A Broadband ONU Design Using A Semiconductor Optical Amplifier-Based Optical Loop Mirror

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Abstract: We demonstrate a novel approach in the implementation of a broadband Optical Network Unit using a Semiconductor Optical Amplifier-based Optical Loop Mirror, both experimentally and via simulations for up to 50 km and 2.5 Gb/s.

OCIS codes: (060.4258) Networks, network topology; (060.2330) Fiber optics communications

1. Introduction

The rapidly increasing bandwidth demand per costumer sets the need for Passive Optical Networks (PONs) imperative. The advantages of PONs such as low cost, transparency and reliability make them one of the most promising solutions for future networks [1]. In order for PONs to become commercially viable, there is a need for decreasing their cost and complexity as much as possible. This, in turn, is translated to a requirement for a simple and low-cost implementation of the Optical Network Unit (ONU), which is the most critical part of PONs [2]. A lot of research groups currently work towards this direction and many approaches have been proposed to provide a low-cost solution, the most dominant being the use of a Reflective Semiconductor Optical Amplifier (RSOA) [3,4]. RSOAs are colorless, due to their large optical bandwidth. However, they present a trade-off between high gain and their needed short length.

In this paper, we propose a novel and simple implementation of a broadband ONU that uses a 50:50 coupler and a Semiconductor Optical Amplifier (SOA) symmetrically placed in a loop to form an optical mirror. The proposed design resembles a reflective optical loop, which offers wide bandwidth (due to the SOA's broad gain spectrum) and high-speed operation. The benefits of using SOAs instead of RSOAs are the following: 1) SOAs are currently commercially available while offering the same functionality as RSOAs; and 2) SOAs are longer than RSOAs, i.e., they exhibit higher gain and electro-optical bandwidth, which leads to higher remodulation data rates at the ONUs. We have evaluated the performance of the proposed scheme theoretically by simulation, for fiber links up to 50 km using 2.5 Gb/s NRZ data, as well as experimentally, for fiber links up to 25 km using 150 Mb/s NRZ data.

2. Experimental configuration

The experimental set-up depicting the network's topology and the proposed ONU's implementation is shown in Fig. 1. The light source is a continuous wave (CW) laser beam that is sent from the transmitter (Tx) of the Central Office (CO) through a circulator to the ONU, passing through several km of standard single mode fiber (SMF). An arrayed waveguide gratings demultiplexer (AWG DMUX) routes the wavelength into the desired ONU. The ONU consists of a 50:50 coupler and a SOA, Corning S.A. [5], which is symmetrically placed in the loop mirror.

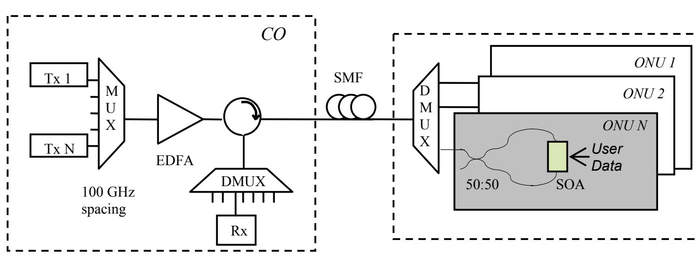

Fig. 1. Experimental set-up for measuring the performance of the proposed ONU's scheme. The downstream CW enters the desired ONU after transmission and splits at the 50:50 coupler's output ports. The two beams cross the SOA travelling in opposite directions while being modulated inside it with the user's data. Finally, they counter propagate in the loop mirror and interfere again in the coupler to travel upstream through the SMF fiber back to the CO.

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After reaching the desired ONU, the CW enters the coupler and it splits equally at the two coupler's output ports. The created beams propagate in opposite directions inside the loop and they enter the SOA through its two facets, crossing the SOA while they are being modulated with the user's data. The two modulated signals leave the SOA in opposite directions, they counter-propagate in the loop and interfere constructively at one of the coupler's outputs. The generated signal travels upstream through the SMF fiber back to the CO, where it is routed and detected in the receiver (Rx) with the use of the circulator.

The SOA used is a MQW device of 1.5 mm length. Its optical gain spectrum is centered at 1510 nm, with a peak gain of 22 dB, a 3-dB bandwidth of 90 nm and a low (<1 dB) polarization dependent gain (PDG). The SOA is being electrically modulated with the end-user's data. During operation, the wavelength of the end-user's data was tuned from 1530 to 1565, while the SOA's input power was kept constant at -10 dBm.

The dominant reason for the degradation of the signal and the deterioration of system's transmission performance that limits the maximum reachable distance between the costumer and the CO in access networks, is due to Rayleigh backscattering and the nonlinearities of the SMF fiber [6,7]. The proposed scheme maintains the advantages of wide bandwidth and high-speed operation, as well as low-cost implementation using off-the-shelf components. In addition, the scheme is stable in operation and requires no integration, primarily due to the balanced loop configuration.

