EFFECT OF GAIN DISTRIBUTION AND PUMP NOISE TRANSFER ON NOISE GENERATION IN RAMAN AMPLIFIERS

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Abstract *: Role of gain distribution in noise generation in Raman amplifiers is pointed out by using a new classical formalism allowing to distinguish noise sources which are input noise, intrinsic amplifier noise and transferred pump noise.*

Introduction

The spectral bandwidth required to go with WDM systems being enlarging continuously and noise accumulation in cascaded amplifiers having to be counteracted [1], new types of amplifiers, such as Raman amplifiers are considered. Optical noise contribution in signal degradation being a key issue, it is crucial to determine the different origins of noise power and to point out the parameters inducing noise reduction or control in these optical amplifiers. Previous published works have already shown the importance of gain distribution in linear amplifiers [1] for limiting noise generation. After introducing a new classical formalism [2-3] presented in section 2, noise generation process in Raman amplifiers is discussed for backward and forward configurations by distinguishing the different noise contributions in section 3. The different parameters determining the output noise power are finally pointed out.

The classical noise formalism

In Raman amplifiers, the output signal at frequency ν_S and its associated noise powers, in an optical bandwidth B_0, depend on power of pump at frequency ν_P and of its associated noise because of pump depletion and of crossed signal-pump components [4]. This dependence is introduced in the propagation noise equations [2-3] by additive crossed terms. Under a first order approximation, cross terms between signal noise and pump noise are neglected. Effects of transmission fiber temperature are neglected [5]. Amplifiers are assumed to have gain and loss coefficients homogeneous at signal and pump frequency all along the effective amplification length. The different loss contributions are internal losses expressed by the α_S and α_P coefficients and those resulting from Rayleigh backscattering expressed by α_{RS}, α_{RP} [6]. The subscripts S and P refer to contributions at signal and pump frequency. The input signal is assumed shot noise limited, meaning zero-point fluctuation input condition as far as the optical field is considered. The fiber is single mode with a constant effective interaction area and a constant Raman amplification coefficient, g_R. Adding the different noise contributions, the differential equations for the signal power P_S and for the associated noise power N_S are :

$$P_S(z+dz)=P_S(z)-[\alpha_{RS}+\alpha_S]P_S(z)dz+g_R P_P(z)P_S(z)dz \quad \textbf{(1)}$$

$$\begin{aligned}N_S(z+dz)=\;&N_S(z)+[-\alpha_{RS}-\alpha_S+g_R P_P(z)]N_S(z)dz\\&+g_R(2P_P(z)N_P(z))^{1/2}P_S(z)dz\\&+[\alpha_{RS}+\alpha_S+g_R P_P(z)](h\nu_S/2)B_0 dz\end{aligned} \quad \textbf{(2)}$$

Similarly pump power P_P and the associated noise power N_P are :

$$\begin{aligned}P_P(z+dz)=\;&P_P(z)-[\alpha_{RP}+\alpha_P]P_P(z)dz\\&-(\nu_P/\nu_S)g_R[P_S(z)+N_S(z)+(h\nu_S/2)B_0]P_P(z)dz\end{aligned} \quad \textbf{(3)}$$

$$\begin{aligned}N_P(z+dz)=\;&N_P(z)-[\alpha_{RP}+\alpha_P]N_P(z)dz\\&-[(\nu_P/\nu_S)g_R P_S(z)](2P_P(z)N_P(z))^{1/2}dz\\&+[\alpha_P+\alpha_{RP}](h\nu_P/2)B_0 dz\\&+[(\nu_P/\nu_S)g_R P_S(z)](2P_P(z)(h\nu_P/2)B_0)^{1/2}dz\end{aligned} \quad \textbf{(4)}$$

Equations (1) and (3) are the well-known propagation equations [4] in which depletion induced by signal P_S and associated noise N_S are added. In equations (2) and (4) the two first terms express the well-known propagation of noise components and the last terms are the contributions of amplification and attenuation noise at signal and pump frequency respectively. In equation (2), the third term expresses the contribution of pump fluctuations at signal frequency in an optical bandwidth B_0.

