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Wideband Flat–Gain Hybrid Fiber Amplifier Utilizing Combined Serial–Parallel Configuration

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ABSTRACT

In this paper a combined serial–parallel hybrid fiber amplifier (SP–HFA) in the C+L–band is investigated and simulated via OptiSystem 7. The gain spectra of the C+L–band are flattened by optimizing the coupling ratio of the input signal power. The gain bandwidth of 62.5 nm from 1530 nm –to– 1592.5 nm within the gain variation of about 2.68 dB is achieved with small input signal power of –20 dBm. In addition, the proposed design produced several advantages over conventional P-HFA, such as; increased flat gain bandwidth by 2.5 nm, constant splitting ratio of 0.7 for small and large signal regions, high saturation gain (wide dynamic range) in the L–band window.

Keywords: Combined Serial–Parallel Hybrid Fiber Amplifier, Erbium Doped Fiber Amplifier, Raman Fiber Amplifier.

1. INTRODUCTION

The HFA is proposed to solve several problems in the dense wavelength division multiplexing (DWDM) communication systems as well as to improve the overall system performance by; 1) increasing the span length, 2) decreasing the fiber nonlinearities impairments, 3) maximizing the bandwidth of EDFA, 4) increasing gain level and, 5) improving the pump conversion efficiency. In general, the HFA can be divided into two categories, namely, serial hybrid fiber amplifiers (S–HFA) and parallel hybrid fiber amplifiers (P–HFA) [1]–[3]. In the serial configuration, there are two stages of amplification for the input signal in a single path; this means that the output signal from the first stage is considered as the input signal for the second one [4], [5]. This type of HFA has high gain level and acceptable noise figure but, shorter 3–dB gain bandwidth as compared with P–HFA[1]. Therefore, the P–HFA is a more preferable architecture for DWDM communication systems especially within inline applications. Different designs are proposed in order to optimize and enhance the performance of the P–HFA. S.K. Liaw et al. proposed wide flat gain P–HFA about 70 nm from 1530 nm to 1600 nm, by splitting the pump power going into gain media. The optimum ratio of pump power going to erbium and Raman was found to be 1:29. The gain variation is 3–dB within small signal region of –20 dBm. However, as the signal power increases, the gain flatness degraded to about 35 nm and 30 nm within large signal region of –10 dBm and 0 dBm, respectively [6].

In our previouse work [1] we provided wide bandwidth P–HFA utilizing gain control technique. The input signal power is controlled via a variable coupler and divided into branches, one for EFDA and the other for RFA. The gain flatness is kept about 60 nm for small and large signal regions, but need to change the splitting power ratio from 0.4 to 0.8 for the small signal region of –30 dBm and large signal region of –5 dBm, respectively. In addition, for single wavelength

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investigation, there is no problem in dispersion issue. However, for a comb coming from a DWDM system, there is a problem with dispersion compensation in EDFA branch.

In this paper, we proposed a new HFA based on the combination between serial and parallel architecture by adding a DCF in series with the EDFA branch to compensate the dispersion and improve the overall system performance. In addition, the proposed design produced several advantages over our previous work as follows: 1) increased flat gain bandwidth by 2.5 nm, 2) constant splitting ratio of 0.7 for small and large signal regions, 3) high saturation gain (wide dynamic range) in the L–band window.

2. SIMULATION MODEL

The simulation model of the proposed combined CSP–HFA is illustrated in Figure 1. A variable optical coupler is used to control the input signal power between the two branches (RFA/EDFA and RFA). The input signal is provided by a tunable laser source (TLS) with maximum power 10 dBm, wavelength ranging from 1530 nm to 1595 nm and linewidth of 150 kHz. The RFA is a 7 km of dispersion compensating fiber (DCF1), pumped in a counter pump direction by a Raman pump unit (RPU) with output power of 800 mW at 1480 nm. The EDFA is a 3 m erbium doped fiber (EDF) pumped by the residual Raman pump power about 100 mW, controlled by a variable optical attenuator (VOA). The Er^{+3} ion concentration is 440 ppm, core radius is 1.65 μm, Er doping radius is 1.65 μm, and cut–off wavelength is 1300 nm. The dispersion compensation is represented by 7–km DCF2 pumped in a counter pump direction by an RPU with output power of 300 mW at the wavelength 1495 nm. The DCF has total loss of 4.4 dB, effective area of 20 μm^2, a nonlinear coefficient of 14.5×10^{-10} W^{-1} and dispersion parameter of –110 ps/nm/km. A wavelength selective coupler (WSC) is used to separate the residual Raman pump from the reflected Rayleigh scattering signal. An optical fiber coupler (OFC) is used to collect the output signal from the two branches. Finally, optical spectrum analyzer (OSA) is used, to record the total system gain.

