Cost Efficient Directly Modulated DPSK Downstream Transmitter and Colourless Upstream Remodulation for Full-duplex WDM-PONs

R. Maher, L.P. Barry and P.M. Anandarajah

Research Institute for Networks and Communications Engineering, Dublin City University, Dublin 9, Ireland.

robert.maher@dcu.ie

Abstract: We implement a cost efficient 10.7Gb/s directly modulated DPSK transmitter in a bidirectional WDM-PON, which also remodulates the downstream phase encoded signal for 2.5Gb/s OOK upstream transmission.

OCIS codes: (060.4510) Optical communications; (060.5060) Phase modulation

1. Introduction

Wavelength division multiplexed passive optical networks (WDM-PON) are vying to become the ultimate solution for implementation in the next generation optical access network as they provide the inherent potential for protocol transparency and extremely high bandwidth to the home. In spite of the numerous advantages associated with WDM-PON (such as reach, split ratio etc), the high cost attributed to wavelength selective components and wavelength specific transmitters at both the optical line termination (OLT) and within each optical network unit (ONU) has reduced the competitiveness of this technology in the current optical transport market [1]. Hence, there exists a requirement to develop cost efficient solutions for the optical transmitter in the OLT and also to negate the requisite of a dedicated laser source in the customer premises equipment (CPE). By maintaining colourless operation within the CPE, significant CapEx and OpEx reductions can also be obtained by reducing the substantial inventory and sparing of wavelength specific components.

Recently, several schemes have been proposed to achieve full-duplex transmission over a single fibre for implementation in WDM-PONs. Such architectures included the use of the on-off keyed modulation format for downstream transmission, which was subsequently remodulated using a gain saturated semiconductor optical amplifier (SOA) for the upstream path. However, to maintain an optimum level of system performance the extinction ratio (ER) of the downstream data had to be degraded in order to achieve an adequate re-write for the upstream signal [2]. To overcome this ER limitation, phase [3] or frequency shift keyed [4] modulation formats were employed for the downstream transmission, which provided an almost continuous wave (CW) signal for data remodulation in the optical network unit (ONU). To generate a DPSK optical signal either a phase modulator or a Mach-Zehnder modulator is commonly employed, however this inherently adds an additional component to the OLT transmitter. The extra component adds significant cost to the transmitter, while also increasing the loss of the optical signal, thus affecting the overall power budget of the optical system.

In this paper the authors demonstrate for the first time the application of a directly modulated distributed feedback laser (DFB) [5] for cost efficient downstream DPSK transmission in a PON. The directly modulated laser generates an optical signal with the PSK modulation format for downstream transmission. Due to the low level of intensity modulation (IM) the downstream signal can be subsequently remodulated at the ONU for OOK upstream transmission. This technique is more cost efficient than conventional external modulation and adds no additional loss to the optical signal. Error free performance at a data rate of 10.7Gb/s is achieved for the downstream signal after propagating through 24km of single mode fibre (SMF). The residual intensity modulation of the downstream signal is significantly reduced using a gain saturated SOA prior to OOK remodulation at 2.5Gb/s using a MZM.

2. Experimental Setup

The experimental setup used to realise the full-duplex WDM-PON is illustrated in Fig. 1. A pulse pattern generator supplied a 10.7Gb/s pseudorandom bit sequence of length 2^{15}-1 directly to a passive electrical impulse forming network that exhibited a 3dB bandwidth of 10GHz. The impulse network created a bipolar electrical signal which was essentially the time derivative of the input bit pattern and consisted of short bipolar electrical pulses with a full width half maximum (FWHM) of 45ps. The differential electrical pulses were amplified using a 12.5Gb/s data amplifier before being used to directly modulate a DFB laser biased at 60mA. By directly modulating the DFB laser with the electrical bipolar signal a corresponding frequency shift was generated at the output of the laser diode, which contained the same bipolar waveform as the modulating current. As the optical phase is a time integral of the instantaneous frequency, it was a replica of the differentially encoded NRZ signal. An optical phase shift of π can

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therefore be obtained if Δf•Δt=0.5, where Δf is the optical frequency deviation caused by the direct modulation of the laser and Δt is the pulse width of the bipolar electrical pulses. To ensure that the optimum frequency shift was obtained, the peak-to-peak voltage of the NRZ data signal was adjusted. A voltage of $1.5V_{pp}$ was required to provide an exact π phase shift between a logical one and zero. However, this resulted in residual IM as seen at the output of the DFB laser in Fig. 1(a). The directly modulated signal was subsequently passed through an optical circulator before traversing a reel of standard SMF of varying length from 12 to 24km. At the ONU the signal was split using a 3dB coupler with one arm fed directly into a delay interferometer which translated the phase modulation into an amplitude variation. The demodulated signal was detected prior to BER analysis, which was carried out using a 12.5Gb/s ED. It is important to note that single ended detection was employed for the downstream DPSK signal. If a balanced receiver was used for detection, a 3dB improvement in OSNR could be achieved.