Influence of pump noise transfer

Pump noise power has a non negligible contribution in noise generation and degrades significantly performances of Raman amplifiers. Using equations (1) to (4) and assuming a shot noise limited signal, i.e. a signal Relative-Intensity-Noise (RIN) equal to 1, the contributions of each source of noise in the total noise power at signal frequency, namely due to pump noise to signal transfer, are calculated for distributed Raman amplifiers in forward and backward configuration. The different noise contributions are the input signal power fluctuations (first and second terms in equation (2)) which are equal to zero-point fluctuations, the amplification and partition intrinsic noise (last bracketed part in equation (2)) and the input pump power fluctuations (third term in equation (2)) which are assumed successively shot-noise limited, 10dB and then 20 dB above the shot-noise level (cf. figures).

The OSNR for each value of input pump noise powers are reported on figure 1 for forward configuration, and on figure 2 for backward configuration. The mechanism of pump noise to signal transfer and its consequences appears significantly different between the two configurations because of the difference of gain distribution.

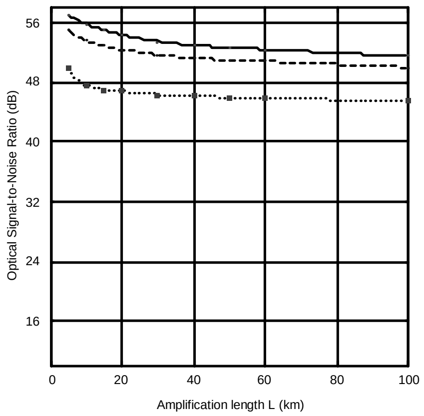

Figure 1 *: O.S.N.R. vs. amplification length in forward configuration for different pump noise values and for 3 values of pump noise : SNL (plain line), SNL+10dB (dashed line), SNL+20dB (dotted line)* (ν_p = 206THz, ν_S = 192THz, $\alpha_P = \alpha_S$ = 0.2dB/km, $\alpha_{RP} = \alpha_{RS}$ = 0.7dB.μm^4/km, $g_R = 8.10^{-14}$ m/W. $A = 70.10^{-12} m^2$.

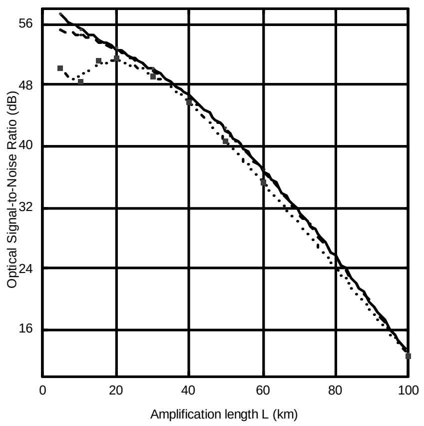

Figure 2 *: O.S.N.R. vs. amplification length in backward configuration for different pump noise values and for 3 values of pump noise : SNL (plain line), SNL+10dB (dashed line), SNL+20dB (dotted line)* (ν_p = 206THz, ν_S = 192THz, $\alpha_P = \alpha_S$ = 0.2dB/km, $\alpha_{RP} = \alpha_{RS}$ = 0.7dB.μm^4/km, $g_R = 8.10^{-14}$ m/W, $A = 70.10^{-12} m^2$.

Influence of gain distribution

Comparing figure 1 and 2, the effects of gain distribution on smoothing pump fluctuations are underlined. As shown on figure 1, Raman amplifiers in forward configuration are very sensitive to pump fluctuations. On the other hand, in backward configuration, pump fluctuations have little influence on OSNR values. In forward configuration due to the simultaneous propagation of signal and pump, the gain is localized at the input of Raman fiber where pump power is the highest. Signal power and signal noise power are so significantly amplified on a short amplification length and the pump noise to signal transfer is maximized. On the other hand, in backward Raman amplifiers, gain factor per unit of length is smaller than in forward configuration because it is distributed all along the fiber. Pump noise to signal transfer is minimized.

Raman amplifiers in backward configuration seem particularly adapted for long amplification length processes when a noisy pump is used (noise > 10 dB) for in this case, noise amount is minimized since the role of pump noise in signal degradation is reduced. On the other hand, forward configuration is suitable for short amplification lengths and/ or when initial pump noise power is close to the SNL since the signal-to-noise ratio and gain are better than in backward configuration.

Conclusion

By using a new classical formalism, the effects of pump noise to signal transfer in Raman amplifiers are derived as well as the importance of gain distribution control to limit the effects of noise sources, namely pump noise.

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