Raman Amplifier

Introduction

- Raman amplifier is a **non-linear effect** because it affects the signal to noise ratio(**SNR**) in a wavelength division multiplexing (**WDM**) system. It can also be used for **amplification** of the optical signals in a long optical communication link.
- Incase of spontaneous Raman scattering, a small portion of the incident light is **transformed** into a new wave with lower or higher frequency
- The transformation efficiency of spontaneous Raman scattering is
- Typically 1 part per million photons are transformed to the new wavelength per cm length of the medium

Raman Scattering in Optical Fibers

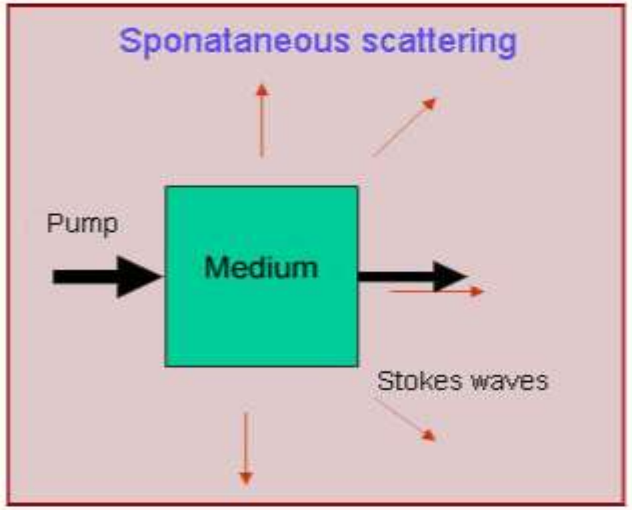
- The basic material used in optical fibers is **glass** which is not crystalline but is amorphous in nature.
- The **molecular resonance frequencies** of the vibrational modes in glass are overlapped with each other to give a broad frequency band. The optical fibers therefore show Raman scattering over a **large frequency range**.
- The energy conversion process between the pump and the Stokes is characterized by a parameter called the Raman Gain which depends on the material composition of the fiber core.

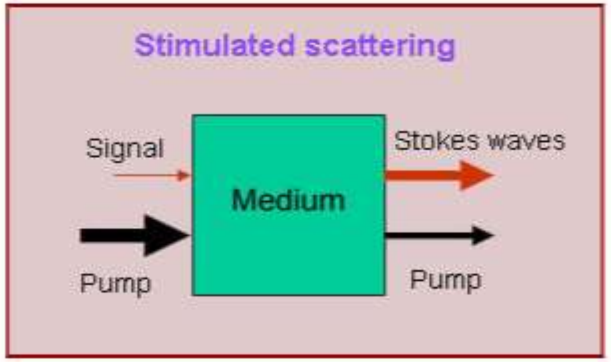
Raman gain

- the **maximum** Raman gain in pure glass is Gr(max) = 1.9 X10^{-13}m/W
- The maximum gain is practically constant over a bandwidth from 9THz to 16THz. The mean of the high gain region is around 13THz
- Raman gain is **inversely proportional** to the wavelength of the pump and depends on the polarization of the wave.

Fiber Raman Amplifier

- For optical amplification we need stimulated Raman scattering. The basic difference between spontaneous and stimulated Raman scattering is shown in Fig.
- If the intensity of the **incident field** is below a threshold, spontaneous scattering occurs





- The important thing to note is, the stimulated process can be used for light amplification. If a small signal at Stokes frequency is present along with the pump, the signal get samplified keeping all the characteristics of the input signal.
- The differential equations governing the intensities of the pump and the Stokes waves are

$$\frac{dI_s}{dz} = g_R I_p I_s - \alpha_s I_s \quad \text{(A)}$$

$$\frac{dI_p}{dz} = -\frac{\omega_p}{\omega_s} g_R I_p I_s - \alpha_p I_p \quad \text{(B)}$$

α_p, α_s

Where I_p and I_s are the **intensities** of the pump and the signal respectively. W_p and W_s are the **frequencies** and are the **attenuation** constants of the pump and the stokes waves.

