C+L Band Remote Node for Amplification in Extended Reach Full-Duplex 10Gb/s WDM/TDM Passive Optical Networks

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Abstract *A remote node design for C+L band amplification is shown to cover the advanced optical power budget for a 50km reach, symmetrical 10G/10G WDM/TDM-PON. 5-10dB of margin is left despite OSNR degradation.*

Introduction

Access networks have gained importance in research due to services with high bandwidth demand. Passive Optical Networks (PON) are beneficial for operators as no active components have to be maintained at the fibre plant. The number of customers is extended by WDM and TDM techniques[1], including also L-band wavelengths[2]. Colourless Optical Network Units (ONU) face the requirements for mass deployment and cost. The most typical design is based on the Reflective Semiconductor Optical Amplifier (RSOA) or its derivatives, such as integrated SOA and Reflective Electroabsorption Modulator (REAM) for higher data rates. Extended reach and high splitting ratios require amplification between Optical Line Terminal (OLT) and ONU, performed remotely in conjunction points at the ring, referred to as the Remote Nodes (RN). Wideband C+L Erbium Doped Fibre (EDF) amplifiers[3] already exist, while the technique of remote pumping for both bands has been shown in long-haul systems[4] and has been introduced into PONs for the C-band[5].

Remote Node Design

The RN was designed to serve the needs of combined C+L-band amplification in an extended reach PON (Fig. 1) with unidirectional rings for down- and upstream and bidirectional tree. C/L splitters divide the RN into sub-RNs, holding different type of EDF, designed for its dedicated waveband. A sub-RN consists of two remotely pumped EDFs that are used for independent amplification of down- and upstream. The add/drop from the ring into the sub-RNs was performed with four 200 GHz thin film add/drop filters. Resiliency is provided by a 50/50 coupler. Another 100 GHz thin film filter after the EDFs rejects the amplified spontaneous emission from the EDF or in case of the upstream from the ONU, and circulators are placed before the C/L splitters that feed the bidirectional tree. The insertion loss from the ring to the EDF is 4.5 (6.9) dB and 1.5 (3) dB from the EDF to the tree interface. The remote EDFs were pumped at 1480 nm with two laser diodes (LD) of each 19 dBm for the downstream EDFs and two LD with 16 dBm for the upstream EDFs. As strong pumps were missing for their transmission from the OLT, local pumps were used, showing a worse case as no extra Raman gain benefit was present. The weaker pump for the upstream reflects the better sensitivity in reception of the OLT compared to the ONU, and also the constraints of the pump requirement in a PON.

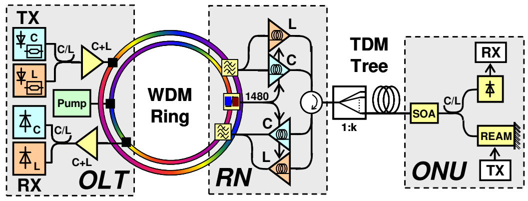

Fig. 1: WDM/TDM-PON with remote C+L amplification.

For the C-(L-)band, 15m (15m) of HE980 (iXF-FGL) EDF is used for the down- and 15m (10m) for the upstream. This choice is based on the investigation for both fibre types. Fig. 2a shows the gain for an input power of -10 dBm into the L-band EDF and Fig. 2b the gain and the OSNR for a pump of 19 dBm. Considering operation at 1585 nm for the L-band, it can be seen that for the downstream with the stronger pump an EDF of 15m shows good performance as a longer one doesn't benefit. For the upstream, the short EDF with 10m is the best choice as longer EDFs already miss gain due to insufficient pump. For 15 m of HE980 EDF, then gain is 18 dB with 19 dBm of pump power and 17 dB for 16 dBm for 1560 nm.

Remote Amplification in an Extended Reach PON

The experimental setup for the integration of the RN into a PON is shown in Fig. 3. This PON achieves full-duplex operation by dedicating different wavebands (C and L or vice versa) for down- and upstream. The optical carriers in the C- (1560.61 nm) and L-band (1586.2 nm) were modulated with Mach-Zehnder modulators (MZM). The data rate was 10 Gb/s and a PRBS of 2^7-1, equivalent to the block coding of Ethernet PON systems, was used. The extinction ratio (ER) was better than 13 dB. The bias of the MZM was readjusted to pass the unmodulated carrier. Due to the long reach, dispersion compensating fibres

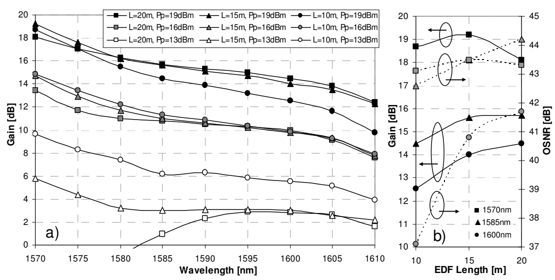

Fig. 2: Characterization of the L-band amplifier in the RN.

