Reduction of Rayleigh Backscattering and Reflection Effects in WDM-PONs by Optical Frequency Dithering

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Abstract

The reduction of both Rayleigh backscattering and reflections in passive optical networks with remotely seeded network units by means of optical frequency dithering is demonstrated.

Introduction

Passive Optical Networks (PON) are a beneficial solution for access networks due to their high capacity combined with wavelength and time division multiplexing (WDM/TDM) techniques [1]. To maintain the cost-effectiveness of PONs, reflective network units such as reflective semiconductor optical amplifiers (RSOA) at the customer premises are a suitable approach. However, due to the bidirectional nature, degradations from physical effects like Rayleigh backscattering (RB) as well as from reflections at connectors in between the optical line terminal (OLT) and the optical network unit (ONU) arise and lead to decreased performance, especially with ONUs that contain RSOAs which amplify these effects. To mitigate these penalties generated by these effects, spectral broadening can be applied as proposed earlier [2], [3], [4]. Frequency modulation of the feeder signal can be used to reduce the spectral overlap and to add incoherence between the bidirectional signals, resulting in an increased performance. In this paper, we propose a combined solution for reducing the penalty due to RB and reflections along the optical light path.

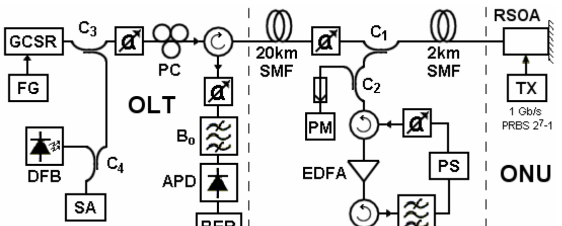

Figure 1: Setup for an access solution with remotely feeded ONUs. Reflections were emulated by an unconnected patchcable in the passive fibre plant

Experimental Setup

Figure 1 shows the experimental setup. The OLT comprises of a 4-sections grating-assisted coupler sampled reflector (GCSR) tuneable laser with a full-width half-maximum (FWHM) linewidth of about 25 MHz and an avalanche photodiode (APD) with a bandpass filter in front of it as the receiver. RB is caused by 20km of standard singlemode fibre (SMF) between the OLT and the ONU which is longer than the effective length. To adjust the optical signal to RB ratio (OSRR) while maintaining the input power of the RSOA at the same value, two attenuators are inserted after the GCSR laser and after the fibre. The latter ensures the same gain conditions for different ratios of OSRR.

At the ONU, a RSOA is used for intensity modulation of the feeder signal provided by the OLT with a data rate of 1 Gb/s and a PRBS of 2^7-1. Several connectors used in the setup are angled to avoid reflections. A reflection was placed before the 2km drop fibre via insertion of a 3dB-coupler (C_1) at the location of the power splitter normally used in PONs. The reflection is caused by an unconnected FC/PC connector together with a variable attenuator to provide a wide range for the reflectivity which is monitored with a powermeter behind an additional coupler (C_2) and an isolator. The polarisation state of the reflected signal was scrambled (PS) as the polarisation state of the reflected signal cannot be controlled in a deployed system. An Erbium-doped fibre amplifier (EDFA) was further utilised to achieve higher values of reflectivity. As the amplified spontaneous emission (ASE) noise is at least one order of magnitude lower than the reflected signal power and therefore much weaker than the incoming signal power at the RSOA, the change in the spectrum after filtering with a bandpass filter is negligible.

The broadening of the signal spectrum takes place at the coupler section of the GCSR with a function generator (FG) which provides a sinusoidal RF signal. This section features a low residual amplitude modulation which is at least one order of magnitude less than the response due to frequency modulation, up to a modulation frequency of around twice the bit rate. By adjusting the RF power and monitoring the spectrum (SA) of the downstream signal via extracting a small portion of the feeder signal with coupler C_3 and performing heterodyne detection via coupler C_4 and a tuneable laser, the frequency deviation of the modulation was chosen with 10GHz up to the bandwidth limit of the GCSR laser but to stay inside the ITU channel and avoid dispersion effects, and was further kept the same for all modulation frequencies.

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Results and Discussion

To investigate the improvement that can be achieved due to frequency dithering, the BER curves for RB as well as for reflections are shown in Figure 2 and 3. For the first case, the BER curves with low OSRR show an error floor which can be also seen when combining the effects as shown in Figure 4.

