High gain low noise L-band preamplifier with cascade double-pass structure

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An optimized two-stage-cascade double-pass structure L-band preamplifier was proposed and experimentally studied to overcome the shortcomings of low gain coefficient and high noise figure of L-band erbium-doped fiber amplifier (EDFA). The fiber lengthes of 6.5 and 32.5 m, pump powers of 130 and 119 mW for the first and second stages respectively are used in the experiment. When input signal power is −30 dBm, the amplifier can provide gain above 38.84 dB in a wavelength range of 34 nm (1568—1602 nm), gain ripple less than 2.04 dB (40.88—38.84 dB), and noise figures lower than 5.29 dB with the lowest value of 3.95 dB at 1590 nm. Experimental and simulation results show that this low cost and high pump efficiency amplifier is suitable for the application as an L-band preamplifier in the broadband fiber communication system.

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With the rapid growth of Internet business and the interchange of multimedia data, there is an ever-existing demand to expand the capacity of fiber optical transmission system. The most efficient and economical step to upgrade the capacity of current wavelength division multiplexing (WDM) system is to explore the simultaneous transmission potential of C- and L-band signal in the silica fiber. Broadband fiber amplifiers have attracted much attention as one of the key devices in such broadband-transmission system. Recently rare-earth-doped especially erbium-doped fiber amplifiers (EDFAs) are widely investigated for it can work in the minimum-loss window of the silica fiber covering C- and L-band. Compared with commercial C-band EDFAs, L-band EDFAs are more difficult to built since the L-band signals can only be amplified in the gain shift state[1,2], which makes the gain coefficients of L-band signals much lower than that of C-band signals. In order to obtain enough signal gain, the length of erbium-doped fiber (EDF) needed for L-band amplification is much longer than that for C-band amplification. However, long fibers used in L-band EDFA increase the amplifier's cost and degrade the noise property[3]. Recently, efforts have been taken to reduce the fiber length, which involve the use of EDF with a high erbium-doping concentration[4] and the use of backward C-band amplified spontaneous emission (ASE) as a secondary pump source to pump an EDF section[5,6]. However, a high concentration of erbium ions may reduce the pump power conversion efficiency and degrade the noise figure for an EDFA. Another effort to reduce the fiber length and improve gain performance of an EDFA is the use of a double-pass technique[7−9]. Compared with conventional EDFA configurations, double-pass amplifiers configuration can improve the wavelength gain equalization because they work in saturated regime. Moreover, double-pass amplifiers use fewer components than a bi-directionally pumped configuration, which makes them more effective.

In this letter, an L-band preamplifier of flat high gain and low noise figure is proposed, which has the advantages of high pump efficiency and low cost. The long EDF used in L-band EDFA will favor the growth of ASE, and high power of ASE will be observed at the signal input end. We found that the backward propagating ASE became large and saturated near the input end of the EDFA and degraded the noise figure directly. A cascade structure was reported for L-band amplifier to get better noise characteristics and high gain simultaneously[10]. In cascade amplifiers, long EDF enables high gains for signals, and the properly situated isolator between two stages ensures the low noise figure by preventing the backward propagating ASE from the second stage into the first stage. Here we also adopt the cascade structure with the modification of the second stage using double-pass structure.

The schematic diagram of our experiment is shown in Fig. 1. Two 980-nm laser diodes (LDs) were used as pump sources for the two amplification stages. Since C-band ASE plays an important role in the amplification of L-band, a counter-pump structure was used in both stages[6]. After the amplification of the first stage, input signals passed through the isolator (IS2) and entered into the second stage via the port 1 and 2 of the circulator (CIR). When these signals reached the end of the second stage, they were reflected by the broad band reflector (BBR) and re-entered the second stage where they underwent a second amplification. These signals will enter the optical spectrum analyzer (OSA) via the port 3 of the

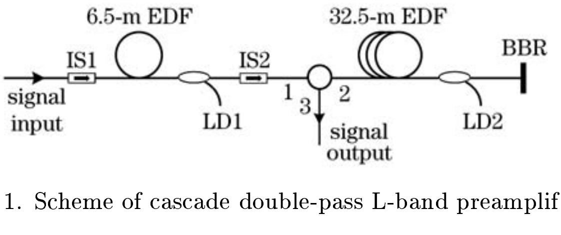

Fig. 1. Scheme of cascade double-pass L-band preamplifier.