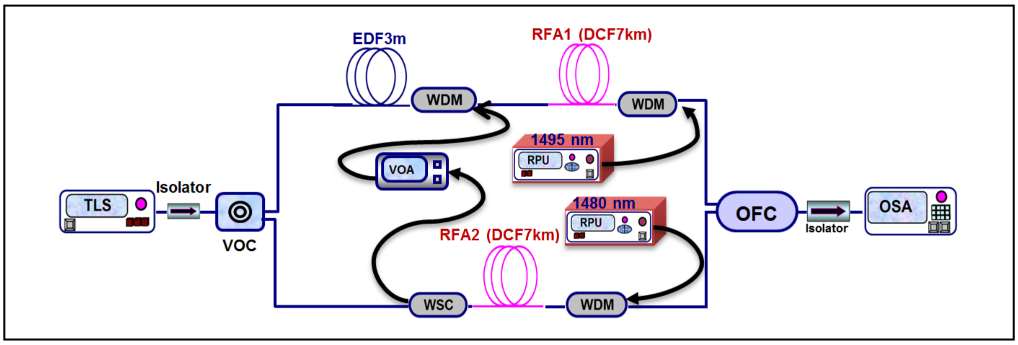


Figure 1. Schematic diagram of CSP–HFA utilizing gain controlled technique.

3. RESULTS AND DISCUSSION

The innovative steps in adding RFA1 to EDFA branch are compensating the chromatic dispersion [7], [8], boosting the gain bandwidth in the L–band region and enhance the overall amplifier performance. In order to evaluate the performance of the proposed SP–HFA, as well as to determine the optimum splitting ratio (R), the gain level is investigated versus different input signal wavelength; as depicted in Figure 2. The ratio R represents the percentage of the input signal power that goes into EDFA. In this work, R is varied from 0.2 to 0.8; the pump power is fixed at 100 mW, 300 mW and 800 mW for EDFA, RFA1 and RFA2, respectively.

In addition, the input signal wavelength is varied from 1530 nm to 1595 nm step 5 nm. The overall gain spectra can be divided into three regions; C–band region extended from 1530 nm –to– 1565 nm, where EDFA is more effective, L–band region extended from 1575 nm –to– 1595 nm, in which the RFA is more efficient and neutral region or balance point where the input signal is amplified by equal gains from both EDFA and RFA for all coupling ratios. In a small input signal region of –20 dBm, the average gain is increased in the C–band region from 9.95 dB –to– 13.92 dB, and is decreased from 14.24 dB –to– 11.86 dB as the *R* is changed from 0.2 –to– 0.8. The proposed amplifier shows better performance at *R* = 0.7 within the average gain of 13.38 dB, 3–dB bandwidth of 62.5 nm and gain variation of 2.68 dB as illustrated in Figure 2 (a). In the large signal region of -5 dBm, the proposed HFA shows similar behavior increasing in the C-band region and decreasing in L-band region as depicted in Figure 2 (b). As well as the best performance is found at *R* = 0.7. This represents a constant splitting ratio of 0.7 for small and large signal regions, therefore, the proposed HFA considered as more practical as compared with our previous work [1], which need to change the splitting ratio from for small and large signal, respectively.