- The equations show that the Stokes **grows** exponentially with distance whereas the pump **decays** exponentially with distance.
- In first approximation it is generally assumed that the pump depletion due Raman scattering is small. So the first term on the RHS in equation (B) can be neglected.

$$I_p = I_p(0)\, e^{-\alpha_p z}$$

- Introducing I_p in (A) we get intensity of the Stokes wave as

$$I_s = I_s(0)\exp(g_R I_p(0) L_{eff} - \alpha_s z)$$

where L_{eff} is the effective interaction length of the pump and is given as

$$L_{eff} = \frac{1-\exp(-\alpha_p z)}{\alpha_p}$$

- For long fibers $\alpha_p z \gg 1$, and $L_{eff} = \dfrac{1}{\alpha_p}$

- The threshold for stimulated scattering is defined as input intensity I_{pth} value of the pump for which Stoke wave shows gain in the fiber. The Raman gain process then must exceed the fiber loss to give

$$g_R I_{pth} L_{eff} \gg \alpha_S z$$

- Assuming that the length of the fiber is approximately L_{eff}, we can get threshold intensity for Stimulated Raman Scattering (SRS) as

$$I_{pth} \gg \alpha_s / g_R$$

- For a SM fiber typically the core effective area is $80\ \mu\text{m}^2$, and $\alpha \approx 0.2$ dB/Km, Raman gain is 7×10^{-14} m/W, the Raman threshold power $P_{th} = I_{pth} A_{eff} \gg 53\text{mW}$.

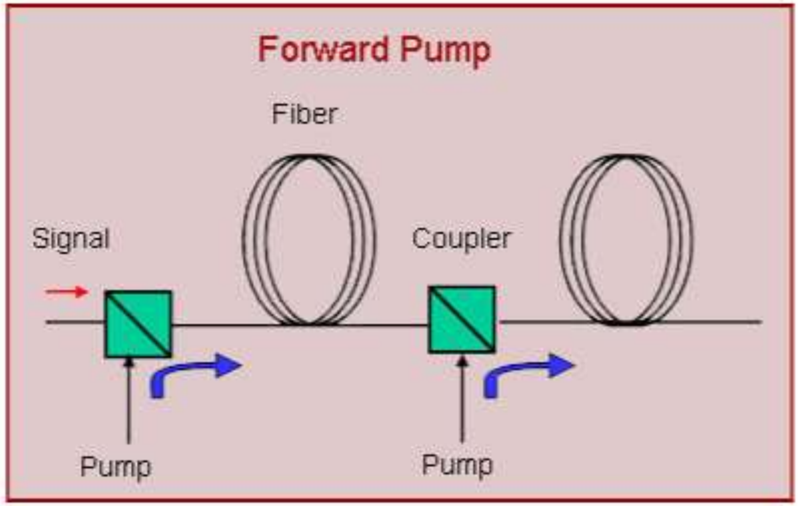
Some important points

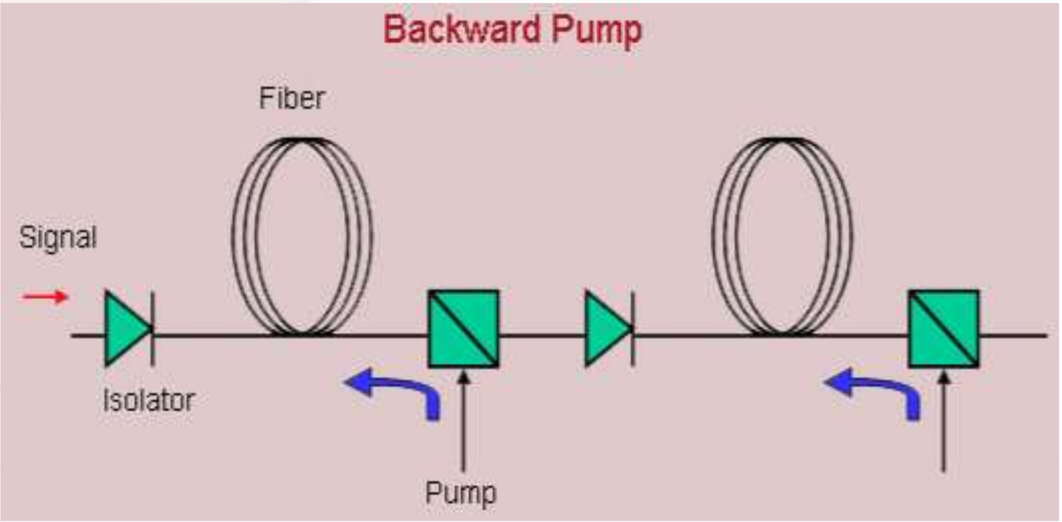
- The threshold given above just tells that above this pump power there will be gain for any signal above the noise. However still the Stokes power is orders of magnitude smaller than the Pump.
- If we define the threshold as the input power for which the output powers of pump and Stokes are equal, then its value is $I_{th} = \frac{16}{g_R L_{eff}}$ approximately. L_{eff} is the effective interaction length

•Typical power to achieve this threshold intensity in a SM fiber is about 1 W.