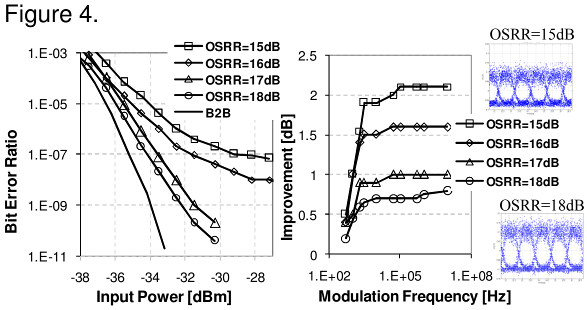

Figure 2: Measured BER curves and improvement in sensitivity (BER=10^{-6}) for Rayleigh backscattering

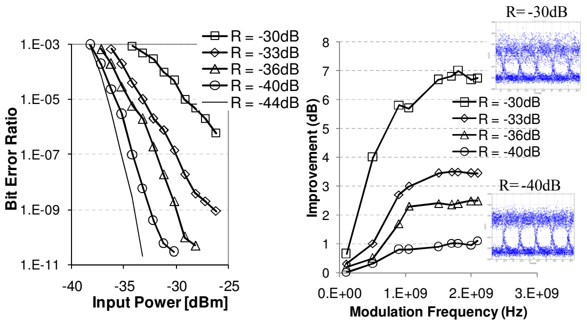

Figure 3: Measured BER curves and improvement in sensitivity (BER=10^{-6}) for reflection effects

The mentioned improvements obtained regarding the penalties of both impairments are referenced to the case without modulating signal. The results presented were taken for a BER of 10^{-6} as a function of the modulation frequency as it presents an intermediate value. The measured improvement was around 70% of the penalty.

By increasing the modulation frequency, the power of the modulating signal was adjusted properly to keep the frequency deviation at a fixed value which was 10GHz for compensating RB. The deviation used for the reduction of reflections was the same; however, due to the high modulation frequencies the spectrum was strongly discretisized in this case.

The reduction of RB requires low modulation frequencies and a significant and stable RB penalty can be obtained with a modulation frequency of above 3kHz. Reflections show a similar behaviour regarding the improvement. In this case, the necessary modulation frequency required to scramble the optical phase in the bit time, must be much higher than for RB reduction. For a data rate of 1Gb/s, a frequency modulation of about 750 MHz to 1.6GHz is required as shown in Figure 3.

Considering both impairments, the BER curves are clearly shifted towards worse performance and suffer from high penalty compared to the back-to-back (B2B) case as can be seen in Figure 4. Some ripple in the improvement was observed and avoided by slightly readjusting the modulation frequency. Compensating both effects leads to a characteristic of the improvement which features two slopes that correspond to the slopes of the cases with just one impairment.

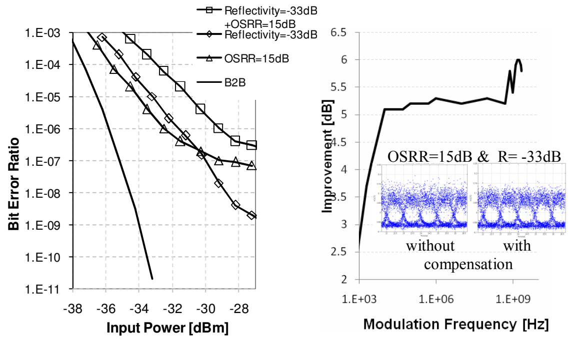

Figure 4: Measured BER curves and improvement in sensitivity (BER=10^{-6}) for both impairments

Conclusions

By applying frequency dithering to the downstream signal, we have showed the capability of reducing both RB and the effect of reflections. While a frequency deviation much higher than the bit rate and a modulation frequency in the kHz region is necessary to compensate for the RB, reflections require a deviation large enough to scramble the optical phase sufficiently, but with a frequency higher than the bit rate. The resulting improvement is high enough to recover around 70% of the penalty which leads to a sensitivity closer to the back-to-back case. Using this principle, the two main impairments of WDM-PONs are mitigated in a cost/efficient way as no additional optical components are needed.

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References

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