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Analyzing Gain Spectrum and ASE (Amplified Spontaneous Emission) of EDFA (Erbium Doped Fiber Amplifier) by using MATLAB

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ABSTRACT

The scope of this paper is to analyze the performance is augmented gain EDFA systems using single and multi-wavelength input sources. The performance of an Optical Communication System can be improved by the use of EDFA as an Optical Amplifier. Erbium Doped Fiber Amplifier (EDFA) is an important element in DWDM networks. A significant MATLAB code is developed, which provides the ability to handle multiple channels, thereby allowing to observe the EDFA gain versus wavelength. Since the gain is non-uniform, it is important to know its characteristics in WDM applications where many channels are sent through the amplifier. Addition to this includes the forward Amplified Spontaneous Emission (ASE). The resulting model is practical and accurately represents EDFA gain dynamics and forward ASE.

Keywords: *EDFA System, Optical Communication, MATLAB, Amplified Spontaneous Emission (ASE), Augmented.*

1. INTRODUCTION

Optical amplifiers are interesting because they provide a method by which long distance communication over optical fiber can be done. However, when transmitting over long distances, signal attenuation can occur. In this case, an optical amplifier must be used to regenerate the signal. This ensures that the received signals characteristics are comparable to the characteristics of the transmitted signal. One of the most widely used amplifiers for long-haul telecommunication applications is erbium doped amplifiers (EDFA). EDFA's are popular because they provide all-optical amplification, as opposed to electrical amplifiers that use optical-electrical-optical amplification. Electrical amplification works well for moderate-speed single wavelength operation, however, it is complex and expensive for high-speed multi-wavelength systems; this is where all-optical amplification is desired.

EDFA's are widely used in wavelength division multiplexed systems because as mentioned before, electrical amplification is complex and expensive for multi-wavelength systems. However, there is a problem with using EDFA's in WDM systems because the gain of the EDFA is not uniform over the entire 1550 nm window (i.e. 1530 nm – 1560 nm). Different wavelength signals experience different gains and therefore experience a different signal to noise ratio. It is important to compensate for this non-uniform gain spectrum.

Currently, the simulation tools available to investigate EDFA dynamics consist of OASIX and the photonic transmission design suite (PTDS). These software programs allow for simulations of EDFA models that are mostly static. However, the MATLAB code is developed to provide a dynamic EDFA model with the ability to modify the input signal power and more importantly the input pump power.

2. OVERVIEW OF EDFA EQUATIONS

An ordinary nonlinear differential equation for studying EDFA gain dynamics is shown below:

$$\frac{\partial}{\partial t}N_2 = P_S(0,t)[1 - e^{B_S N_2 - C_S}] + P_P(0,t)[1 - e^{B_P N_2 - C_P}] - N_2/\tau \quad (1)$$

Equation (1) is the key equation for studying gain dynamics in an EDFA. The co-directional input pump power is $P_P(0,t)$ and the input signal power is $P_S(0,t)$. These input powers are in photons/second and are related to the power in Watts by $P_{P,S}=P_{P,S}(h,\upsilon)$, where υ is the frequency in Hertz and h is Plank's constant in Units of J/Hz. For our purposes where we must consider the wavelength, the equation is rewritten as $P_{P,S}=P_{P,S}\frac{hc}{\lambda}$, where c is the speed of light in m/s and $\boldsymbol{\lambda}$ is the wavelength in m. The outputs pump and signal powers are

$$P_P(L,t) = P_P(0,t)\, e^{B_P N_2 - C_P}$$

$$P_S(L,t) = P_S(0,t)\, e^{B_S N_2 - C_S} \quad (2)$$

In equation (2), quantities B and C characterize the physical EDFA and are given by

$$[B_P, B_S] = \frac{\alpha+\beta}{4.3429\rho A}$$

$$[C_P, C_S] = \frac{\alpha L}{4.3429} \quad (3)$$

The scale factor 1/4.3429 converts decibels to log base e. This is important because the gain produced by the EDFA model is in base e and must be multiplied by 4.3429 to convert it to decibels.

3. HANDLING MULTIPLE WAVELENGTHS

Multiple signal wavelengths are handled by allowing B_S and C_S in equation (3), as well as the input signal P_S (0,t), to be multidimensional. The input signal is wavelength dependent as shown by the formula $P_{P,S} = P_{P,S}\frac{hc}{\lambda}$. So, the input signal power to the EDFA module had to calculated for each wavelength. Furthermore, the parameters that determines the wavelength dependency of B_S and C_S are α and β, the emission and absorption cross-section coefficients, coefficients, respectively.

It is important to note that simulating one wavelength at a time will give different results than simulating all the wavelengths simultaneously. EDFAs are designed to work in the nonlinear regime, so properties like linear superposition don't hold. This is because when there are several channels in an EDFA there is an effect called gain stealing. How much of the energy each of the channels takes from the pump depends on the details of the emission and absorption spectra. This provided an adequate representation of gain versus wavelength, however, more channels can be used to get a more accurate representation.

So, an important relationship for EDFA's is found, i.e. gain versus wavelength. Using a length of 12m, the small signal gain over 1520 nm≤ $\boldsymbol{\lambda}_S$ ≤1570 nm is plotted. An input signal power of -30 dBm is used because a large signal would drive the EDFA into saturation causing the difference in the gains at different wavelengths to be small.

4. GAIN FLATTENING

It is important to compensate for the non-uniform gain spectrum in WDM applications so that each wavelength experiences approximately the same gain. A different approach gain flattening is considered in this paper. Usually, the gain is flattened using a notch filter or a fiber Bragg grating, however in this paper considered how gain flattening can be done using the pump signal only. If the gain can be flattened by varying the pump signal (according to a certain relationship), then there is no need for external filters.

