# AMPLIFIED SPONTANEOUS EMISSION IN FIBER OPTIC LINES USING RAMAN AMPLIFIERS

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***Abstract:*** *New methods for a regeneration and an enhancement of the optical signal have been developed all over the world. The main reason is the increasing bit rate and optical fiber length. A new method for optical amplifiers based on nonlinear effects is discussed in this report. Amplification changes are surveyed as a function of the signal power at different pump configurations and different wavelength.*

**Keywords**: Fiber Raman Amplifier (FRA), Amplified Spontaneous Emission (ASE), Optical noise, Raman amplification, Raman Gain Coefficient.

## *1. Introduction*

Communication systems are used to transfer information both within a country, continent and for intercontinental transmission. Systems development and the growing information traffic require a new traffic area like fiber optic to be involved.

As nowadays Wavelength Division Multiplexing (WDM) systems are those with growing bit rate information and the length of fiber optic lines and use of repeaters leads to limitation of bandwidth, it is necessary to use another type of units to replace these devices.

Retransmission limitation also influences the transmission of information in modern multilateral (MLAT) systems that are increasingly used in radar-free areas. The limitations of the radio channels used in MLAT systems also contribute to the involving of optical lines in this type of surveillance system [7, 6].

For these reasons, alternative approaches to loss decrease are required in optical amplifiers that amplify the optical signal directly without requiring transformation in the electrical signal [4].

One of the most effective methods of amplifying optical signals is the use of the non-linear effects of Stimulated Raman scattering and Stimulated Brillouin scattering. Optical amplifiers built on these effects, and in particular the Raman effect, can successfully replace optical repeaters, and even massive used Erbium-Doped Fiber Amplifier (EDFA) [4].

At the beginning of the 21st century, almost any long distances optical system (usually defined from 300 to 800 km) or ultra-long distances once (typically defined over 800 kilometers) uses the Raman Optical Amplifier (FRA).

A great FRA advantage is a very wide bandwidth amplifying which allows that to be used in various optical systems using the existing optical lines. The gain is accomplished in the fiber itself with significantly better figure noise resistant.

FRA gain using the transmission fiber as a carrier is an advantage technology in DWDM optical telecommunication systems. To amplify signal more pump power is needed, but thus the noise of Amplified Spontaneous Emissions (ASE) increases and other noises generated in the amplifier also reduces the power of the input signal to the amplifier. So, ASE takes an important part in transmitting the optical signal to the receiver [4, 5].

It is important to research the gain variation as a function of the signal power in the different pump configurations and fiber lengths. One of the main noises, namely ASE, can be used in the FRA. By adding ASE to the amplification process, it is possible to improve the amplifier operation and increase the gain of the amplifier [8].

## *2. Mathematical models on ASE influence on Raman Amplifier gain coefficient.*

The FRA bandwidth is above 40 THz, with a dominant peak at 13.2 THz relative to the pump frequency (Figure 1) [3, 9].

The gain coefficient $g_r$ is related to Raman's spontaneous scattering cross section, which is measured experimentally and generally depends on the optical fiber characteristics, and is also highly dependent on the polarization state between the pump and the signal. For a fiber of several tens of meters in length, propagation of the signal and the pump through it will cause the two states of polarization to decrease $g_r$.

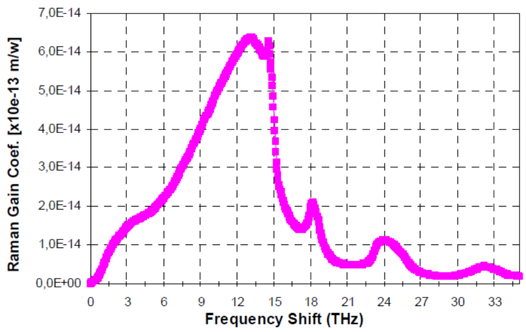



***Figure 1.*** *The Raman amplifier gain coefficient $g_r$ for the wavelengths of the signal and of the pump [3, 9].*

We examine the simplest case of spreading a beam entering in the optical fiber used for amplification.

It is necessary to calculate the amplification of Raman's amplifier signal with or without spontaneous emission.

*2.1 Raman gain without amplified spontaneous emission.*

The amplification of the signal and propagation of the pump signal along the length of the optical fiber is described by the following equations:

$$\frac{dP_s}{dz} = -\alpha_s P_s + \frac{g_r}{A_{eff}} P_p P_s \quad (1)$$

$$\frac{dP_p}{dz} = -\alpha_p P_p + \frac{g_r}{A_{eff}} \frac{\omega_p}{\omega_s} P_p P_s \quad (2)$$

where $P_s$ and $P_p$ are the signal power and pump power;

$g_r$ is the gain coefficient to the Raman amplifier;

$\alpha_s$ and $\alpha_p$ are the optical fiber attenuation coefficients for the wavelengths of the signal and the pump;

$\omega_s$ and $\omega_p$ are carrier of signal waves and pump waves.

