Ultra-low noise C-band erbium-doped fiber preamplifier

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Focused on the low noise figure requirements of erbium-doped preamplifiers, a two stage cascade preamplifier was presented based on the optimized design. With the total fiber length of 31.4 m and total pump power of 135 mW, this preamplifier can produce above 30-dB gain and keep the noise figure below 4.76 dB for all C-band signals, with the minimum noise figure as low as 3.38 dB for −30-dBm, 1550-nm signal.

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The invention of fiber amplifier was regarded as a milestone of fiber communications. It ultimately solved the "bottle neck" and signal incompatibility problems that electronic amplifiers encountered. The ideal fiber amplifier was supposed to have properties such as high gain, low noise figure (NF), broad band, and insensitivity to polarization. Most researches are engaged in rare-earth-doped fiber amplifiers especially the erbium-doped fiber amplifiers (EDFAs) because it can work in the minimum-loss window of the silica fiber[1−4]. EDFA used in communications can divided into three types, namely preamplifier (PA), booster power amplifier (BA), and in-line amplifier (LA). They were used in different situations to meet different requires. For example preamplifiers were usually placed directly in front of the optical receivers to improve the receivers' sensitivity, which requires preamplifiers must possess high gain ($>$ 30 dB) and low NF ($<$ 5 dB) in the same time. Since the typical input signal power of preamplifiers is in the small signal range (−40 to −30 dBm), obtaining a low NF is the key point in building up a eligible preamplifier. In this letter we successfully set up a C-band preamplifier using the cascade structure.

It was found that the backward propagated amplified spontaneous emission (ASE), which becomes large and causes saturation near the input end of the EDFA, degrades the noise figure directly. So it was preferred to use cascade structure to get better noise characteristics while obtaining high gain in the same time[5,6].

A two stage amplifier was proposed with 5-m EDF in the first stage and 26.4-m EDF in the second stage as shown in Fig. 1. The fiber lengths selected for each stage were optimized to achieve the lowest noise figure for C-band signals and both stages were pumped with 980-nm LDs. The erbium ion density of the fiber used in this experiment is 0.56×10^{25} ions per cubic meter, the isolator insertion loss is about 0.55 dB with isolation bigger than 45 dB. The wavelength division multiplexing (WDM) coupler is responsible for the insertion losses of 0.44 and 0.6 dB for signal and pump lights, respectively. Signals were produced by a tunable distributed feedback (DFB) laser and the output was measured by an optical spectrum analyzer (OSA). It is worth emphasizing here that when the fiber length is rather short, co-pumping and counter-pumping can realize almost the same upper-level inversion ratio along the fiber whilst counter-pumping can reduce insertion loss for input signals with the WDM coupler putting behind the EDF and decrease the ASE power near the signal input end which contributes to get a higher inversion level and a better NF. Therefore the first stage used counter-pumping structure in our experiments. Figure 2 shows the output of this cascade amplifier for −30-dBm, 1550-nm input signal, with the pump powers of 45 mW in the first stage and 90 mW in the second stage. The NF was as low as 3.38 dB and the gain was 37.21 dB. Figure 3 shows the results of gain and noise figure of this cascade amplifier for the all C-band signals with −30-dBm input power by scan method under the same pump condition. It was shown that for all C-band signals above 30-dB gains were obtained while keeping the noise figure below 4.76 dB. The minimum

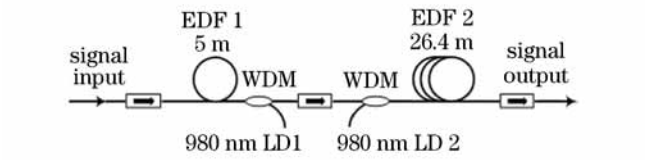

Fig. 1. Structure of cascade C-band pre-amplifier.

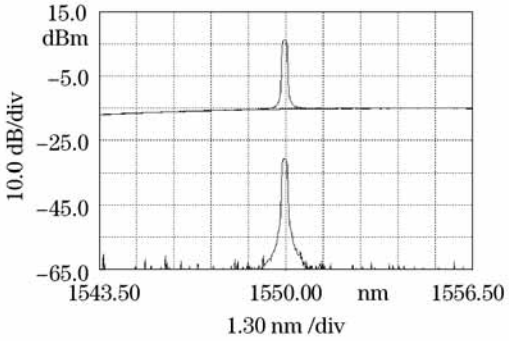

Fig. 2. The low noise output of the preamplifier for −30-dBm, 1550-nm input signal.

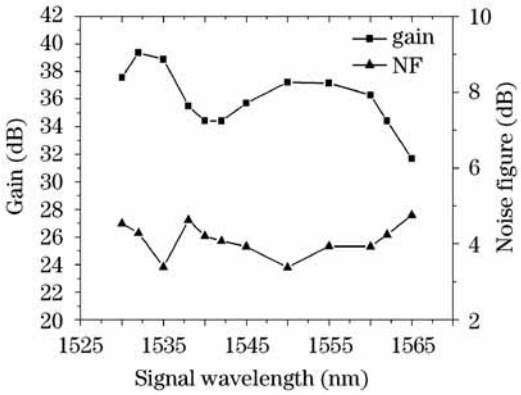

Fig. 3. Gain and noise figure properties of the preamplifier for C-band signals.

noise figure was as low as 3.38 dB for 1550-nm signal. These experiment results proved that our optimized low noise C-band cascade preamplifier was successful.

In summary we present a low noise cascaded C-band erbium-doped preamplifier using counter-pumping structure for the first stage in addition to optimized fiber length for both stages. With the pump powers of 45 mW in the first stage and 90 mW in the second stage, gains above 30 dB and noise figures below 4.76 dB were achieved for all C-band signals with the minimum of 3.38 dB for 1550 nm. This amplifier fully met the practical requirements for preamplifiers with rather good NF property with only 31.4-m EDF and 135-mW pump power in total.

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