A relationship between the pump gain and the signal gain can be derived using equations (2) and (3) as follows.

$$N_2 = C_P / B_P + \ln(P_P(L,t)/P_P(0,t)), \quad (4)$$

$$\ln(P_P(L,t)/P_P(0,t)) = B_S N_2 - C_S \quad (5)$$

substitute equation 4 into 5

$$\ln\left(\frac{Pp(L,t)}{Pp(0,t)}\right) = \left(\ln(Gs) + Cs - \frac{BsCp}{Bp}\right)\left(\frac{Bp}{Bs}\right)$$

Therefore, the final equation relating the pump gain to the signal gain can be represented as follows.

$$\ln(Gp) = \left(\ln(Gs) + Cs - \frac{BsCp}{Bp}\right)\left(\frac{Bp}{Bs}\right) \quad (6)$$

In equation (6), the signal gain ($G_{S)}$ is chosen to be 30dB, B_P & C_P are constant, and B_S & C_S vary with wavelength. The equation is plotted versus wavelength is shown. The pump gain is negative because the pumps energy gets transferred to the signal resulting in the amplification. This figure shows how the pump gain should vary over wavelength in order to achieve a flat signal gain.

Comparing it is clear that the location of the large peak (around 1530 nm) is where the pump gain should be slightly larger than for the rest of the wavelengths.

In a practical sense, it might be difficult to obtain a different pump for many different wavelengths so this approach to gain flattening is something to be further researched.

5. AMPLIFIED SPONTANEOUS EMISSION

The forward ASE is now considered for the EDFA model. The forward ASE power is given by

$$P_{ASE} = 2n_{SP}h\upsilon\Delta\upsilon(G-1) \quad (7)$$

$$\text{Where, nsp} = \frac{1}{1-\frac{\beta p\alpha s}{\alpha p\beta s\beta}} \quad (8)$$

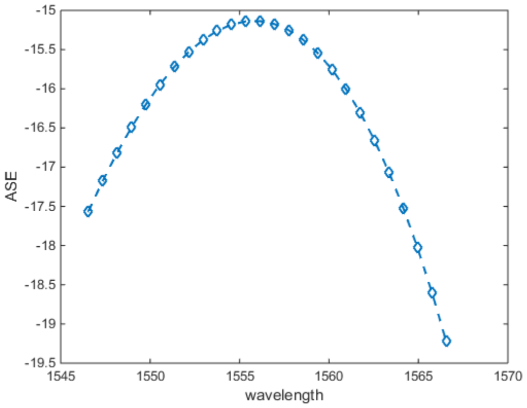
The ASE power is in Watts, G is the gain, Δυ and υ refer to the wavelength deviation of the ASE power around **λ**, h is Plank's constant, and nsp is the population-inversion factor which is dimensionless. In an EDFA, complete inversion can only be obtained when being pumped at 980 nm $\beta_P = 0$ and therefore nsp = 1.

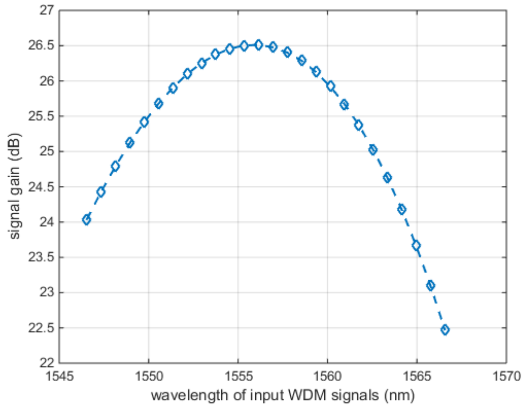
It is clear that the ASE power builds up as the length of the fiber increases. This is an expected result because as spontaneously emitted photons travel down the fiber they get amplified and they also stimulate the emission of more photons. It is observed that the ASE power is relatively small at length around 4m. In this case, the optimum length is chosen to be 4m compared to the 12m. However, at 4m the EDFA gain is reduced as shown. Essentially, this is one of the compromises that have to be considered when making a selection of amplifier length. The output spectrum of the ASE is shown for a signal wavelength of 1530 nm.

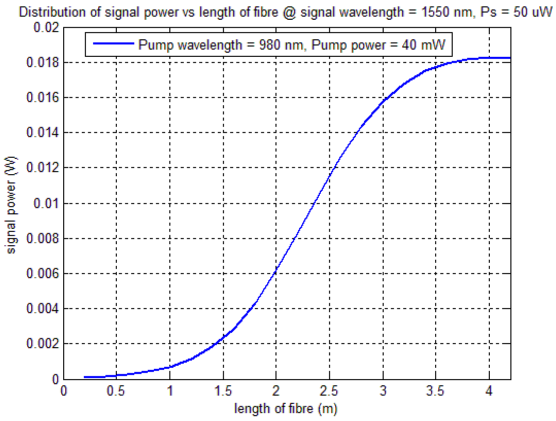
The ASE spectrum is very similar to that of the gain spectrum. This is expected because of the relationship of the relationship in equation (7). Also, the ASE is present over the whole operational range of the EDFA, thereby reducing the overall gain of the system. The obvious difference between the ASE spectrum and the gain spectrum is the output power. In the EDFA usable range of 1530 nm ≤ λ_S ≤ 1560 nm, the ASE spectrum varies from -5.95 dBm to -14.7 dBm. It is clear that ASE is a dominant noise generated in the amplifier.

6. RESULT

ASE power versus wavelength for λ_S of 1530 nm and λ_P of 980 nm for 4m amplifier length.
Gain versus wavelength for 12m amplifier length at λ_P = 980 nm, pump power is 18dBm and signal power is 30 dBm.







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