Series and Parallel Configurations for Broadband Double Pass EDFA with an Embedded DCF

João B. Rosolem, Antonio A. Juriollo, Roberto Arradi and Murilo A. Romero

***Resumo* – Neste artigo descrevemos e comparamos dois novos circuitos para EDFAs de dupla passagem (paralelo e série), incorporando as bandas C e L e que permitem a inserção de uma fibra DCF, eliminando, porém, os sérios efeitos de degradação de sinal causados pelo retroespalhamento do sinal. O objetivo é estender os benefícios da configuração de dupla passagem para amplificação de banda larga, com aplicações em redes DWDM e CWDM. Os DP-EDFAs foram caracterizados em termos de ganho e figura de ruído de 1541 até 1555 nm (banda C) e 1577 até 1590 (banda L) em um sistema DWDM de 16 canais.**

***Palavras Chave* – CWDM, Add-drop, redes metropolitanas.**

***Abstract* – In this paper we describe and compare two novels double pass EDFA circuits (parallel and series), incorporating C and L bands, which allows for DCF insertion in the double pass amplifier circuit without imposing the serious performance degradation related to the backscattered signal. The goal is to extend the benefits of the double pass configuration for broadband amplification, with applications to DWDM and CDWM networks. To this aim, gain and noise figures were measured from 1541 to 1555 nm (C band) and 1577 to 1590 nm (L band) in a 16-channel DWDM system.**

***Keywords* – optical fiber amplifiers, optical fiber communication, optical circulators, L and C band.**

1. INTRODUCTION

CWDM and metropolitan DWDM networks are demanding low cost optical subsystem such as lasers, optical amplifiers, multiplexers and add-drops and several technologies for optical amplification have been investigated [1]. EDFAs have been demonstrated to be the more efficient solution for long distance as well as for core metropolitan networks. However, as far as edge and access metropolitan networks a cost reduction is still necessary. One option is to use double pass configuration EDFAs (DP-EDFA). DP-EDFAs have the advantage to require fewer components than a two stage bidirectionally pumped configurations, which makes them more cost-effective than conventional amplifiers. Furthermore, double pass amplifiers have attracted a great deal of attention in recent years because they require shorter erbium doped fiber length in L band applications, providing efficient optical amplification [2-3]. Considering that dispersion compensation is very critical for high-speed CWDM and DWDM systems operating in with STD-SMF (standard single mode fiber) another timely topic of investigation concerns the embedding of the high insertion loss DCFs (dispersion compensating fibers) into optical amplifier configurations. In order to suppress the problems related to the Brillouin scattering (SBS), arising due to the DCF small effective area, as well as the Rayleigh backscattering, we resorted to a previously proposed double pass amplifier circuit [4] which uses circulators to minimize the amplitude of the backscattered signals.

In this paper we describe and compare two novel DP-EDFA circuits (parallel and series), incorporating C and L bands, which allows for DCF insertion in the double pass amplifier circuit without imposing the serious performance degradation related to the backscattered signal. The goal is to extend the benefits of the double pass configuration described in [4] to broadband amplification, with applications to DWDM and CDWM networks. To this aim, gain and noise figures were measured from 1541 to 1555 nm (C band) and 1577 to 1590 nm (L band) in a 16-channel DWDM system.

2. SERIES AND PARALLEL DOUBLE PASS AMPLIFIER

The double pass, double band amplifiers, parallel and series circuits with an embedded DCF, are depicted in Figure 1(a) and 1(b) respectively. The overall idea is to implement a low-cost configuration, by using low power pump lasers and short lengths of erbium doped fiber. A circulator (# 1) was used at the amplifier input to couple light in and out of the doped fiber. Two band multiplexers were used to separate the signal from C and L band in order to provide distinct amplification paths. The erbium-doped fiber is pumped by a co-propagating pump scheme. In the series configuration, the first stage of amplification is common to the two bands. The residual 1480 nm pump power at the L band multiplexer port goes to the amplification second stage together the L band signal that was pre-amplified in the first stage. None second amplification stage is used for C band. A second circulator (# 2) was placed at the opposite end of the erbium doped fiber to connect the DCF module in such a way that the signal passes only once through the DCF and return to the amplification circuit, by port # 1 of circulator. As a consequence, the backscattered light is removed from the amplification circuit. The circulators used can also contribute to diminish the multi-path interference noise