Second part of the equation (2) represents the transmitted power from the pump if we ignore it and solve the equation and replace in (1) the following expression:

$$\frac{dP_s}{dz} = -\alpha_s P_s + \frac{g_r}{A_{eff}} P_p(0)\exp(-\alpha_p z) P_s \tag{3}$$

Where $P_p(0)$ is pump power at $z = 0$.

After reading the length of the optical fiber, meaning $z = L$ and by the equation (3) is obtained

$$P_s(L) = P_s(0)\exp\left(\frac{g_r P_p(0) L_{eff}}{A_{eff}} - \alpha_s L\right) \tag{4}$$

where $L_{eff}$ the effective length of interaction between the signal and the pump is determined by the equation:

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

After integrating equation (4) for Raman gain coefficient [dB] is obtained:

$$G_s[dB] = -\alpha_s L + \frac{0{,}434 g_r P_p(0) L_{eff}}{A_{eff}} \tag{6}$$

where $L_{eff}$ is effective length of interaction between the signal and the pump in meters.

*2.2 Raman gain with amplified spontaneous emission.*

ASE is a typical noise in optical amplifiers. FRA is used to increase amplification of the optical amplifier.

ASE is added to the signal power in equation (1). Then equation (1) takes the following form:

$$\frac{dP_s}{dz} = -\alpha_s P_s + \frac{g_r}{A_{eff}} P_p\left(P_s + P_{ASE}\right) \tag{7}$$

where $P_{ASE} = 2n_{sp} h\upsilon_s \Delta V_R$ and $h = 6{,}6260.10^{-34}[m^2 kg/s]$ is Planck's constant.

$$n_{sp} = \frac{1}{1-\exp\left(\frac{-h\Omega}{K_B T}\right)}$$ is the spontaneous emission factor.

$$\frac{dP_s}{dz} = -\alpha_s P_s + \frac{g_r}{A_{eff}} P_p P_s + \frac{g_r}{A_{eff}} P_p 2n_{sp} h\upsilon_s \Delta V_R \tag{8}$$

After reading the length of the optical fiber, meaning $z = L$ and integrating an equation (8) the gain with added ASE is obtained:

$$G_{ASE}[dB] = 0{,}434\left(-\alpha_s L - \frac{g_r P_p(0) L_{eff}}{A_{eff}} - \frac{P_{ASE} g_r P_p(0)\left(1-\exp(\alpha_s - \alpha_p)\right)L}{A_{eff} P_s(0)(\alpha_s - \alpha_p)}\right) \tag{9}$$

## *3. Simulations and results.*

In order to study the impact of ASE on the FRA gain ratio, two types fiber optics, Standard single mode fiber (SMF) [1] and Non-zero dispersion-shifted fiber (NZ-DSF) [2] were used. The fiber parameters are given in Table 1.

*Table 1. Fiber optic parameters*

| Optical fiber | Attenuation coefficients $\alpha_s$ [dB/km] | Wavelengths $\lambda_s$ [nm] | Raman gain coefficient $g_r$ [1/mW] | Fiber effective area $A_{eff}$ [μm²] | Fiber optic length [km] |
|---|---|---|---|---|---|
| SMF | 0,13 dB/km | 1550 nm | $4{,}2.10^{-14}$ | 80 μm² | 100 km |
| NZ-DSF | 0,18 dB/km | 1550 nm | $4{,}2.10^{-14}$ | 72 μm² | 100 km |

To calculate the effective length of interaction between the signal and the pump, it is more convenient to translate the equation (5) $L_{eff}$ into decibels.

It is more convenient to use an equation in which the attenuation coefficient set in the reference data in dB/km is used directly. Then (5) acquires the following form:

$$L_{eff} = \frac{4{,}343}{\alpha_p}\left(1-\exp\left(-0{,}23\alpha_p L\right)\right) \tag{10}$$

Figure 2 shows the results of the equation (10) of the effective length of the signal and pump interaction depending on the length of the optical fiber.