3. Results and Discussion

In order to evaluate the performance of the upstream transmission, we have performed simulation studies (using VPITransmissionMaker) and evaluated the bit error rate (BER) as a function of the received power for different transmission spans from 0 to 50 km. Fig. 2 shows the degradation in the BER performance in the back-to-back case, as well as for 10, 20 and 50 km transmission distance. From Fig. 2, it can be seen that the power penalty decreases with the increase of the transmission span and the responsible degradation effects saturate for distances longer than 50 km. This is also clear from Fig. 3, where the power penalty versus transmission span length for three different BER values is illustrated. The power penalty for error free operation is about 2.5 dB for 10 km distance, 4.4 dB for 20 km and 6.4 dB for 50 km upstream transmission distance.

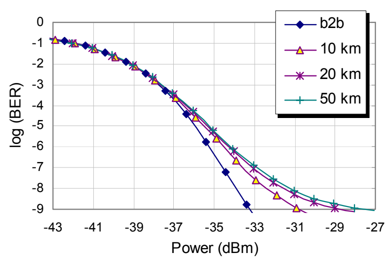

Fig. 2. Simulated upstream transmission performance.

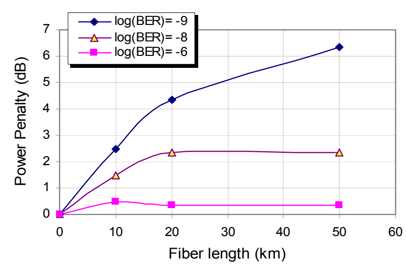

Fig. 3. Simulated power penalty vs. fiber length for different BERs.

We have also experimentally evaluated the proposed design with a 2^7-1 Pseudo-Random Binary Sequence (PRBS) at 150 Mb/s NRZ user's data. The low bit rate selected was due to the limited printed circuit board (PCB) design that the SOA was mounted on. Clearly, a SOA with an optimized electrical interface could be modulated at higher speeds as with RSOAs [3]. Fig. 4 illustrates the eye diagram at (i) the output of the SOA (with an open loop), (ii) the output of the ONU (coupler's output port) and (iii) the receiver Rx in CO after 25 km of transmission distance.

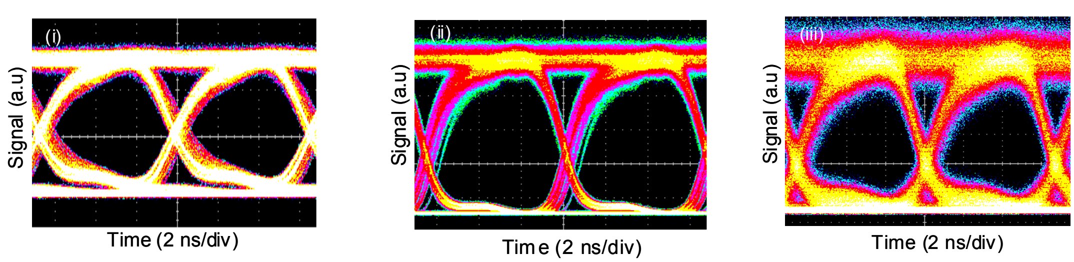

Fig. 4. Experimental eye diagrams at (i) the output of the SOA, (ii) the output of the ONU (coupler output port) and (iii) at the CO Rx after 25 km transmission. The wavelength that was used is λ= 1550.00 nm and the SOA's input power was kept constant at -10 dBm.

The system's performance, shown through the eye degradation in Fig. 4, is mainly impaired by the SOA's and EDFAs' noise accumulation as well as the Rayleigh backscattering effect, which is the most important signal's disturbance when transmitting over a single fibre on both directions using the same wavelength [8,9]. The BER performance was decreasing with the increase of fiber length and, more precisely, the power penalty for error-free operation was measured to be about 2.8 dB for 25 km transmission distance.

In order to assess the wavelength tuning range of the proposed scheme (which is important for ensuring ONU's colorless functionality), eye opening was measured for different wavelengths, as shown in Fig. 5. It is clear that the proposed ONU design possesses an operating spectrum range of 35 nm, while it could be further increased with the use of an S-band EDFA at the CO, since the SOA's gain spectrum was measured to be 90 nm. Performance across the tuning range was almost constant with the tendency to slightly improve at the blue side of the spectrum.

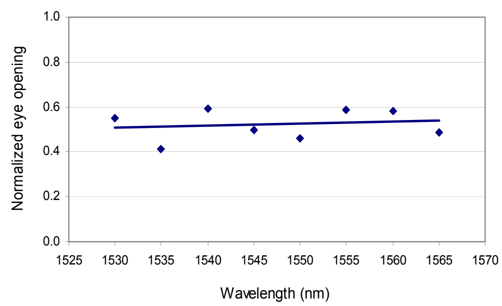

Fig. 5. Broadband operation of the proposed ONU's scheme measured experimentally back-to-back.

4. Conclusions

In this paper, we have presented and evaluated the performance of a new design of a broadband ONU to be used in PONs, utilizing a SOA-based optical loop mirror to encode upstream data. The transmission performance was demonstrated with respect to BER, power penalty and eye diagram. It was shown that the proposed scheme could achieve error free operation up to 50 km taking into account the SOA's characteristics and especially its electro-optical bandwidth. The proposed ONU design encompasses broadband, colorless functionality that is necessary for implementing cost effective and simple ONU's for future passive optical networks.

Acknowledgement

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