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inside the amplifier. We used two 980 nm pump lasers in the parallel configuration and one 1480 pump laser in the series configuration. The co-propagating pumping scheme was chosen due to the improved performance regarding the noise figure. Noise figure improvement was also the reason for the use of an ASE filter before the L band amplifier circuit since the C band spectrum of backward ASE generated in L band section is very high and could degrade the noise figure in C the band [2]. In Figure 1(c) we show, the simulation results (using the software OASIX v.3.1) without optical filter, for the backward ASE power at parallel input amplifier circuit for the pump power of 100 mW at the erbium doped fiber input. A signal input power per channel of -20 dBm was used. It is observed that the ASE power from L band circuit is very significant in the C band region, in opposition of the ASE power from C band circuit in L band region. This is the reason why an ASE filter was placed at the L band amplification path.

Thus, the parallel configuration has the advantage of band independent amplification but uses two pump lasers. The series configuration has the advantage of using only one pump laser but the first amplification stage is common to the two bands.

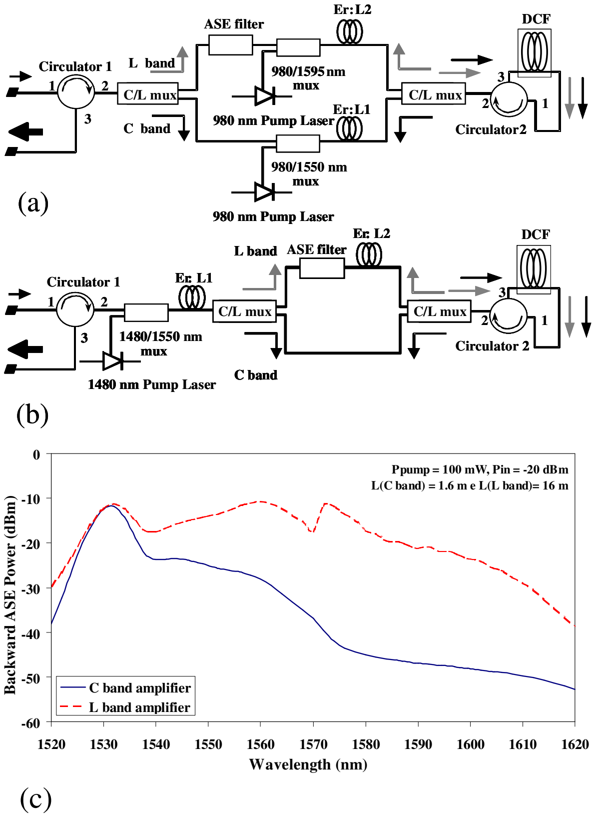

Fig.1- Double pass EDFAs using DCF (a) parallel configuration, (b) series configuration and (c) Backward ASE at input of parallel amplifier circuit.

In order to compute the required length of erbium doped fiber we simulated the circuits of Figure 1 by using the software OASIX v.3.1. In this simulation we used a high concentration erbium doped fiber with 16 to 24 dB/m peak absorption around the wavelength of 1530 nm. We considered a gain of 20 dB +/- 2 dB for the C band and 20 dB +/- 5 dB for the L band, the DCF attenuation as equal to 6 dB, the extra loss (band mux and circulator # 2) inside the double pass circuit as 2.0 dB and the input/output insertion loss (circulator, pump mux and band mux) as 2.0 dB. The simulation results are showed in Figures 2(a) to 2(d). The erbium doped fiber length for the 8-channel DWDM (1539 to 1556.5 nm) in the C band amplifier resulted in 1.6 m for parallel configuration and 3 m for series configuration. The erbium doped fiber length for the 8-channel DWDM (1587 to 1564.5 nm) in the L band amplifier resulted in 16 m for parallel configuration and 7 m for series configuration. The pump power into the erbium doped fiber was 100 mW and the input power per channel was - 20 dBm. In the series amplifier, the gain and the noise figure have dependence with both erbium doped fiber lengths. In the simulation, when the length L1 was changed, the length L2 was fixed for some values and when the length L2 was changed, the length L1 was fixed for some values. The Figures 2(c) and 2(d) show the better combination of L1 and L2 for the both bands. It was not possible to optimize the fiber length simultaneously for gain, gain flatness and noise figure.

