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Analysis of Noise Figure of Fiber Raman Amplifier

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Abstract: ***Raman amplification is based on stimulated raman scattering (SRS).Raman amplifiers are widely used for high capacity communication systems. The main reason for which it can be used is its excellent noise figure. The source of noise and its effects on the noise figure is discussed and the methods to reduce the noise figure are given. In this paper noise figure of Raman amplifiers is studied and analyzed for different pumping schemes.***

Keywords: Amplified Spontaneous Emission (ASE), Double Rayleigh Scattering (DRS), Noise Figure (NF) and Signal to noise ratio (SNR).

1. Introduction

Raman amplifiers using the fibers as a gain medium is a encouraging technology for the optical dense wavelength division multiplexing (DWDM) communication systems. The noise figure mainly is a measure of how much the amplifier degrades the signal. Noise figure is a main parameter which decides the performance of the Raman amplifier. The basic definition is the ratio of signal to noise ratio at input to signal to noise ratio at output. Later, other definitions are given by other authors which shows the dependency of noise figure to other parameters of amplifier. These parameters are gain, spectral density of output noise, Noises (DRS, ASE, RIN), length, attenuation coefficient of signal and pump dispersion characteristics of an optical fiber.In the case, if a signal travels along the fiber with no loss and with no amplification of its SNR would be equal to its input value and the NF equal to one. But practically it is not possible. The other case is if the signal experiences the total loss during transmission and then amplified. As high gain is needed to amplify the signal in this case, therefore, the gain required from the amplifier at the end of the transmission is increased. To get this, more pump power is required resulting in large amplified spontaneous emission (ASE) noise and other noises generated in the amplifier and the input signal power to the amplifier is also decreased. The lower signal power means that the ASE is more successfully competing with the signal for receiving gain. These two factors combine to decrease the output SNR and hence increase the NF.

2. Basic Formulae for Noise Figure

The basic formula for NF is the ratio of SNR at the input of an amplifier to the SNR at the output of an amplifier.

$$F = \text{input SNR} / \text{output SNR} \quad (1)$$

where SNR is ratio of the signal power to the noise power.

$$SNR = \text{signal power} / \text{noise power} \quad (2)$$

If the two amplifiers are cascading to each other and gain of first amplifier is low, then the noise figure of the cascaded system is given by

$$F=F_1+F_2-1/G_1 \quad (3)$$

Where F_1 is the N.F. of a first amplifier, F_2 is the N.F. of a second amplifier and G_1 is the gain of avfirst amplifier. The NF on basis of a Photon number fluctuations, F_{pnf} is given by

$$F_{pnf}=1/G+2\theta(1-1/G)+\theta(1-1/G)[1/G+\theta(1-1/G)]/\langle n_s\rangle \quad (4)$$

$\theta=n_{sp}$ is a noise enhancement factor this equation indicates that the noise figure is signal dependent. $\langle n_s\rangle$is average photon number.

Generally an approximation is taken that a signal photon number is large so last term in (4) can be neglected and so the equation becomes

$$F_{pnf}= 1/G +2\theta(1-1/G) \quad (5)$$

The (5) has a problem, so it does not fit for cascaded system and signal photon number is not always large, so this equation cannot used in such cases. In Fiber Raman Amplifier, the noise figure on the basis of vacuum fluctuation which is the minimum level of the optical noise.

$$NF = N_s/(Gh\nu_s/2)=1+G-1/G+_2\alpha_{sDinv} \quad (6)$$

Where N_s is spectral density of an output optical noise, G is total gain, h is Planck's constant, v_s is signal frequency and α_s is fiber attenuation coefficient for the signal[3]. Noise Figure can also be defined in terms of ASE. In that NF can be calculate by measuring the noise power added by the amplifier (P_{ASE}).

$$NF = (2P_{ASE}+h\nu B0)/Gh\nu B0 \quad (7)$$

Where hνB0 is an optical shot noise partition. ASE noise figure can also given on the basis of a pumping scheme.

3. Different Factors Which Affect Noise Figure

Noise figure is mainly affected by noise sources like Relative Intensity Noise (RIN), Double Rayleigh back scattering (DRBS), Amplified Spontaneous Emission (ASE). These sources of noise not only affect the noise figure but also its spectrum. The noise DRS is proportional to the length and the gain in a fiber, where lengths of several kilo meters are typically needed. We also observe that if the

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upper-state lifetime of Raman amplification is short as 3 to 6 sec, it also produces noise. Noise figure of Raman amplifier can also degraded by the pump depletion. In discrete Raman amplifiers pump depletion creates gain saturation which affects the amplifier transients, noise figure and pump mediated crosstalk. In distributed Raman amplifiers, the pump to signal energy transfer creates higher effective pump attenuation. Hence a smaller pump penetration into the fiber, leading to NF degradation[7].

