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Flexible single pump hybrid fiber amplifier for the S+C bands

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ABSTRACT

This work proposes optical amplification in the S+C bands using a hybrid optical fiber amplifier (HFA) that uses a single wavelength pump. Its configuration is based on an erbium doped amplifier (EDFA) to provide gain over the C band and a distributed Raman fiber amplifier (RFA) to attain gain over the S band. Moreover, the proposed amplifier uses standard commercially available fibers. The HFA was numerically characterized and its optimal configuration was calculated using optimization procedures based on genetic algorithms. A flexible HFA configuration was achieved allowing a span length up to 100 km.
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1. Introduction

The rapid growth of the Internet and data traffic, and the continuous demand for high speed solutions lead to the need to increase the transmission capacity of the wavelength division multiplexing (WDM) systems. One solution is to expand the transmission window into the entire low loss region of the silica optical fibers. Optical amplifiers schemes, with broadband gain and low-noise at reasonable cost, are indispensable to broadening the WDM bandwidth.

Wideband fiber amplifiers covering C–L bands have been demonstrated using several techniques, such as erbium-doped fiber amplifiers (EDFAs) with a wider band gain [1], Raman fiber amplifiers (RFAs) [2] and, especially, hybrid fiber amplifiers (HFA) that combine EDFA and RFA in a hybrid configuration. HFAs proved to give better gain and noise performance, becoming a promising technology for wideband WDM systems [3,4].

Expanding the WDM bandwidth into the S band is another option that has attracted considerable attention. This band has the advantage to be less affected by the fiber bend losses [5]. Several S-band optical amplifiers techniques have been demonstrated, such as thulium-doped fiber amplifiers [6], S-band EDFAs which use erbium-doped silica fibers with depressed cladding design [7] or multi-stage EDFAs with C-band ASE filters in a complex setup [8]. RFAs for the S-band have also already been demonstrated [9,10], showing promising results. Furthermore, HFAs covering the S+C bands have been reported, using a special silica fiber with an erbium-doped cladding and a germanium doped core to achieve amplification over the S+C band. This fiber allows the S band amplification by stimulated Raman scattering (RFA) in the core, and the C band amplification by Er ions transitions (EDFA) in the cladding [11].

In this work, the feasibility of a single pump wideband HFA is evaluated. The hybrid configuration proposed uses a standard erbium-doped fiber (EDF) to provide an optical gain over the C band and the S band is amplified by Raman amplification through the transmission link with a standard single mode fiber. In contrast to [11], this HFAs configuration uses standard commercially available fibers which reduce the cost. In addition, both amplifier stages are pumped jointly with a single wavelength pump laser. Single pump HFAs have been reported for the C+L bands showing that the pump efficiency increases; however, these HFAs have complex pumping configurations [4]. Our approach uses a forward single pump laser to simultaneously pump both amplifiers stages, which allows a simple setup.

This study is focused in the steady-state regime, but in reconfigurable networks, the addition and dropping of channels can cause sudden power fluctuations in the overall input power. These fluctuations induce, in the output, power transients and power differences between steady-states. This can be minimized, as already demonstrated in [12], by actively tuning the pump power.

The hybrid amplifier performance was evaluated through numerical simulation considering different EDF lengths and pump powers. The proposed configuration was optimized through a

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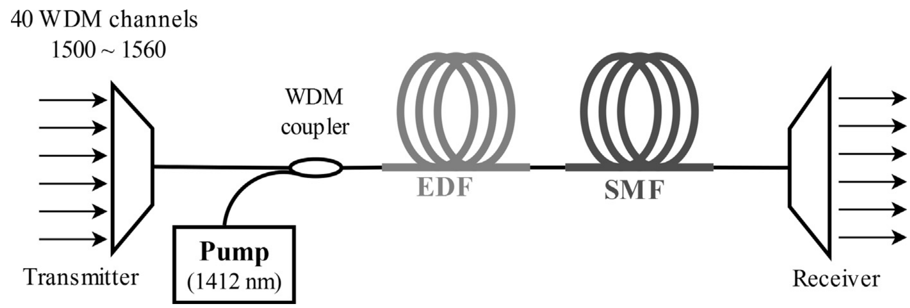

Fig. 1. Schematic diagram of the proposed hybrid amplifiers.

hybrid genetic algorithm in order to achieve maximum gain with minimum ripple (difference between maximum gain and minimum gain) and noise figure (NF).

2. Design and analysis

Fig. 1 shows the schematic configuration of the proposed hybrid amplifier, which consists of a single stage EDFA, followed by a distributed RFA. The pumping scheme consists of a single forward pump; thus the residual pump of the first amplifier stage is used to produce amplification in the second one.