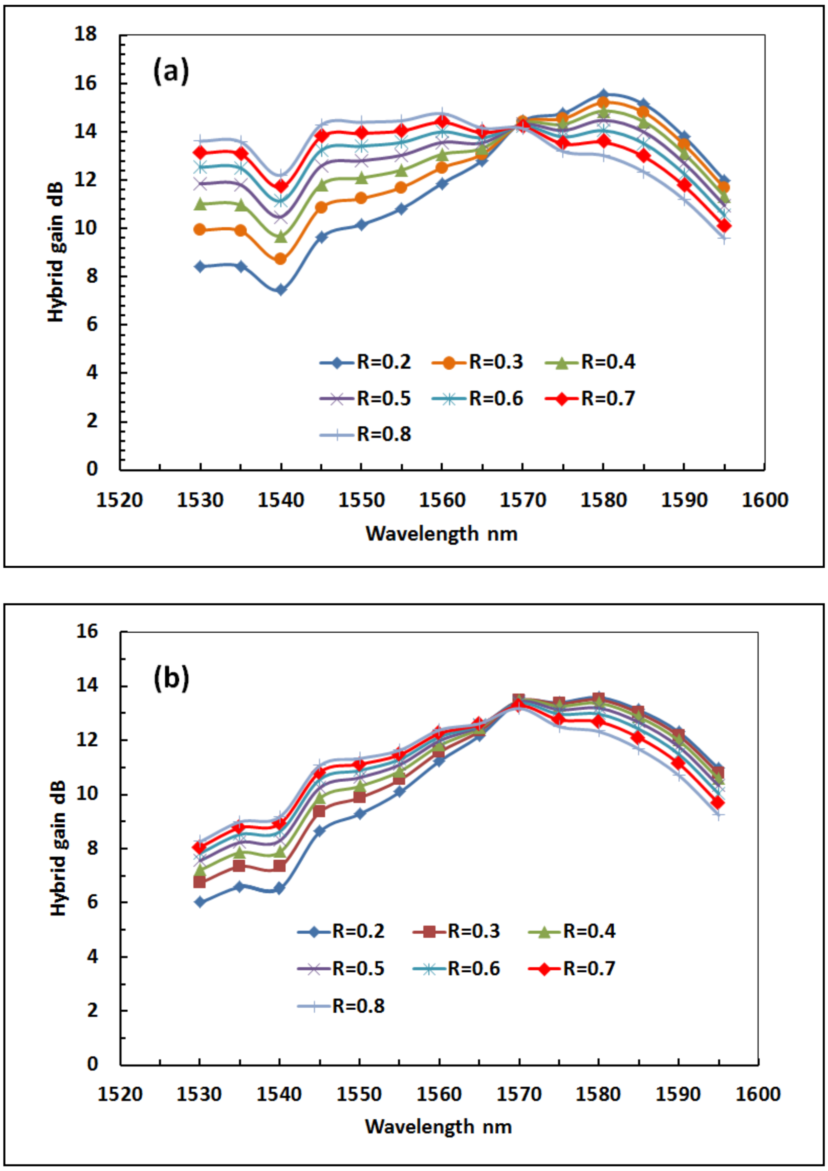


Figure 2. Gain profile at different coupling ratios for: (a) Pin of –20 dBm and (b) Pin of –5 dBm.

In order to investigate the performance of the proposed amplifier under two different input signal regions, namely, small and large regions, the gain profile and NF at $R = 0.7$ is investigated as depicted in Figure 3. According to the results, the 3-dB bandwidth is decreased from 62.5 nm to 47.5 nm as the input signal power is increased from -20 dBm to -5 dBm. As well as the average gain level is decreased from 13.38 dB to 12.01 dB.

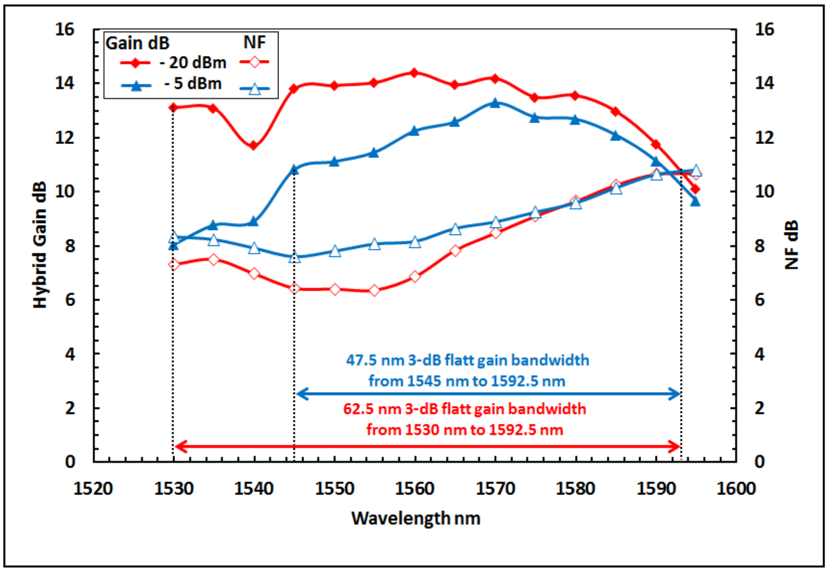
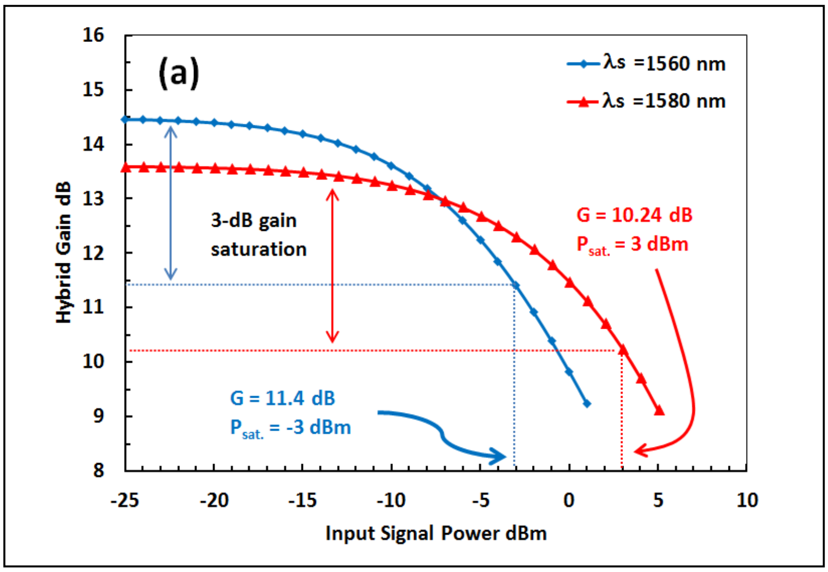


Figure 3. Gain level and NF versus input signal wavelength at the optimum ratio of $\mathbf{R} = \mathbf{0.7}$ for Pin of −25 dBm and −5 dBm.