978-3-8007-3173-2

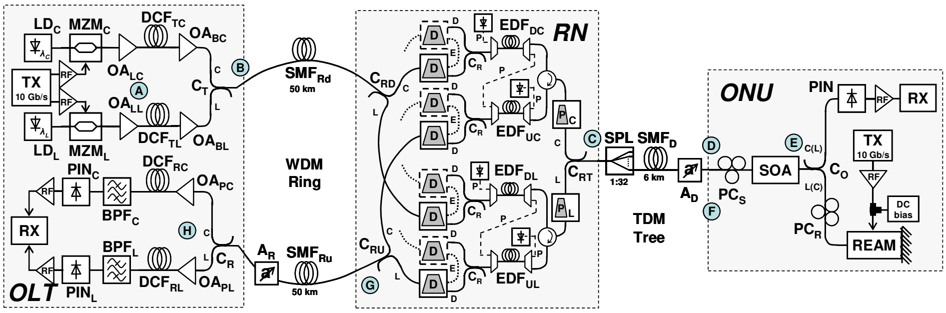

Fig. 3: PON with unidirectional ring and bidirectional tree. The RN provides a wavelength in both C+L band for the ONU.

(DCF) with a dispersion of -1365 ps/nm were placed. A first EDF amplifier (OA_{LC}, OA_{LL}) with 5m of HE980 (iXF-FGL) and a low noise figure is used before the booster amplifier (OA_{BC}, OA_{BL}). A C/L splitter then combines both wavelengths. A ring with 50 km of standard single mode fibre (SMF) connects RN and OLT. The 6 km SMF drop fibre was put after the 1:32 splitter to keep the Rayleigh backscattering (RB) low.

At the ONU, a SOA with a small signal gain of 21 dB, centred in the C-band serves as preamplifier and booster, providing still 16.4 dB of gain in the L-band. Remodulation and detection path in the ONU were swapped to show that they have in principle no preferred waveband. Although the L-band wavelength will miss gain in the SOA, the REAM that was used for remodulation was designed for the L-band. It was biased at -1.4V (-1.9V) and modulated with 3.5 V_{pp} at a data rate of 10 Gb/s with a PRBS of 2^7-1, leading to an ER of 14 (18) dB. With the intrinsic REAM losses of 15 (11) dB, no cross gain modulation was observed in the SOA, even with a bias of 200 mA. A PIN diode with a sensitivity of -18.5 dBm was used as detector.

The Optical Signal-to-Noise Ratio (OSNR) was 47.5 dB for the C- and 46.6 dB for the L-band after the first amplifier (point A in Fig. 3). The further power levels and OSNRs (Fig. 4) for C-(L-)band are 6 dBm and 44.5 (44.7) dB after the booster (B), 3.2 (2.6) dBm and 37.8 (41.1) dB at the tree (C), -15 (-15.4) dBm at the ONU input (D), 35.4 (35.8) dB after preamplification (E), 2.5 dBm (-1.8) dBm and 34.1 (33.4) dB after being remodulated and boosted (F), resulting in a net gain of the ONU of 17.5 (13.6) dB, and -3.7 (-9) dBm and 32.2 (32.6) dB when injected into the upstream ring fibre (G). The OLT preamplifier (OA_{PC}, OA_{PL}) with a noise figure of 4 (4.1) dB (H) was followed by a 60 GHz bandpass filter and a PIN diode with a sensitivity of -18.5 dBm. The RN gives therefore a net gain of 7.7 (7.1) dB for the downstream and 11.8 (7.2) dB for the upstream.

The optical signal-to-RB ratio was 35 dB for the upstream, while the downstream is not degraded by RB. Attenuators (A_D, A_R) were used for the BER measurements (Fig. 5). For the downstream, the sensitivity for the back-to-back case where the ring+tree fibres were replaced by attenuation in the C-(L-)band is -24 (-24.3) dBm for a BER of 10^{-10}. When adding these fibres and DCFs, there is an additional penalty of 3.6 (3) dB. The upstream sensitivity is -30.2 (-30.3) dBm for the back-to-back case and a penalty of 4.6 (2.8) dB is caused when the attenuation is replaced with fibre and DCFs. Nevertheless, power margins of 5.4 (5.9) dB for the downstream and 10.9 (7.5) dB for the upstream are provided.

Conclusions

A RN design satisfying the requirements of an extended reach and high split WDM/TDM-PON has been shown. Despite the reduced OSNR of 32 dB at the OLT receiver, error-free operation can be obtained with a margin of 5-10 dB for C- and L-band.

This work was supported by the European FP7 Sardana project, the Eurofos NoE and the Spanish MICINN project TEC2008-01887.

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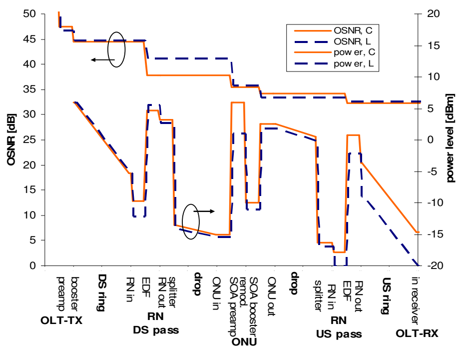

Fig. 4: Evolution of OSNR and signal power in the PON.

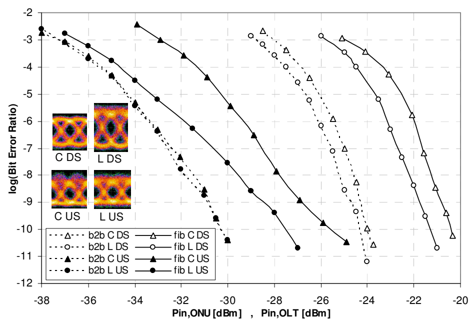

Fig. 5: BER curves for full-duplex 10 Gb/s downstream (DS) and 10 Gb/s upstream (US) transmission.