The amplifier was designed with standard commercially available fibers as an amplification medium. For the EDFA stage was considered an erbium doped fiber (EDF) suitable for pumping at 1480 nm, MetroGain EDF M3 (1480/125) produced by Fibercore, that has the characteristics shown in Table 1. For the transmission fiber (distributed RFA stage) a standard singlemode fiber (SMF −28) was considered.

The performance of the hybrid amplifier was evaluated theoretically through numerical simulation. In order to describe numerically a hybrid optical amplifier, a model for each amplifier stage, EDFA and RFA, was developed. The EDFA theoretical model used is based on the propagation and rate equations proposed by Giles and Desurvire in [13], where the EDFA is treated as a low level system and no distinction is made between pumps and signals wavelengths. This model describes the power evolution of the pumps, signals and amplified spontaneous emission (ASE) along the doped fiber. The theoretical model used to obtain the power evolution in the Raman amplifier is based on the system of differential equations proposed in [2]. This model considers the pump-to-pump, pump-to-signal, and signal-to-signal interactions, the attenuation, the ASE and its temperature dependence. Both mathematical models were solved numerically through an expansion method, namely a collocation algorithm. The numerical models for both amplifiers stages were combined in order to obtain a model for the hybrid amplifier. Thus, the output spectrum of the first amplifier stage is the input to the second one. In both models, all the signals are modeled as a spectral line with no spectral width.

To characterize the proposed HFA the overall gain (ratio of the output to the input signal powers) and overall noise figure (NF) were determined. If two amplifiers are cascaded together, the overall NF is expressed by [2]:

$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} \quad (1)$$

where NF_1 and G_1 are the noise figure and gain for the EDFA stage, respectively and NF_2 is the noise figure for the RFA stage.

The transmission was analyzed for 40 channels spaced by 200 GHz over the S and C bands in the range of 1500–1560 nm, with an initial power of −15 dBm for each channel. For the pump we considered a generic high power source.

Table 1
EDF M-3 (1480/125) – parameters.

Absorption@1480 nm	3.45 dB/m
Absorption peak (1530 nm)	9.5 dB/m
Attenuation@1240 nm	5.8 dB/m
Cut-off wavelength (nm)	1300 nm
Mode field diameter	5.2 μm
Numerical aperture	0.24
Erbium ion density	6.24×10^{24} m^{-3}

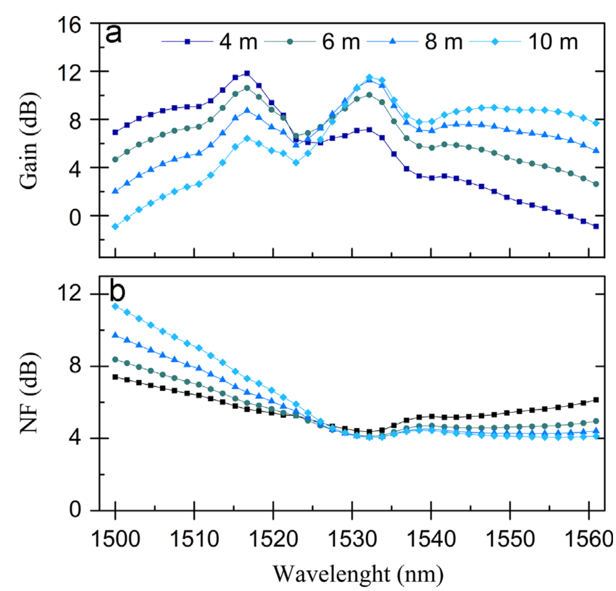

Fig. 2. Gain (a) and NF (b) wavelength dependency after 80 km transmission for different EDF lengths and a pump wavelength of 1412 nm and fixed power of 800 mW.

To describe EDF-M3 we used the parameters presented in Table 1 and for the SMF-28 fiber an effective area of 80 μm^2, an attenuation of 0.2 dB/km and a polarization factor of 2 were considered. The fiber Raman gain coefficient used are experimental values reported in [14].

The gain and noise figure (NF) were calculated for different EDF lengths, assuming a span length of 80 km of SMF-28 and a pump wavelength of 1412 nm, the results being displayed in Fig. 2. The amplification of the C band is dominated by the EDFA; thus the gain in this band tends to increase with the EDF length as shown in Fig. 2(a). On the other hand, the S band gain decreases with the EDF length, as the available pump power for the RFA stage decreases. It is clear that the optimum EDF length for a flat HFA gain should be around 6 m. In addition, the available gain after

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