Furthermore, to complete the gain characteristics of the proposed HFA, the gain saturation at a different input signal wavelength is investigated, at the peak and the tails of the gain profile. The peak gain is observed at two wavelengths, namely, 1560 nm and 1580 nm for C- and L-band, respectively. The gain tails are considered at input signal wavelengths of 1530 nm and 1595 nm. In this work, the input signal wavelength is tuned at the peak and the tail's location, the ratio R = 0.7 and the saturation power ($P_{sat.}$) is determined gain level is dropped to 3-dB from its maximum value. According to the results, the Psat. was determined at Pin of –3 dBm, 3dBm, - 10 dBm, 6 dBm for a wavelength of 1560 nm, 1580 nm, 1530 nm and 1595 nm, respectively as depicted in Figure 4 (a) and (b).



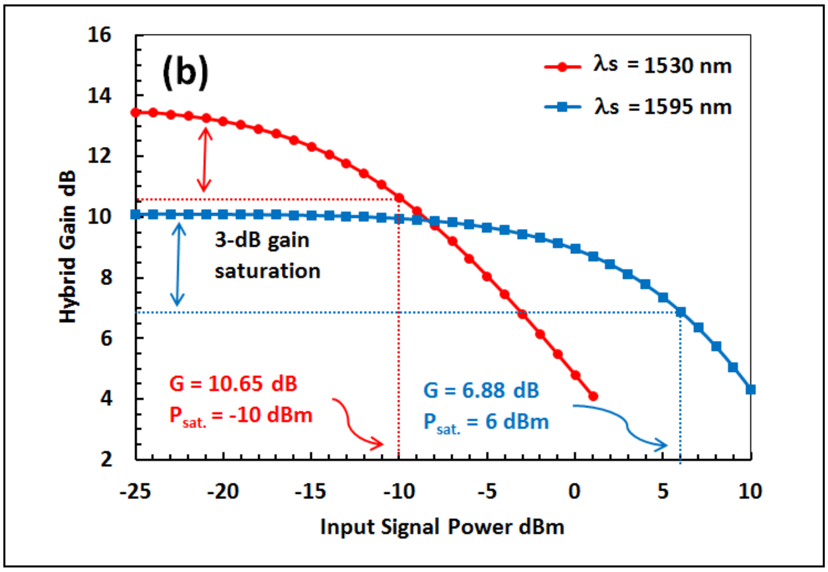


Figure 4. Gain versus Pin for several different wavelengths (a) 1560 nm and 1580 nm, (b) 1530 nm and 1595nm.

4. COMPARISON

In order to evaluate the performance of the proposed design, a comparison was made between the obtained results and those which were achieved in [1], as depicted in Table 1. From the results, the gain bandwidth is about 60 nm from 1530 nm –to– 1590 nm and 62.5 nm from 1530 nm –to– 1592.5 nm for work of reference [1] and our work, respectively, this represents enhancement in the gain bandwidth of 4 %. In addition, the wider 3–dB flat gain bandwidth is obtained at a constant splitting ration of 0.7, which consider more practical as compared with variable ratio as in previous work. Finally, for a comb coming from a DWDM system, there is a problem with dispersion compensation in EDFA branch in [1]. While, the proposed design can be compensate the chromatic dispersion for 80 km in both branches.

Table 1 Summaries of our and previous simulation works of P–HFA

Work	Operating Band nm	Pumping Technique	RFA Length km	EDFA Length m	HFA Structure	GBW nm	Splitting Ratio R
Work of Ref. [1]	C+L 1530–1595	Single pump 1480 nm	7	3	P–HFA	60	Small region (0.4) Large region (0.8)
Our work	C+L 1530–1595	Dual Pump 1495 nm/1480 nm	7+7	3	CSP–HFA	62.5	0.7 for both regions

5. CONCLUSION

We investigated a new HFA that can substantially compensate the chromatic dispersion as well as enhance the gain bandwidth and the overall performance of the P-HFA by adding the extra RFA to EDFA branch. Wide gain bandwidth of 62.5 nm from 1530 nm –to– 1592.5 nm is obtained within an average gain of 13.38 dB and average NF of 7.98 dB. The gain variation is about 2.68 dB at small input signal.

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