3. EXPERIMENTAL RESULTS AND DISCUSSION

We tested the amplifiers depicted in Figure 1 making use of the same wavelengths employed in the simulations. In the measurements the amplifiers were characterized for input power levels of - 20, - 25 and - 30 dBm by using 120 mW of pump power in each pump laser in such way to assure 100 mW at the erbium doped fiber input. The band multiplexer isolation is 36.5 dB in the L band and 16.3 dB in the C band. The band multiplexers insertion losses are 0.4 dB in the C band and 0.2 dB in the L band. The ASE filter isolation is 43.5 dB in the C band and its insertion loss in the L band is 1.0 dB. In Figures 3(a) to 3(b) we show the experimental results for gain and noise figure for the parallel configuration and in Figures 4(a) and 4(b) the experimental results for gain and noise figure concerning the series configuration. The circulators add an insertion loss of 0.6 dB each and the DCF module has 6 dB insertion loss. It is observed in Figure 3(a) (parallel amplifier circuit) that for an input power level Pin of - 20 dBm, we obtained a flattened gain around 19.5 dB (+/- 1.0) and values of noise figure around 5.5 dB. The gain increase for input powers lower than - 20 dBm as expected.

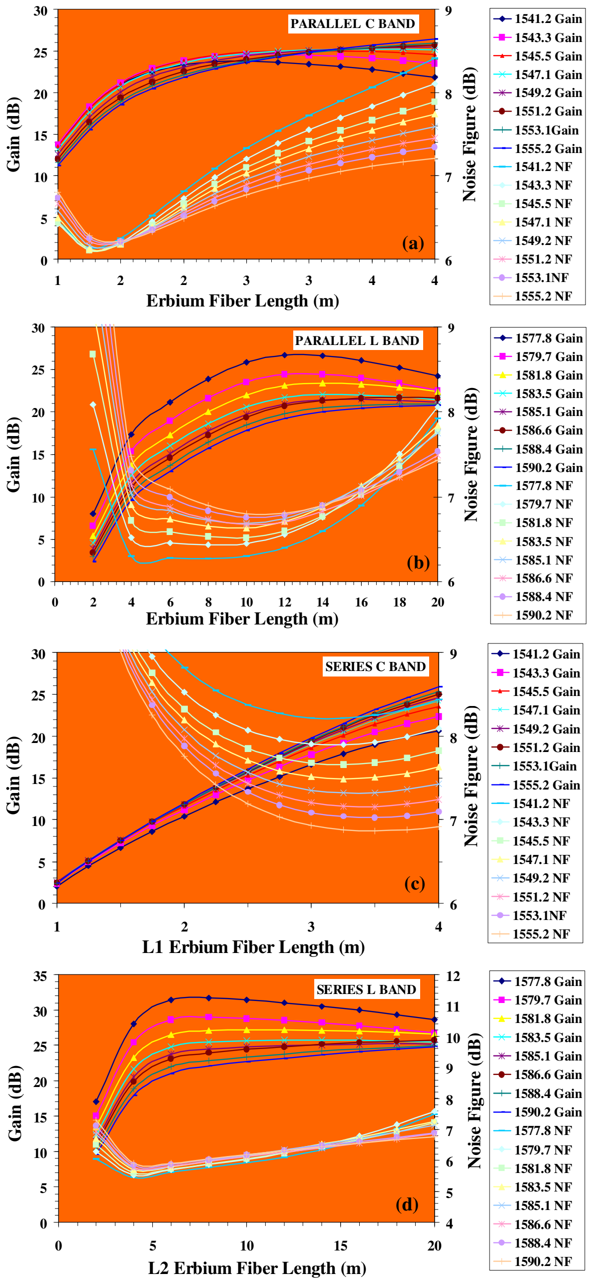

Fig 2 - Simulated results for gain and noise figure versus erbium doped fiber length for (a) parallel C band, (b) parallel L band, (c) series C band for L_2 = 7 m and (d) series L band for L_1 = 2.5 m.

The flattened gain is maintained for all values of input power. On the other hand, Figure 3(b) indicates that the gain is not as flat at the L band, as we obtained 20 dB +/- 2.5 dB for an input power of -20 dBm. This gain performance can only be corrected if a GFF (Gain Flattened Filter) is inserted into the amplification circuit. Furthermore, the measured noise figures are between 6.9 and 7.7 dB. These values are in accordance with the simulation and can be reduced by using shorter erbium fiber length as well as an ASE filter with low insertion loss.

