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# Investigation and performance evaluation of filter aided configurations for erbium doped fiber optical amplification system

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ABSTRACT

Various possible configurations of EDFA's namely Single Pass (SP) EDFA, Double Pass (DP) EDFA, Double Pass with Filter (DPF) EDFA, Triple Pass with Filter (TPF) EDFA and finally Quadruple Pass with Filter (QPF) EDFA are designed. DPF EDFA is an upgraded and enhanced version of DP EDFA configuration designed by using an optical filter in cascade. This filter has been designed with an optimal set of internal parameters namely center wavelength, bandwidth and depth. TPF and QPF EDFA configurations have also been designed. It is observed that in absence of upconversion, maximum Figure Of Merit (FOM) of about 40.35 dB is achieved in QPF EDFA configuration. With upconversion mechanism enabled the FOM of QPF EDFA reduces to only about 37.45 dB thus making QPF EDFA configuration suitable for practical applications. QPF and TPF EDFA had minimum gain ripple thus can be used in WDM applications, where flattened gain spectrum is an important requirement. The configurations offered here are less bulky with only one filter used instead of two as was the case in earlier configurations. QPF EDFA designed in this work has a reduced noise figure of about 4.85 dB at smaller lengths of EDFA of about 4.5 m and lower pump powers of about 90 mW. This configuration has highest sensitivity with the capacity to detect minimum signal power of −41.6 dBm. The QPF EDFA has an improved gain with reduction in noise figure, therefore QPF EDFA can be used as a preamplifier, to improve the sensitivity of receiver.



## 1. Introduction

The discovery of optical amplifiers has revolutionized optical fiber communication [1]. Different types of optical amplifiers are available such as: Semiconductor Optical Amplifiers (SOA), Raman and Rare Earth Doped Fiber Amplifiers (REDFA's) [2,3]. Semiconductor Optical Amplifiers (SOA) amplify optical signal in the range of 1310–1550 nm [1–3]. These amplifiers when used around 1310 nm and at −20 dBm input signal power, provide better results up to 243 km transmission distance with acceptable quality factor (15 dB) and bit error rate ($10^{-9}$) and without any dispersion compensation methods [3]. Even though SOA's can be used at zero dispersion wavelength still these amplifiers suffer from disadvantages like high noise figure, small gain, coupling loss and polarization dependence [1]. Raman amplifiers eliminate accumulation of noise in long distance transmission, but these amplifiers need expensive pump excitation systems for amplification [1]. REDFA's are fabricated by doping different rare earth ions such as Erbium ($Er^{3+}$), Ytterbium ($Yb^{3+}$), Praseodymium ($Pr^{3+}$), Neodymium ($Nd^{3+}$), Samarium

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($Sa^{3+}$), Thulium ($Tm^{3+}$) and Holmium ($Ho^{3+}$) in the core of optical fiber [2]. Erbium doped fiber amplifiers (EDFA) belonging to a class of REDFA's have drawn much attention due to their operating window and other potential applications. EDFA is an attractive medium for optical amplification and is an important component of long haul communications [4]. Its gain band coincides with third telecommunications window of silica fiber at wavelength of 1550 nm [5]. Stark splitting and thermal broadening effects generate a wide spectral bandwidth in EDFA [1,4,6]. Local environment of erbium ion has considerable effect on its gain spectrum and it is observed that different host glasses change the gain spectrum of doped erbium [1,6]. The rapid development of EDFA technology has been aimed to increase gain and reduce noise figure [5,7]. The EDF length, pump wavelength, intrinsic parameters, input signal power and pump power are important factors for optimizing the performance of EDFA [8]. In this context gain and noise figure are most important performance evaluation parameters to be considered [8,9].

Gain spectrum of EDFA is typically irregular, with a sharp peak around 1530 nm and a broad band of reduced gain at longer wavelengths [10]. Methods exploited to suitably shape the spectrum include controlling the doped fiber length and the pump power, employing Mach-Zhender interferometer, employing long period Fiber Bragg Grating (FBG), using an acousto-optic tunable filter or using notch filters [1,11–13]. To achieve improved performance in WDM networks, the broadband tunability and high power of erbium-doped fiber amplifier (EDFA) combined with less noise features of Raman amplifiers are used in hybrid amplifier configurations [14,15]. Careful choice of host glass like alumino-silicate glass also improves gain spectrum [6].

