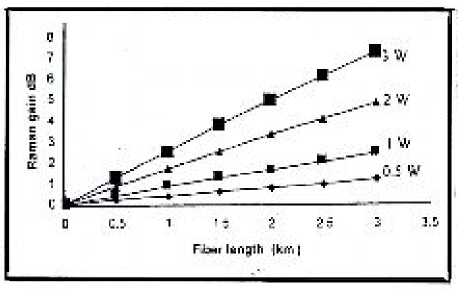

Figure 4: Raman gain as a function of the fiber length for different pump power when the stocks shift is 16

It may be observed that the Raman gain become larger as the fiber length increase up to around 3km. Moreover, it is clears that higher Raman gains are achieved with high pump power and lower loss fiber. The gain peaks it a stokes shift in the region about (12-14) THz. The amplification factor increases exponentially with pump power but then starts to deviate for p>5 W because of gain is saturated.

As see in Fig. (3), fiber Raman amplifier can provides 30dB gain at a pump power of about 3 W when the fiber length about 3km.

Conclusion

Simplified calculation model to estimates the Raman gains of standard single mode optical fiber is proposed and verified. This calculation model is accurate to get the Raman gains in a standard signal gain can be achieved in a specific fiber given its length and attenuation parameters at pump and signal wavelengths. The Raman gain becomes larger as the fiber length and pump power increase around 3 Km and 3 W respectively. Moreover, it is also that higher Raman gain obtained when the frequency shift in the range (12-14) THz.

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