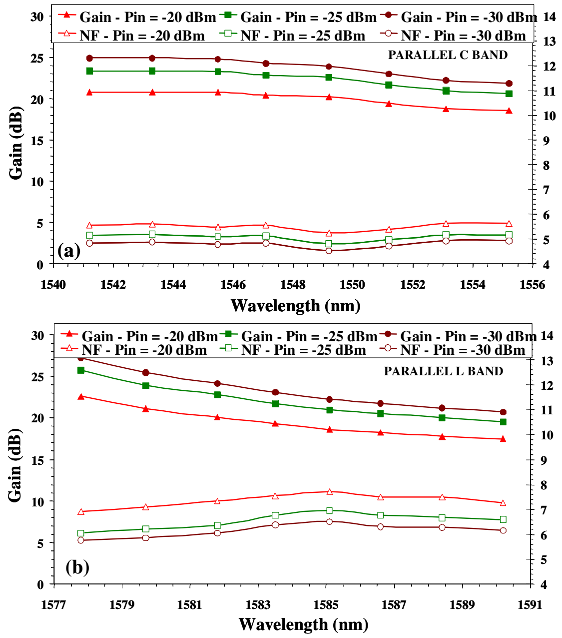

Fig. 3 - DP-EDFA parallel circuit DWDM characterization (a) C band and (b) L band.

On the other hand it is observed in Figure 4(a) (series amplifier circuit) that for an input power level P_{in} of - 20 dBm, we obtained a flattened gain around 18 dB (+/- 1.0) and values of noise figure are between 8 and 9 dB. The gain increases for input power levels lower than - 20 dBm, as expected. The flattened gain is maintained for all values of input power. On the other hand, Figure 4(b) indicates that the gain is not as flat at the L band, as we obtained 15 dB +/- 5 dB for an input power of -20 dBm. The measured noise figures are between 7.5 and 9.0 dB. Comparing these results, it is possible to conclude that the parallel configuration achieved better performance than series configuration. The worse gain and noise figure of the series configuration can be attributed to noise reamplification and simultaneous gain competition in the first stage

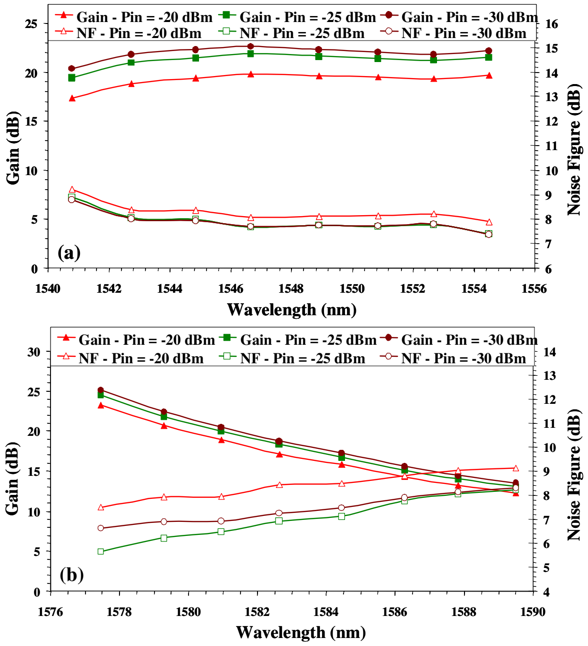

Fig. 4 - DP-EDFA series circuit DWDM characterization (a) C band and (b) L band.

4. CONCLUSION

In this paper we described a novel optical circuit for C and L band operation, which allows for DCF insertion in the double pass amplifier circuit. Gain and noise figures were measured from 1539 to 1556 nm (C band) and 1577 to 1590 nm (L band) in a 16-channel DWDM system. We obtained satisfactory values of gain and noise figure in the C band. For the L band, it seems necessary to use a GFF in order to achieve flat gain. Special attention is to be paid to reduce the noise figure in the L band by using low insertion loss multiplexers and filters. For series configuration the amplifier optical performance was worse than parallel configuration mainly due to the simultaneous use of first stage of the amplifier. We believe that parallel configuration may be a candidate for a cost-effective solution for simultaneous loss and dispersion compensation in DWDM and CDWM networks.

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