The basic manifestation of noise in EDFA is in the form of spontaneous emission. Spontaneous emission is present in a spectral interval corresponding to the gain spectrum of the amplifier, and the spectral density of the noise is proportional to the gain as shown in following equation [1].

$$P_{ASE} = n_{sp}(G-1)h\nu\Delta\nu \tag{1}$$

where G is the signal gain, hvis the photon energy and $\Delta\nu$ refers to range of frequency over which spontaneous emission occurs and $n_{sp}$ is the spontaneous emission factor that depends on the relative populations N1 and N2 of the ground and excited states respectively and quantifies population inversion as given in following equation [1].

$$n_{sp} = \frac{N2}{N2-N1} \tag{2}$$

Thus if gain is increased power spectral density of spontaneous emission will also increase, thereby increasing the noise.

SP EDFA operates on the basis of a three-level pumping scheme, as N1 tends to 0 and nspapproaches 1, hence the noise figure of SP EDFA is expected to be larger than the ideal value of 3 dB. Since N1 and N2 vary along fiber length because of their dependence on the pump and signal powers, noise figure also depends on amplifier length L.

Essential demand for preamplifier as well as inline amplifier operation of EDFA is to achieve simultaneous high gain and noise figure close to quantum limit [5,8,9]. In conventional configuration of SP EDFA, fiber isolator or a filter was placed in between a long length of fiber to enrich the population inversion [8]. This configuration resulted in high gain and low noise figure. Since longer lengths of fibers are used, it was not economical. To keep fiber length small and yet achieve appreciable amplification various other approaches have been investigated. These include Double Pass (DP) single stage [16–20], Triple Pass (TP) [21,22] and Quadruple Pass (QP) dual stage configurations [23–26]. In these configurations, more the number of passes, more is the gain achievement even over shorter EDF length. However a serious concern is the resulting increase in noise figure with the increase in passes [25–27]. Though noise figure can be controlled with the use of filter but as the number of passes increase the control on noise figure decreases.

In this work we have estimated the attenuation required to reject ASE and on the basis of that we have designed a filter with static parameters. The system configurations offered here use only one filter instead of two as was the case in earlier configurations [23,25,26]. This feature has been reflected in the QPF configuration designed in this work. This QPF configuration uses only three port circulators and one filter with appropriate characteristics. Its achievements include a reduced noise figure of about 4.8 dB at smaller lengths of EDFA of about 4.5 m. In [24] a new configuration namely QPF three stage EDFA was proposed for the first time. It reported noise figure of about 3.98 dB at 175 mW pump power. This configuration uses three pump lasers at 1550 nm. However this wavelength is prone to Excited State Absorption (ESA) [1], so it is not a good idea to use 1550 nm pump as far as pumping efficiency is concerned. Our work provides an improvement over this design by reporting Noise Figure of about 4.8 dB at lower pump power of 90 mW, with only two stages of EDFA instead of three. In presence of upconversion mechanism, this Noise Figure gets increased to only about 5 dB. Thus our system is reasonably immune to ESA and upconversion mechanism. In [10–15] it has been pointed out that flattening of EDFA gain is still a major problem. Our design of QPF EDFA has almost a flattened gain at input signal powers of around −35 dBm over a range of 28 nm. As compared to previous designs, smaller lengths of EDFA and lower pump power is used. In spite of the use of passive optical equipments with insertion loss, the given designs provide better FOM. Thus configurations designed are most cost effective for practical implementation.

This work aims at achieving appreciable value of Gain at low values of Noise Figure. Further comparison of performance sensitivity between all configurations has been investigated with respect to external operating conditions namely Pump Power ($P_p$, mW), Input Signal Power ($P_{sin}$, dBm) and Input Signal Wavelength ($\lambda_s$, nm). As compared to previous designs, smaller lengths of EDFA and lower pump power is used. Also less passive equipments are used such that overall insertion loss is reduced thus making design more practicable and less expensive. Performance of EDFA is measured by taking gain