Novel Burst-mode EDFA Using Backward Laser Injection for 40-Gb/s TWDM-PON

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Abstract—**In this paper, we propose a burst-mode EDFA for 40-Gb/s TWDM-PON supporting 100-km reach with 50-dB loss budget. Backward laser injection using a low-cost Fabry-Perot laser suppresses the burst surge whilst achieving low noise figure.**

Keywords—Burst-mode EDFA, TWDM-PON

I. INTRODUCTION

Time and wavelength division multiplexed-passive optical network (TWDM-PON) architectures have been selected as the primary solution for the next generation passive optical network stage-2 (NG-PON2) [1-2]. To reduce capital and operation costs, central office consolidation is essential. However, this leads to a higher loss budget in supporting more users and results in a longer reach. Work has been undertaken in improving sensitivity of the downstream receiver [3]. In this scenario, an erbium doped fiber amplifier (EDFA) is required in the optical line terminal (OLT) to manage the upstream loss budget. Since the upstream data stream operates in a time-division-multiplexing (TDM) manner, burst-mode EDFA (BM-EDFA) are required to suppress the burst surge worsened by the fast transient effect that occurs in EDFA. The BM-EDFA should have high gain and low noise figure (NF) for high receiver sensitivity. Furthermore, the BM-EDFA should be very low cost and be suitable for mass production. Current EDFAs topologies have very poor performance in ultra-fast transient conditions, especially in burst-mode operation. To solve this, several methods have been proposed [4-5].

One popular design employs a controlled auxiliary laser source injected at the EDFA input keeping the total input power at a fixed value therefore stabilizing the erbium ion inversion [6-7]. However, the forward laser injection schemes have three drawbacks: 1) the coupling loss at the input port of EDFA will directly degrade the NF; 2) a band filter is required at the output port of EDFA to separate the laser and auxiliary signal wavelength; 3) generally a high cost DFB laser with TEC control is required as the auxiliary laser source to avoid temperature-dependent wavelength drift. Here, for the first time, we propose a backward laser injection method to suppress the burst surge. Since the laser is counter-transmitted with the signal, no band filter is required to separate them, and a low cost Fabry-Perot (FP) laser can be used as the auxiliary laser source. Furthermore, since there is no coupling loss at the input port, NF will not be degraded. A BM-EDFA with 45dB gain and 3.6-dB NF has been developed, enabling -40-dBm receiver sensitivity (considering 3.8e-3 FEC limit) after 100-km reach, and providing a cost-effective and practical solution for a high loss budget TWDM-PON system.

II. CONTROL SCHEME

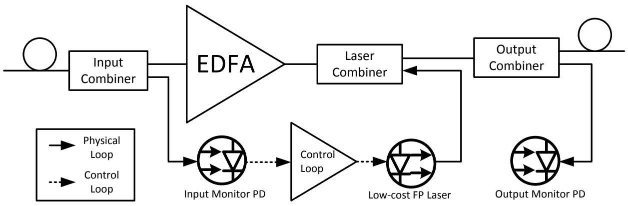


Fig. 1: Backward Laser Injection Scheme

The control scheme of our proposed backward laser injection BM-EDFA is shown in Fig.1. An input monitor is used to detect the bursty input signal power variation. A loop-back control for the auxiliary laser drive bias is modified according to the input power variation. The auxiliary FP-LD is coupled into the EDFA by a laser combiner. In practice this is achieved with an optical circulator which has inherent low loss. Since an optical isolator is required at the output of the EDFA to prevent the backward reflection, the optical circulator can replace the optical isolator in the BM-EDFA. An output monitor is used to detect the output power and in conjunction with the input power reading is used to control the gain of the EDFA.

In the forward laser injection case the auxiliary laser power is used to compensate the input signal power variation by reducing the auxiliary laser power as the input signal power increases. Conversely, when the burst surge input power increase occurs in the backward lasing design the auxiliary laser power is also increased to quickly deplete the available Er inversion, thus reducing the burst surge.