circulator for analysis. The BBR used in this experiment was a fiber-based device that introduces very small insertion loss (< 0.05 dB) and provides a reflectivity of above 99% for C- and L-band signals. The EDF (FIBERCORE, DFL1500) used in the setup was manufactured with the basic parameters as follows: lifetime of $^4I_{13/2}$ level $\tau = 10.2$ ms, erbium radius $r_e = 1.513\ \mu$m, theoretical erbium ion concentration $n_t = 1.25\times10^{25}\ \mathrm{m}^{-3}$, peak absorption at 980 nm $\alpha_{980} = 2.362$ dB/m, peak absorption at 1480 nm $\alpha_{1480} = 1.729$ dB/m. The fiber lengths and pump powers used in our experiment were chosen according to our optimization design. When the pump powers of 120 mW were used in both stages, the optimized fiber length ratio of the first stage EDF to total fiber was about 0.17, so the fiber lengths of 6.5 m in the first stage and 32.5 m in the second stage were used in the system. Besides the isolation of port 2 to port 1 in circulator, another isolator (IS2) between two stages was used to ensure the thorough elimination of backward ASE. Input signals were provided by a tunable distributed feedback (DFB) laser with the power fixed at -30 dBm.

The output property of this amplifier measured with scan method is shown in Fig. 2, with the pump powers of 130 and 119 mW for the first and second stages, respectively. From Fig. 2, we can observe that in the range of 1570—1590 nm the signal gains were all above 40 dB with the gain variation less than 0.61 dB (40.88—40.27 dB), and in the range of 1568—1602 nm the signal gains were all above 38.84 dB with the gain ripple less than 2.04 dB (40.8—38.84 dB). The noise figures of the whole L-band signals are all lower than 5.29 dB with the lowest noise figure of 3.95 dB at 1590 nm. These results proved that this amplifier had well met the high gain and low noise requirements of L-band preamplifier, in addition to its natural gain flattening property.

According to our simulation results, this double-pass structure can reduce the L-band fiber length of the second stage to 45% compared with single-pass structure and can enhance the pump efficiency at the same time, which can largely reduce the amplifier cost. During the experiment we found that the reflectivity of the BBR was a crucial factor that can influence the output properties of this preamplifier. In order to take a deep look into this factor, a broadband variable optical attenuator (VOA) was inserted before the BBR to simulate different reflection conditions.

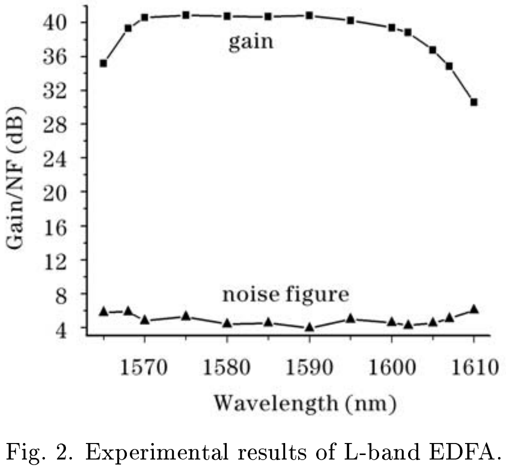

Fig. 2. Experimental results of L-band EDFA.

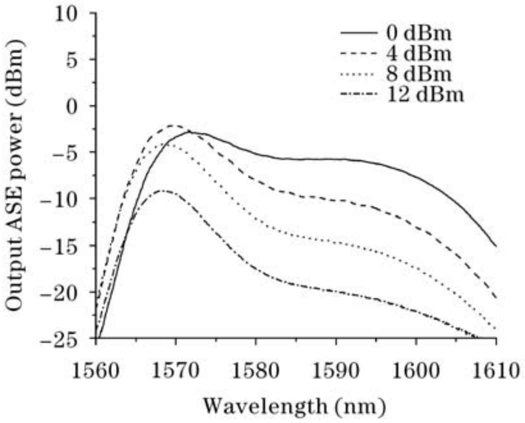

Fig. 3. Output ASE spectra for different reflection.

Figure 3 shows the output ASE spectra under different attenuation levels. It can be seen from Fig. 3 that the ASE power at the longer wavelength of the L-band reduces dramatically and the spectrum is no longer flat. From these results we can deduce two important results. Firstly, the amplification of L-band signals especially at the longer wavelength range, strongly depends on the ASE power of C-band. In other words, C-band ASE should be fully considered in designing the L-band amplifier as we did in this experiment. Secondly, the reflectivity of BBR is a key parameter for achieving high pump efficiency and flat high gain output for L-band amplifier. We think that the higher the reflectivity of BBR, the better the output property of the L-band amplifier.

In summary, a flat high gain low noise L-band amplifier was demonstrated by using a cascade double-pass structure. For -30-dBm input signals from 1568 to 1602 nm, gains above 38.84 dB were obtained with the gain varying from 40.8 to 38.84 dB. The L-band signal noise figures were below 5.29 dB with the smallest value of 3.95 dB at 1590 nm. These results demonstrate that this amplifier is competitive for the application in broadband fiber transmission systems.

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