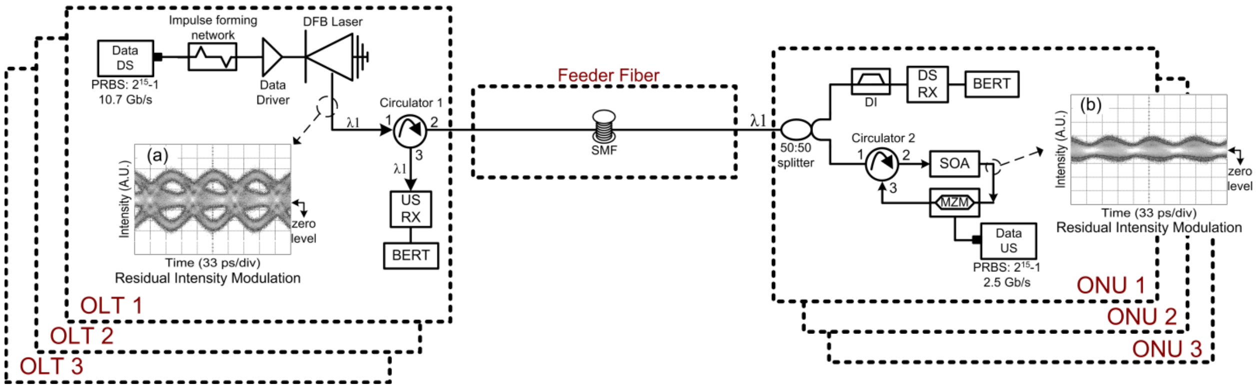

Fig. 1. Experimental setup of full-duplex WDM-PON, also illustrating residual intensity modulation caused by direct modulation of DFB both (a) before and (b) after the SOA

The second arm of the 3dB coupler in the ONU was fed directly into a second circulator before being applied to a SOA. The SOA was a commercially available device from CIP and exhibited a saturation power of 12.1dBm at 1550nm and small signal gain of 25dB. This device was used to simultaneously boost the input signal and also to erase the residual IM of the downstream data by operating in gain saturation as seen inset of Fig. 1(b). The subsequent CW like signal was connected to the input of a MZM which was modulated with a 2.5Gb/s pseudorandom bit sequence of length 2^{15}-1 from a second PPG. The output of the MZM was passed back through the circulator for upstream transmission. The OOK upstream data signal was dropped via port three of circulator 1 and was detected using a high speed pin photodiode before bit error rate analysis was performed. To reduce the cost and complexity of the ONU, the second circulator, SOA and the MZM would ideally be replaced by a reflective EAM-SOA; however such a device was not available at the time of this work.

3. Experimental Results and Discussion

The bit error rate as a function of received optical power for both the downstream and upstream transmission is illustrated in Fig. 2. In the downstream path, the 10.7Gb/s directly modulated DPSK signal provided a BER of 10^{-10} at a received power of -32dBm for the B2B scenario, with a clean eye diagram (o) also displayed as an inset of Fig. 2(a). The high level of performance achieved for the DS signal remained relatively unchanged after transmitting over 12km of SSMF, with a negligible power penalty being incurred. A small power penalty of 1.8dB, relative to the back to back scenario was experienced at a BER of 10^{-10} after traversing 24km of SMF, which is mirrored by the clean opening of the received eye (◊). Such a small power penalty could largely be attributed to chromatic dispersion, however the consistent performance of the downstream data signal clearly illustrates the applicability of such a cost efficient directly modulated DPSK transmitter for implementation in future WDM-PONs.

The BER performance of the 2.5Gb/s OOK uplink signal is depicted in Fig. 2(b), with the corresponding received eye diagrams for the B2B scenario and after 12 or 24km of single mode fibre. The upstream transmission achieves error free performance (10^{-10}) at a received power of -40.5dBm and this level of performance is clear from the clean eye opening (o). It is important to note that there is very little residual IM present on the mark level for the uplink signal for this scenario and this was due to the SOA. As the downlink signal enters the SOA the gain of the device saturates (providing the input power is sufficiently high enough), thus clamping the output power and reducing the extent of any intensity fluctuations. After propagating over 12km of SMF a received power penalty of 0.7dB was incurred at a BER of 10^{-10}, which is slightly larger than that of the downlink data transmission. However it is evident from the received eye (■) that there is slightly more intensity noise present on the mark level. There are two contributions to this increased noise level. The first is Rayleigh backscattering which is a common effect that is detrimental to bidirectional transmission systems that utilise the same wavelength. Therefore, to reduce the extent of this effect the launch power for the downstream transmission was limited to 0dBm. However after passing through the SMF, a 3dB coupler and a circulator, the input power to the SOA becomes quite close to the unsaturated gain regime. Consequently, if the SOA is not completely saturated, the residual IM of the downstream signal is not fully erased, thus increasing the intensity noise for upstream transmission. Therefore, there exists a trade-off between the level of Raleigh backscattering, which in essence limits the optical signal to noise ratio and the launch power required to saturate the SOA in the ONU.