As decaying through stimulated emission, electrons in the upper energy level also decay by spontaneous emission, which occur randomly, depending upon the glass structure and inversion level that is a source of ASE noise. The photons are emitted naturally in all the directions, but a proportion of those will be emitted in a direction that falls within the length of a fiber and are thus collected and guided by a fiber. Those photons collected may be then interact with other dopant ions, and thus amplified by stimulated emission. The initial spontaneous emission is amplified in the same manner as the signals, hence we use the term ASE noise[9].

3.1 Noise Figure Tilt

There is another most important problem related to the noise figure. As there is Raman interaction between the different pump wavelengths, the bandwidth available for long distance transmission is limited by energy transfer from small wavelength pumps to large wavelength pumps and also from small wavelength signals to large wavelength signals. These effects are result in noise figure (NF) tilt with respect to wavelength, where the NF is degraded for small wavelength signals and the magnitude of the tilt increases with total amplification bandwidth[8].

PMD (Polarization Mode Dispersion) is also affects the noise figure as a progressive fluctuations of the pump state of polarization that is associated with PMD produces additional noises to the signal[9].

4. Analysis of Behaviour of Noise Figure for Different Pumping Schemes

To ensure a high-quality product, diagrams and lettering MUST be either computer-drafted or drawn using Ind Noise Figure changes differently with respect to the length of the fiber for both pumping schemes these are co-pumping and counter pumping schemes.

4.1 Co-pumping Scheme

When the pump power propagates in the same direction as the direction of the signal, it is called co or forward pumping scheme. "Fig.1," shows the schematic for Raman amplifier with co-pumping scheme

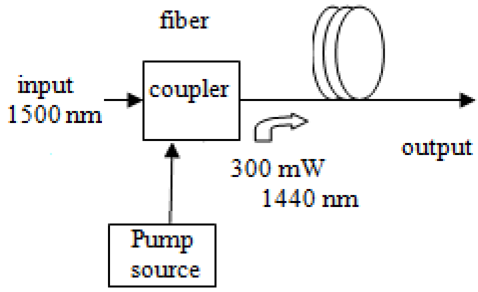

Figure 1: Schematic of Co- Pumping scheme

The values of simulation parameters are wavelength of pump is 1400 nm, wavelength of signal is 1500 nm, pump power of 300 mW and the length for fiber is taken 5 km. In a co-pumping scheme the signal power is large due to the input signal and pump signal are propagates in same direction. So, from the definition of SNR, large signal power leads to large SNR at output and then from the noise figure definition, if SNR at output is large, then Noise figure is low.

4.2 Counter pumping Scheme

When the pump travels in the opposite direction of the signal direction then it is called counter or backward pumping. "Fig. 2," shows schematic for Raman amplifier with counter pumping scheme.

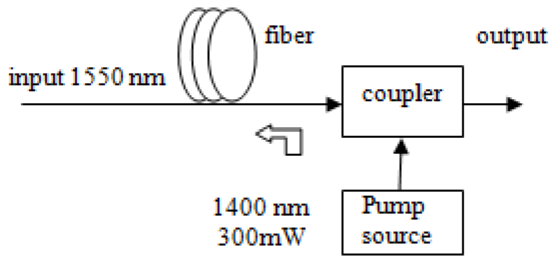

Figure 2: Schematic of Counter Pumping

The values of simulation parameters are wavelength of pump is 1400 nm, wavelength of signal is 1500 nm and pump power of 300 mW and the length for fiber is taken 5 km. The noise figure is increasing with the length because signal power in counter pumping scheme is small at the input of the fiber.

5. Methods of Improvement of the Noise Figure

Noise figure can also be improved by using dispersion-compensation fibers (DCFs) which consist of positive and negative dispersion sections which cancel the dispersion and we can also use fiber Bragg grating (FBG). ASE noise-reduction improvement ranges from 2.3 to 3.6 dB, for the Raman gains from 15 to 30 dB can be received from this method. A second order pumping not only used to improve noise figure but also receive large gain bandwidth. 1.5 dB improvements in noise figure and a 0.9 dB improvement in system performance can be achieved [4]. Also by correct choice of the second order pump wavelength, noise figure tilt can be reduced. As noise figure affected by the losses that are two-photon absorption (TPA) and free-carrier scattering. TPA-induced free-carrier loss degrades the noise

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figure and it depends upon the carrier life time. Hence decreasing the carrier life time, noise figure can be increased [2].

To reduce noise figure the bidirectional pumping method is the most favourable clarification. An NF control under a fixed gain spectrum can be done with proper adjustment of forward/backward pumping ratio[6].

6. Conclusion

In this paper, different characteristic of the noise figure have been explained with reference to different situations how to increase the noise figure. Noise figure for the different pumping schemes has been analysed and seen that co-pumping scheme offers more excellent noise performance than counter pumping scheme. Our study requires more widespread review of the methods to make better the noise figure which comprise the following (higher order pumping, Bragg grating). Our study has found that for multi-pump Raman amplifiers optimizing the noise figure becomes a challenge specially when change of the fiber length, attenuation, cladding and core index values are changed.

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Parul Singh is born in 1989 at Ajmer of Rajasthan, India. She is pursuing M. Tech 2nd year in Digital Communication from Rajasthan Technical University.

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