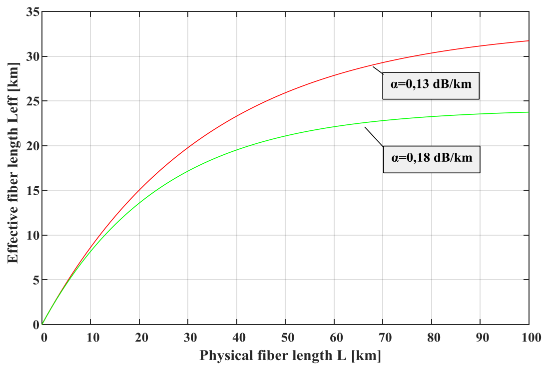
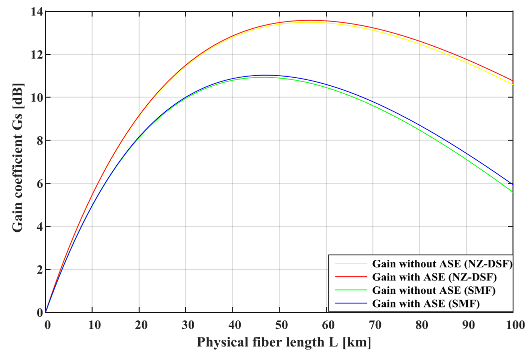


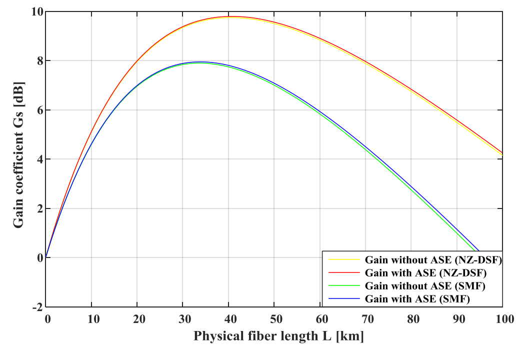

***Figure 2.*** *Effective fiber length* $L_{eff}$ *for both fiber types.*

The figure shows that $L_{eff}$ depends on the attenuation coefficient, i.e. from fiber type.

Figure 3 shows the results obtained for the gain ratio using a pump with power *Pp=500mW* and different wavelength. In the figure, the first graph is obtained with the pump attenuation coefficient $\alpha_p = 0{,}13 dB/km$, and the second with the attenuation coefficient $\alpha_p = 0{,}18 dB/km$.



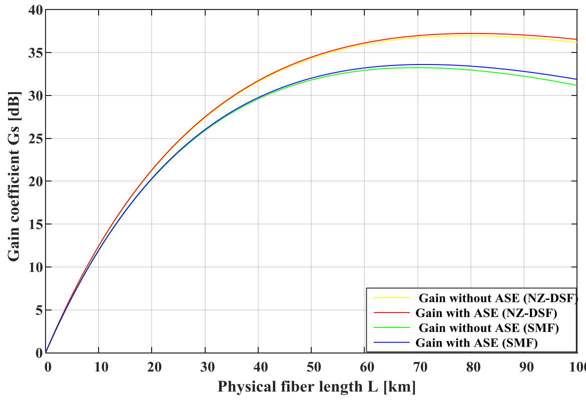

a) with $\lambda_p = 1450nm$



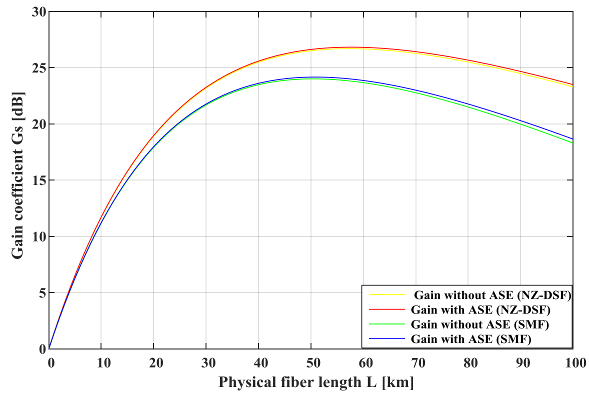

b) with $\lambda_p = 1460nm$

***Figure 3.*** *The Raman amplifier gain coefficient with Pp=500mW.*

Figure 4 shows the results obtained for the gain ratio using a pump with power *Pp=1000mW* and different wavelength. In the figure, the first graph is obtained with the pump attenuation coefficient $\alpha_p = 0{,}13 dB/km$, and the second with the attenuation coefficient $\alpha_p = 0{,}18 dB/km$.



