Reduction of Signal-Induced Rayleigh Noise in a 10Gb/s WDM-PON using a Gain-Saturated SOA

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Abstract We demonstrate mitigation of signal-induced Rayleigh-beat-noise in a carrier-distributed WDM-PON using a gain-saturated SOA. The required signal-to-Rayleigh power was reduced by 11dB thereby enabling 10Gb/s error-free transmission in a 64 way-split, 20km reach PON.

Introduction
Rapid growth in demand for broadband services is currently driving the deployment of optical fibre to homes and businesses around the world and is focussing research attention on the next generation of access network solutions [1]. One promising candidate for the latter is the carrier-distributed WDM-PON [2]. In this approach “colourless” reflective modulators are employed in the customers’ optical networking units (R-ONUs) and wavelength referencing and control is provided by centrally distributed continuous wave (CW) optical carriers, which can be shared by many users on a given PON. However, without suitable mitigation schemes these systems are susceptible to transmission impairments due to interferometric beat noise at the upstream receiver (RX) generated by Rayleigh backscattering (RB) and Fresnel back-reflections [3,4]. In the case of RB, which is an unavoidable property of optical fibre, there are two contributions that interfere with the upstream signal at the RX to generate noise [5]. Carrier-RB is generated by the CW carrier as it is delivered to the R-ONU. In contrast, Signal-RB (Fig. 1) is generated by backscattering of the modulated upstream signal light, which re-enters the R-ONU where it is amplified (the R-ONU has net gain), re-modulated and reflected towards the RX.

In previous work we have proposed and demonstrated RB noise mitigation schemes for 10Gb/s WDM-PONs, which efficiently suppress the noise due to the Carrier-RB, but are much less effective in reducing the Signal-RB noise [3, 5]. Here we study a potential solution to this problem, which employs a gain-saturated semiconductor optical amplifier (SOA) in the R-ONU to compress the Signal-RB noise component. This approach has been extensively explored in the context of ASE spectral-slicing [6] and has also been shown to reduce the impact of Fresnel backreflections in a WDM-PON with an upstream bit rate of 1.25Gb/s [4]. Here, for the first time to our knowledge, we demonstrate the effectiveness of the technique for Signal-RB noise suppression in a CW carrier-distributed 10Gb/s WDM-PON using an all-semiconductor R-ONU design.

Characterisation Experiment
Fig. 2 shows the experimental setup used for quantitative analysis of the optical-signal-to-Rayleigh-noise-ratio (OSRNR) tolerance of the 10Gb/s upstream signal both with and without SOA gain saturation. The setup replicates the operation of an R-ONU in the Signal-RB-limited case, by generating and mixing a modulated CW carrier (the upstream signal) with the twice-modulated RB light (the Signal-RB).

In the experiment, the NRZ data signal was produced by a LiNbO$_3$ Mach-Zehnder modulator (MZM) electrically driven with a 10Gb/s 2$^{31}-1$ PRBS modulating a CW carrier ($\lambda=1554.9$nm) from a DFB laser. The RB was generated from the data signal in a 25km length of SMF, terminated by a low-reflection angled connector and extracted via a circulator. Since the generated RB is 32.2dB below the input power, an EDFA and a linear SOA were used to maximise the RB power. A variable optical attenuator (VOA) then regulated the OSRNR level. The RB signal was then coupled into the MZM, generating the twice-modulated Signal-RB. Polarisation controllers (PC1-3) were used to ensure that the RB and the CW carrier were co-polarised (maximum noise case) and matched to the polarisation-axis of the MZM. The data signal and Signal-RB were then detected in an optically-preamplified RX. In order to measure the impact of gain saturation, a low input saturation power (−16dBm), high gain (G=30.5dB) non-linear SOA (NL-SOA) was placed before PC2 and the input and output powers regulated with VOAs, as shown in Fig. 2. The impact of the RB on the received signal was
analysed in terms of the power penalty (defined throughout at $10^{-9}$ BER) as a function of the OSRNR. Optimum noise suppression was obtained at an SOA input power of $-8$dBm which corresponded to a saturated gain of 21dB. This value was maintained for all experiments. The results in Fig. 3 show that the NL-SOA provides a significant degree of noise suppression, reducing the OSRNR required for 1dB penalty by 11dB from 25dB to approximately 14dB. The effect is also seen in the inset data eyes, which show greatly reduced amplitude noise on the data ones when the gain saturated SOA is present.

![Fig. 3: Power penalty at $10^{-9}$ BER vs. OSRNR. Insets: 10Gb/s eye diagrams at OSRNR of 14dB.](image)

**Network Application Experiment**

The impact of the noise suppression scheme was quantified in a realistic application scenario using a 64 way-split carrier-distributed WDM-PON, similar to that shown in Fig. 1. In order to simulate the worst case for the Signal-RB, the feeder fibre was eliminated and the splitter and customer-side WDM were located close to the central office (CO). This maximised the drop fibre length and hence also maximised the backscattering generated by the upstream signal prior to attenuation by the splitter [3]. Drop fibres of length 0km (B2B), 4km, 8km and 20km were used to emulate the maximum range variation for a conventional PON. The R-ONU was implemented using commercially-available, discrete components comprising two SOAs, as in Fig. 1, and an electroabsorption modulator (EAM) driven at 10 Gb/s with NRZ data ($2^{31}-1$ PRBS). All three components had low polarisation sensitivity and the input to the linear (20dB gain) SOA and the EAM were maintained constant for all the experiments at $-11$dBm and +9dBm respectively. Hence the overall gain of the R-ONU was also maintained constant at 11.5dB. Only one of the wavelength-PONs (1551nm) was implemented in the experiment although the components are specified to allow colourless operation of the R-ONU across the C-band. The BER curves obtained for the various fibre lengths are shown in Fig. 4. Without the gain saturated NL-SOA the power penalties for 4km and 8km were 0.6dB and 2dB respectively, whereas at 20km an error floor at $10^{-8}$ BER was observed. When the NL-SOA was added to the R-ONU the penalty values for the three fibre lengths were reduced to 0.1dB, 0.1dB and 1dB respectively, with no sign of error floors. Hence the noise suppression introduced by the NL-SOA was sufficient in principle to achieve error-free operation for all customers on the network, independent of their distance from the CO. The equivalent OSRNR values for the 4km, 8km and 20km lengths were 25dB, 23dB and 21dB, respectively. Hence, the PON results are generally consistent with the characterisation data, with slight variations explained by small differences in the operating conditions for the NL-SOA in the two experiments. Finally we note that the noise suppression effect can also be exploited in applications where drop fibre lengths are significantly shorter than those used in the experiments described here. For example, if the R-ONU gain is increased, to accommodate larger splits, then the Signal-RB can become appreciable even with short drop fibres. This is because the Signal-RB OSRNR level varies inversely with R-ONU gain due to the additional pass of the RB through the R-ONU compared to the upstream signal [4].

![Fig. 4: 10Gb/s BER Results](image)

**Conclusions**

The use of SOA gain saturation for Signal-RB noise suppression has been demonstrated. The scheme enabled error-free, 10Gb/s transmission to be achieved in a 64 way-split, 20km reach WDM-PON. This work is supported by the Science Foundation Ireland under Grants 03/IN.1/1340, 06/IN/1969 and by the EU under project PIEMAN.

**References**

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