Note that since the auxiliary laser is backward injected, the wavelength of the laser is not so critical and could be anywhere within the signal-band. This is different from the forward injection case where the wavelength has to be stable to match with the waveband filter at the amplifier output. Broad spectrum and wavelength drift of the FP-LD due to the temperature variation has no effect on the feedback control as it can be compensated by fast control of the laser.

III. EXPERIMENTAL RESULTS

Both EDFA module-level performance and systematic performance in NG-PON2 are characterized in this paper. Steady-state performance, including gain and NF, are first tested according to a real-application condition from TWDM-PON. Four channels with wavelength from 1535 nm to 1539.8 nm with 200-GHz channel spacing are used as the upstream channels. The input power is set at -45 dBm, -40 dBm and -20 dBm, and the corresponding gain is set at 45 dB, 40 dB and 20 dB. Therefore the output signal power of the EDFA is always 0dBm, corresponding to the best receiver sensitivity of the PIN-PD after a wavelength demux. From Fig. 2 (a) we can see, with higher signal gain the NF is lower. And the impact of laser on/off on the NF is negligible. With 45-dB signal gain, the NF is as low as 3.6 dB; close to the quantum noise limit of the EDFA. Fig. 2 (b) and (c) show the upstream signal output spectrum from the EDFA and the output spectrum of the backward injected FP-LD, from where we can see the signal and auxiliary laser are operating in the same waveband achieved due to backward injection of the auxiliary laser.

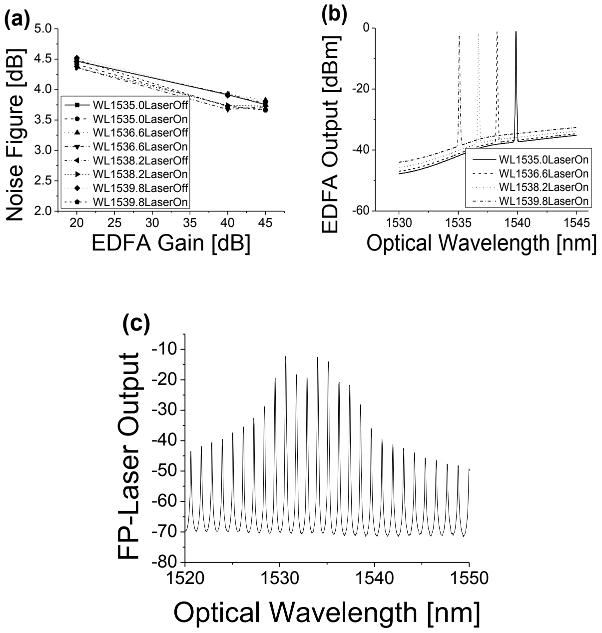
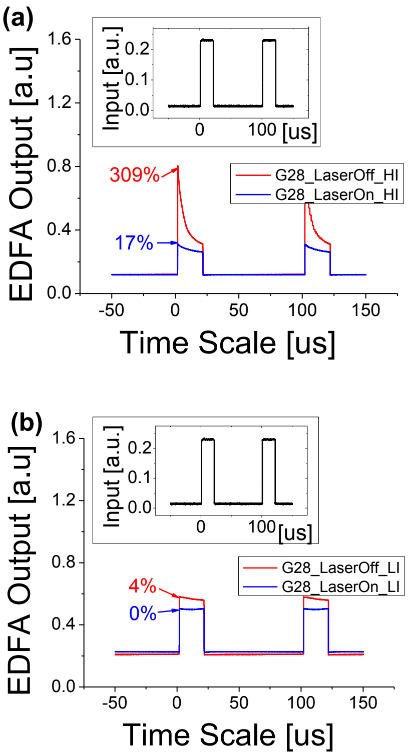


Fig. 2: (a) Noise figure vs. signal gain, (b) EDFA output spectrum at 20-dB gain. (c) Output spectrum of the backward injected FP-LD.

Next we investigated the burst mode operation of the EDFA with different input signal power levels as shown in the insert of Fig. 3. The burst length is set to 20 us and period to 100 us. For all conditions we see significant improvement in transient surge suppression. At the high input power conditions the surge suppression performance is not ideal since the maximum output power of the auxiliary laser is not sufficient to fully deplete the inversion and so suppress the burst surge. However at low input power cases, for both high gain and low gain conditions, the surge suppression is always good. For practical applications in TWDM-PON, the upstream power at the OLT is quite low therefore Fig. 3 (b) and (d) are much more common operating conditions. Therefore by good control of the backward auxiliary laser power matching the input signal power variation, we can achieve a low-cost BM-EDFA with low NF.