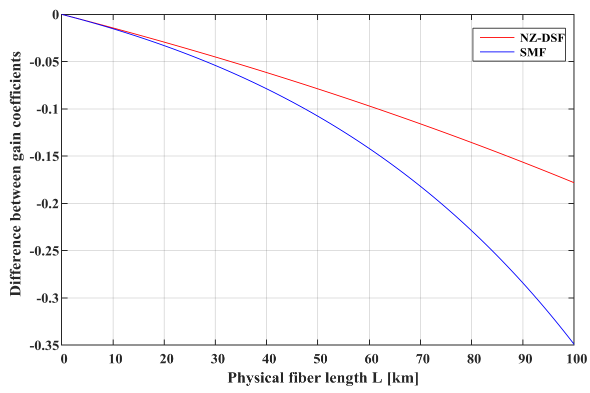

a) with $\lambda_p = 1450nm$



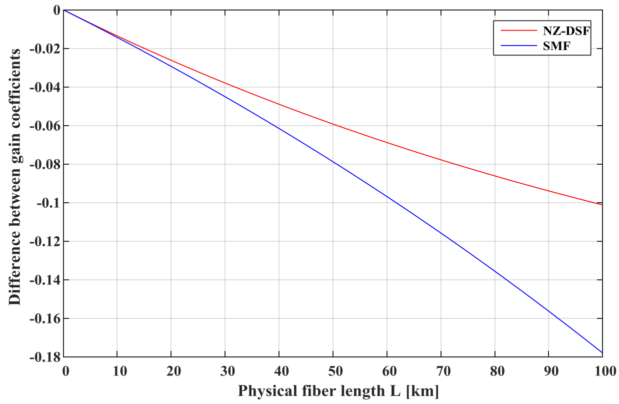

b) with $\lambda_p = 1460nm$

***Figure 4.*** *The Raman amplifier gain coefficient with Pp=1000mW.*

Figure 5 shows a graph of the difference between ASE and non-ASE gains of different fiber types. The attenuation coefficient for the both pumps are respectively $\alpha_p = 0{,}13 dB/km$ and $\alpha_p = 0{,}18 dB/km$.



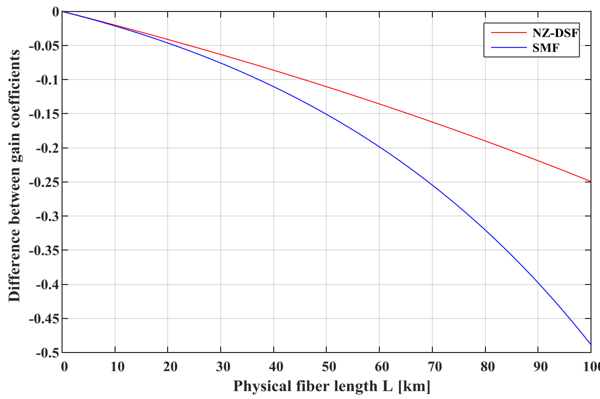

a) with $\lambda_p = 1450nm$



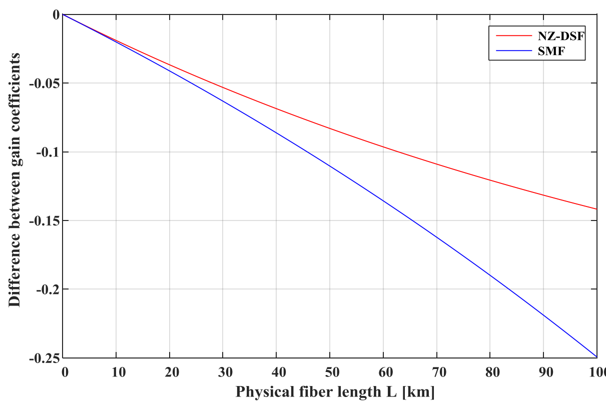

b) with $\lambda_p = 1460nm$

***Figure 5.*** *Subtraction the Raman amplifier gain coefficient with Pp=500mW.*

Figure 6 shows a graph of the difference between ASE and non-ASE gains of different fiber types. The attenuation coefficient for the both pumps are respectively $\alpha_p = 0{,}13 dB/km$ and $\alpha_p = 0{,}18 dB/km$.




a) with $\lambda_p = 1450nm$




b) with $\lambda_p = 1460nm$

***Figure 6.*** *Subtraction the Raman amplifier gain coefficient with Pp=1000mW.*

From the results obtained, it is seen that in order to achieve a higher amplification of the signal, higher pump power is required. At pump power Pp=1000mW the gain is greatest.

The results show that the gain coefficient for both fiber types is higher when ASE is added in the amplification process.

When a specified wavelength of the pump is used, the ASE gain ratio is approaching the gain coefficient without ASE.

From the results derived for the difference between the gains for the two fiber types, it can be seen that the gain rate also depends on the fiber type.

## *4. Conclusion.*

Choosing a suitable laser as a pump can reduce the number of amplifiers used in the long lines. Increasing the power of the pump also leads to a reduction in the number of amplifiers, but so far there are not as many powerful lasers to use in the FRA.

To achieve greater amplification, the selection of an appropriate laser is very important. By selecting a laser with appropriate wavelengths and an attenuation coefficient for a specific fiber type, we achieve a greater effect than ASE.

Using an appropriate fiber type will make a greater use of ASE in the amplification process.

The results obtained and the conclusions drawn show that long and ultra-long lines require a more detailed spontaneous emission study in order to increase the regeneration areas and reduce the number of amplifiers.

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