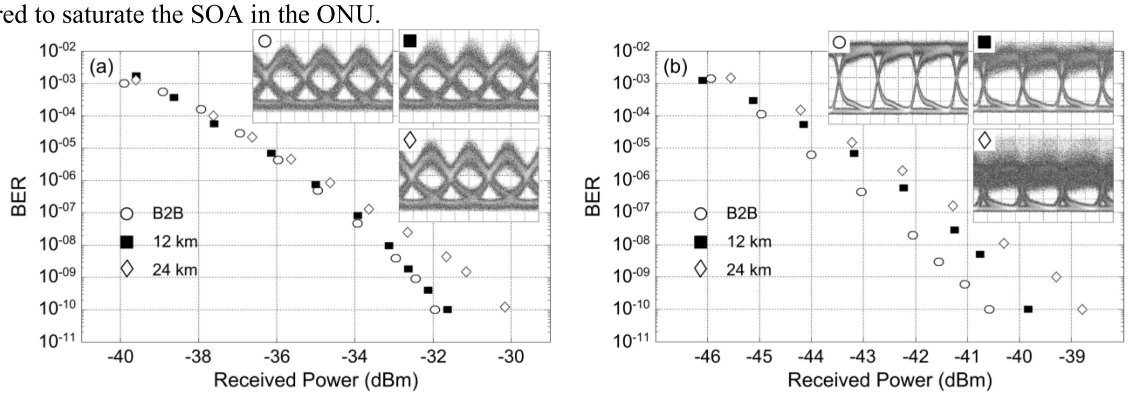

Fig. 2 (a) BER as a function of received power for the 10Gb/s DPSK downstream signal for B2B, 12km and 24km scenario with corresponding eye diagrams and (b) corresponding BER analysis for 2.5Gb/s OOK upstream signal

After propagating over 24km of SMF the power penalty relative to the B2B scenario increases to 2dB. Although error free transmission was achieved, it is evident from the received eye (◊) that there is a large amount of intensity noise. There are again two effects that contribute to the level of intensity noise apparent on the received eye. The input power to the SOA was further attenuated when the 24km reel of fibre was in place, which consequently reduced the level of residual IM erasure. Coupled with that fact, the level of Raleigh backscattering is increased as the fibre link is expanded, therefore the intensity noise on the mark level becomes more severe. To overcome the gain saturation limitation associated with the SOA, a reflective EAM-SOA combination could be utilised, where the SOA would exhibit a lower saturation power and a higher small signal gain. This would ensure that the SOA always remained in saturation, thus reducing the IM present on the downstream signal, while simultaneously enabling the reduction of the signal launch power to limit the extent of the Raleigh backscattering. Such a scheme would also provide a sufficiently large power budget to overcome the loss of two arrayed waveguide gratings that are inherently required at both the OLT and the remote node in any WDM-PON. Additionally a passive splitter could be employed after the feeder fibre to distribute time division multiplexed 10Gb/s bandwidth to a number of users.

5. Conclusions

The authors have investigated the performance of a cost efficient directly modulated DPSK transmitter suitable for implementation in a future bidirectional WDM-PON. Excellent system performance was demonstrated for the phase encoded downstream signal with a small power penalty of 1.8dB experienced after propagating over 24km of single mode fibre. To maintain colourless operation and enhance the cost efficiency of the downstream transmitter, a reflective remodulation scheme was implemented in the optical network unit. Error free performance was also achieved after propagating back up the 24km of single mode fibre. Although error free performance was achieved, the level of intensity modulation of the upstream signal was quite large. Therefore to enhance the upstream transmitter an integrated reflective EAM-SOA combination could be employed, where the SOA would exhibit a lower saturation power, thus ensuring that it remains in the gain saturated regime.

References

[1] F. Ponzini et al., “Evolution scenario toward WDM-PON,” IEEE/OSA J. Opt. Commun. Netw. **1**, C25-C34 (2009).
[2] W. Lee et al., “Bidirectional WDM-PON based on gain-saturated reflective semiconductor optical amplifiers,” IEEE Photon. Technol. Lett. **17**, 2460-2462 (2005).
[3] J. Zhang et al., “A novel bidirectional RSOA based WDM-PON with downstream DPSK and upstream re-modulated OOK data,” in proc. of ICTON, We.P.1 (2009).
[4] J. Prat et al., “Full-duplex single fiber transmission using FSK downstream and IM remote upstream modulations for fibre-to-the home,” IEEE Photon. Technol. Lett. **17**, 702-704 (2005).
[5] R.S. Vodhanel. “5 Gbit/s direct optical DPSK modulation of a 1530-nm DFB laser,” IEEE Photon. Technol. Lett. **1**, 218-220 (1989).