In the following analysis, we measured the receiver sensitivity of the BM-EDFA in both a back-to-back (BtB) case and after 100-km fiber transmission. A directly-modulated laser (DML) operating at 1543 nm and 10-Gb/s bit rate is used as the optical network unit (ONU) as an upstream laser source [8]. For compensating the chirp-induced distortion of the DML and the chromatic dispersion of the fiber, a fixed optical dispersion compensator with -2100 ps/nm is used at the OLT as a post-compensation component [9]. The target of the dispersion compensation value is to achieve the best receiver sensitivity at the longest transmission distance, which is similar to the duo-binary signal case. For 10-dBm output power from the DML, the sensitivity is as high as -40 dBm at 100-km reach enabled by the low NF BM-EDFA, corresponding to a loss budget of 50 dB. We also measured the sensitivity by turning off the backward injected laser. We found the sensitivity is slightly worse for the laser on case even though the NF is lower. The origin of the sensitivity degradation is from the reflection of the amplified backward laser which is in the signal band and induces in-band crosstalk. However, the degradation is under 1 dB and so is small. This can also be suppressed to a negligible level by reducing the reflection of the optical components at the input port.



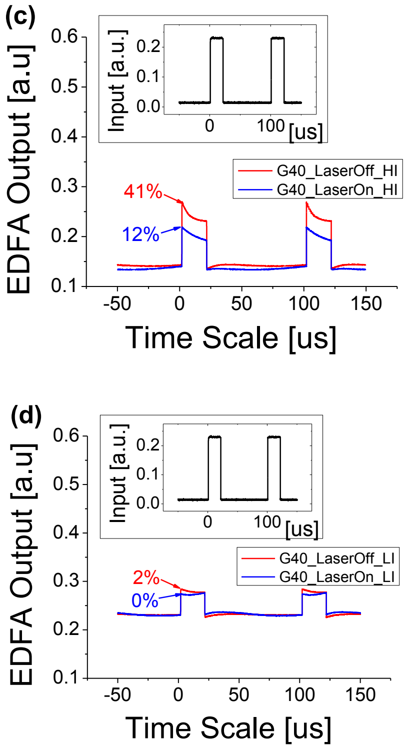


Fig. 3: EDFA performance at burst-mode operation: (a) 28-dB gain and -12-dBm input power, (b) 28-dB gain and -28-dBm input power, (c) 40-dB gain and -28-dBm input power, (d) 40-dB gain and -38-dBm input power.

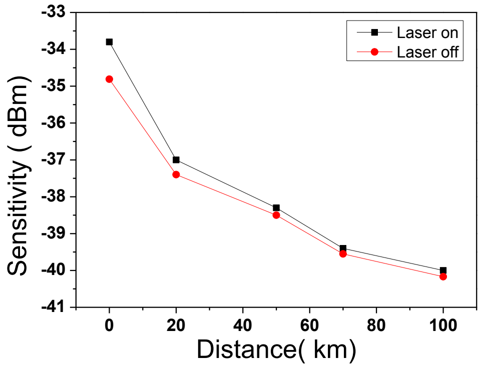


Fig. 4 The sensitivity evaluation by using the BM-EDFA.

IV. CONCLUSIONS

We have designed a burst-mode EDFA with backward injection of an auxiliary laser source into the EDF. The laser power is used to deplete the inversion level and so suppress the burst surge. The burst surge is strongly suppressed for both high gain and low gain cases. Since there is no coupling loss at the input the NF is shown to be as low as 3.6 dB at 45-dB signal gain. Furthermore, the backward laser injection scheme does not need tight laser wavelength control therefore a low cost FP-LD can be used to reduce the cost of the BM-EDFA. By using the low NF BM-EDFA in the OLT, the upstream receiver sensitivity can be improved to -40 dBm, supporting 100-km purely passive reach with 50-dB loss budget.

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