Pumping Schemes for Raman Amplifier

- The Raman amplifier can be pumped with **forward as well as backward** pump since Raman gain is independent of the pump direction. The two schemes are shown in Fig





- The forward pump scheme has two main **drawbacks**

1. The pump level is higher where signal is stronger giving increase of signal power at the beginning of the section
2. The residual co-propagating pump is to be filtered

- The maximum length or gain beyond which the Raman amplifiers no longer improve the system performance is determined by double Rayleigh back scattering (DRBS) multi-path interference (MPI) noise. This can be explained as follows.

  Suppose a signal is amplified by a co-propagating pump. Due to Rayleigh scattering a part of the signal is scattered back. The Stimulated Raman Scattering (SRS) being direction independent amplifies the backward scattered signal. The scattered light becomes strong enough to generate double back scattered signal which travels with the pump. Superposition between the signal and the time delayed double back-scattered light leads to time dependent noise.

Impact of Raman Scattering on WDM system

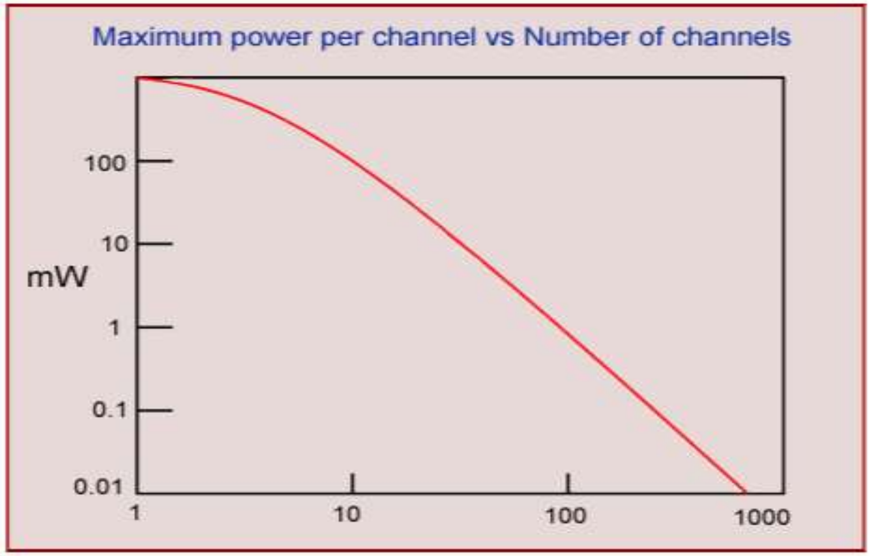
- the Raman effect is observed only if the **input power** of the channel is of the order of the threshold for the forward Raman scattering. Since the threshold is very high the Stimulated Raman Scattering (SRS) can be neglected in a single channel system.
- WDM systems the **initial Stokes wave is not generated** by the spontaneous process because the waves of right frequency shifts are already present in the system. Further the **input power** of the Stokes wave is more or less same as the input power of the pump (the channels of shorter wavelengths act as pump for the channels of the longer wavelengths).
- channels from **different** bands influence each other more and channels within a band also influence each other though to a lesser extent.

- **Decrease** in channel power is a problem in Wavelength Division multiplexing (WDM) system as it reduces SNR and increase the Bit error rate (BER)
- The decrease in power of a channel can be estimated analytically assuming a triangular Raman gain profile from 0 to 15 THz. If the acceptable reduction in the channel power is 1dB, the power-bandwidth product

$$[n P][(n-1)\Delta f] < 500 \text{ W-GHz}$$

Where is the number of Dense Wavelength Division Multiplexing (DWDM) channels, P is the power per channel, and is the channel separation.

- If number of channels is **small**, the maximum power per channel decreases as 1/n, but if the number of channel is large, the power decreases as $1/n^2$.



- In a long haul system with periodic amplification, SNR performance in presence of Raman scattering has been estimated. If the acceptable decrease in SNR in the channel with smallest wavelength is 0.5dB, the number of transmittable channels N can be calculated using

$$n(n-1) = \frac{8.7 \times 10^{15}}{P \, \Delta f \, L_{eff}}$$

Where L_{eff} is the effective interaction length of the system with amplifiers.

Thank You

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